[FROM THE AMERICAN JOURNAL OF SCIENCE, VOL. XXIX, June, 1910.]

CONTRIBUTIONS TO THE GEOLOGY OF THE
GRAND CANYON, ARIZONA.—THE
GEOLOGY OF THE SHINUMO
AREA.

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(With Plate V.)

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THE
AMERICAN JOURNAL OF SCIENCE
[FOURTH SERIES.]

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by L. F. NOBLE.

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PREFACE.

EXPOSURES of unaltered pre-Cambrian sediments are of great interest to the geologist in any part of the world. Especially is this true in the Grand Canyon of Arizona, where the certainty of stratigraphic position and completeness of exposure are almost without a parallel, and where the spectacular nature of the occurrence partakes of the stupendous and fantastic scenery of that mighty gorge, from the spell of which the observer is never entirely free. During a pleasure trip in the Grand Canyon region in January, 1908, in company with Professor H. E. Gregory of Yale and others, the writer chanced to visit a hitherto undescribed exposure of these rocks on the

Colorado River at the foot of Bass Trail. Although only a few hours were spent in the vicinity, the diagrammatic simplicity with which the structural relations were revealed was such that the interest could be immediately realized. In the summer of that year the writer returned with the intention of making a detailed study of these pre-Cambrian rocks. He speedily found that the interest in this part of the Grand Canyon did not end with the study of the pre-Cambrian alone: it was found that the line of displacement of the West Kaibab fault which runs into the Grand Canyon at this point was itself a remarkable structural feature and worthy of considerable attention; that the entire Paleozoic section of the canyon wall was here, as elsewhere, undescribed in absolute detail; and finally that there were problems of physiographic interest in the Grand Canyon region the ultimate solution of which could be greatly helped by a detailed study at this point. It was therefore decided to extend the work to a complete areal study of the region, including for this purpose the greater part of the new Shinumo topographic sheet of the United States Geological Survey. This report, accompanied by an atlas containing the geologic maps, sections, and plates, was presented to the faculty of the Graduate Department of Yale University in June, 1909, as a thesis in partial fulfillment of the requirements for the degree of Ph.D., under the title of "The Geology of the Shinumo Area, Grand Canyon, Arizona."

It is intended to present the substance of the thesis in two or more articles in this Journal. The entire report is to be published *in extenso* at a later date as a Bulletin of the United States Geological Survey. For this reason, as well as because of the large scale and elaborate nature, the geologic map, sections, and plates will not be published here.

The first article will be presented in two parts. Part I, now published, comprises a general introductory description of the Shinumo area and deals with the basement rocks of the Archean. Part II, to follow in a later number, will be devoted to the Algonkian rocks of the Grand Canyon series and will include a map showing the distribution of the Vishnu and Grand Canyon series in the Grand Canyon.

It is also proposed to devote a later article or articles to the Paleozoic section of the canyon wall; to a structural study of the area, including both the pre-Cambrian and later structure and a study of the displacements on the line of the West Kaibab fault; and finally to features of physiographic interest in the area,—such as the drainage system of the plateaus and the origin of the Esplanade and Tonto platforms.

INTRODUCTION.

Location and geography.—The area studied lies in Coconino County in the northern part of Arizona in what is known as the Plateau Province of the Territory. It is inclosed between meridians $112^{\circ} 25'$ and $112^{\circ} 15'$ and parallels $36^{\circ} 20'$ and $36^{\circ} 05'$, and includes about 150 square miles. It comprises rather more than the eastern half of the area of the Shinumo topographic sheet of the United States Geological Survey.

The greater part of the area lies within the depths of the Grand Canyon and includes the Shinumo Amphitheater, which is the largest of the great amphitheaters in the Kaibab division. The eastern and northern parts of the area include that part of the "mainland" north of the canyon which forms the immediate rim of the Shinumo Amphitheater, reaching from the promontory of Point Sublime on the east to the Muav Saddle on the west; this northern mainland is a part of the Kaibab Plateau. The northwestern part of the area includes the surface of Powell Plateau, a great butte, or "island," lying athwart the course of the Grand Canyon. The southwest corner includes a part of the southern "mainland" which culminates in the great promontory known as Havasupai Point; this southern mainland belongs to the Coconino Plateau.

About a mile west of Havasupai Point is situated Bass Camp, the only habitation in the area. The camp was established by Mr. W. W. Bass some twenty-five years ago to accommodate the tourist traffic. From this point a trail was constructed to the river, which was crossed by boat at times of low water. A permanent camp was established in the bottom of the canyon on the north side of the river about a mile up Shinumo Creek, where an irrigated garden was made upon the site of an ancient one cultivated by the prehistoric inhabitants of the region. Later a trail was constructed up Muav Canyon to the north rim, by means of which access may be had to points on the Kaibab Plateau and the settlements in Southern Utah. Recently deposits of copper and asbestos have been discovered by Mr. Bass in the depths of the canyon, to which he has constructed additional trails. In March, 1908, three wire cables were suspended across the granite gorge at the foot of Bass Trail. On these cables travels a wire car, so that at the present time the Colorado River may be crossed at this point regardless of high water. Bass Camp is most easily reached by wagon road from Bass Station on the Grand Canyon branch of the Santa Fe Railroad, a distance of 20 miles southeast; or from the El Tovar Hotel at the terminus of the railroad 25 miles east. Another road leads 20 miles southwest to the rim of Cataract Canyon, into which a trail leads down to the Supai

Indian village. Roads also lead to the towns of Williams and Ash Fork, about 60 miles respectively south and southwest.

Field Work.—The geological field work upon which the thesis is based was begun upon the 23d of August, 1908, and ended upon the 12th day of December of the same year. The greater part of the work was done from a permanent camp on the Shinumo, which served as a base of operations for studying all the region in the greater depths of the canyon. Two trips were made to the north rim. The first was made in September and the second in November. Each trip lasted a week. Camp was established in the Muav Saddle and excursions were made from there over the surface of Powell Plateau and over the Kaibab mainland as far as the head of the Shinumo Amphitheater. The writer was accompanied on these occasions, as well as during his stay in camp on the Shinumo, by Mr. John Walthenberg as guide, whose detailed knowledge of the region and whose assistance in other ways were invaluable. The work in the southern part of the area was done from Bass Camp, from which point excursions were made over the Coconino Plateau and into the upper part of the canyon.

Literature.—Two references to the geology of the area are to be found in geological literature:

Captain Dutton in his monograph entitled "The Tertiary History of the Grand Canyon District" (Dutton, *a*) describes most fully and charmingly the geology of the north rim in this section of the Grand Canyon. In Chapter VII he 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, while Chapter IX describes the walls of the amphitheaters of the north side in detail. The Muav Saddle and Powell Plateau are described on pp. 162–167, and the Shinumo Amphitheater on pp. 167–174. His work, however, did not extend into the depths of the canyon.

Mr. J. S. Diller of the United States Geological Survey describes in his report on the production of asbestos in "Mineral Resources for 1907" (Diller, *a*) the deposits of asbestos occurring in the Algonkian sediments of this area near Bass Ferry. This is the only reference in the literature to the presence of Algonkian strata in this part of the Grand Canyon.

Acknowledgments.—In 1901 Mr. Charles D. Walcott and Mr. G. K. Gilbert spent several days at Mr. Bass's camp on the Shinumo and at that time worked out the structure of the pre-Cambrian sediments, which Mr. Walcott correlated with the section described by him in Unkar Valley (Walcott, *a*, *b*, *c*, *d*, and *e*). 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 Professor Joseph Barrell, to Professor Charles Schuchert, and to Professor Louis V. Pirsson, all of Yale University, the most sincere thanks are due for continued interest and advice during all stages of the work. To Mr. W. W. Bass the writer is indebted for material assistance and guidance during his work in the field.

Geologic Nomenclature.—The geologic names employed in this article are revised names recently authorized by the United States Geological Survey, with the exception of those of the Cambrian, which as yet have not been formally revised. The first table below gives the rock formations of the Shinumo area in terms of the revised terminology, while the second table gives the equivalent of the newer in the older nomenclature.

I.

Geologic column of the Shinumo Area.

System	Series	Group	Formation
Carboniferous	Pennsylvanian . . .	Aubrey . .	{ Kaibab limestone Coconino sandstone Supai formation
	Pennsylvanian and Mississippian	Redwall . .	Redwall limestone
(Unconformity of erosion without uniformity of dip)			
Cambrian . .	Acadian (and Saratogan?) . .	Tonto . .	{ “Marbled limestone” “Tonto shale” “Tonto sandstone”
	(Great angular unconformity)		
Algonkian	Grand Canyon . . .	Unkar	
(Greatest angular unconformity)			
Archean	Vishnu		

II.

*Classic Nomenclature of the reports of
Dutton, Gilbert, and Walcott.*

<i>Revised Nomenclature</i>		
Formation	Formation	Group
Kaibab limestone	Cherty limestone	{ Upper Aubrey
Coconino sandstone	Cross-bedded sandstone	
Supai formation	Lower Aubrey sandstone	Lower Aubrey
Redwall limestone	Redwall limestone	Redwall
“Marbled limestone”	Marbled limestone	{ Upper Tonto
“Tonto shale”	Tonto shale	
“Tonto sandstone”	Tonto sandstone	Lower Tonto

Topography, Climate, and Vegetation.

The surfaces of the plateaus in the Shinumo area through which the pathway of the Grand Canyon is trenched are everywhere developed at the same horizon on the highest member of the Paleozoic series occurring in the Canyon wall and known as the Kaibab limestone, the Mesozoic and Tertiary formations having been stripped back to the terraces of southern Utah.

The surface of the southern, or Coconino, plateau slopes to the southwest away from the canyon rim at the rate of about 200 feet to the mile. The drainage system of the plateau surface consists of a series of mature, open-floored valleys with gently sloping sides, which contain no living streams. These valleys trend southwesterly away from the canyon rim with the slope of the plateau surface and drain into the broad, shallow synclinal basin occupied by Cataract Canyon. In tracing one of these mature valleys toward its head, it is a common thing to find it truncated as a hanging valley by the wall of the Grand Canyon. So general is this phenomenon, that the stranger who loses his way on the southern plateau has only to keep in mind that if he follow any valley far enough headward he will come out upon the rim of the Grand Canyon.

The surface of the northern, or Kaibab, plateau is in every respect similar to that of the Coconino. The same system of mature valleys covers its surface, which slopes southwesterly to the rim of the canyon. The only difference is that the surface drainage runs into the Grand Canyon instead of away from it. Neither plateau surface contains a living stream.

Powell Plateau may be regarded as a dismembered part of the Kaibab. Its surface is developed at the same horizon on the Kaibab limestone, slopes southwesterly at the rate of 900 feet in five miles, and contains the same mature drainage system. It is substantially a great island, surrounded on three sides by mile-deep canyons, and isolated from the mainland by erosion in the line of displacement of the West Kaibab fault. The gap that separates Powell Plateau from the mainland is called the Muav Saddle, and is notched 800 feet below the surface of the plateaus. No more striking topographic contrast can be imagined than that between the mature drainage systems of the plateaus and the youthful topography within the deep-trenched canyon.

The strata of the Paleozoic rock system within the area dip gently and almost uniformly to the southwest at the rate of about 200 feet to the mile, and the surfaces of the plateaus are everywhere accordant with the rock structure. A slight local interruption occurs where the line of the West Kaibab fault crosses the area, along which the strata are flexed into a mono-

cline dipping sharply northeastward. A few minor flexures cross the area in a northwesterly direction; all dip to the southwest and are hardly more than gentle swells upon the general warping.

The Shinumo Area is a critical area for the study of the topography within the canyon itself. It is here that the topography undergoes a transition from the profile which is characteristic of the Kaibab division to that which is characteristic of the Kanab.

In the eastern, or Kaibab, division of the canyon, the descent of the wall is unusually abrupt throughout the entire Paleozoic rock series. The only bench or terrace of any extent or definition is that which is developed near the bottom of the canyon upon the summit of the basal sandstone of the Tonto group. The bench is known as the Tonto platform; in it is cut an inner gorge, in which the river flows upon the basement schists of the Archean. The platform averages a mile in width on either side of the canyon, and is so well defined that one may travel upon it throughout the length of the Kaibab division. In the next western, or Kanab, division of the canyon the lower terrace has disappeared. Instead, a wide bench is opened out upon the summit of the hard red sandstones of the Supai formation of the Aubrey group, about a thousand feet below the level of the canyon rim. This bench forms a broad level platform averaging two miles in width on either side of the canyon, and has been named by Dutton the "Esplanade." Through it is cut a deep and narrow inner gorge, at the bottom of which flows the river.

The topography of the Kaibab division is characterized by a much greater dissection than that of the Kanab; great amphitheaters are eroded back into the north wall, thronged with buttes and outliers fashioned out of every formation of the Paleozoic rock series and trenched by a multitude of side gorges. The topography of the Kanab division is very simple, consisting only of a broad outer canyon in which is cut the inner gorge; the great dissection which makes the fantastic scenery of the Kaibab division is entirely lacking.

Eastward from Havasupai Point in the Shinumo area the topography in the canyon is that which is characteristic of the Kaibab division. Westward, however, the upper platform or "Esplanade" begins to appear. The Shinumo amphitheater, which occupies the greater part of the area to be described, presents a combination of both types of topography; the great dissection and the presence of the Tonto platform are features characteristic of the Kaibab division, but the Esplanade characteristic of the Kanab division is developed to quite an equal extent upon the upper surface of the Supai sandstone. In the

western part of the area the Tonto platform fades out, the river closes in a deep inner gorge in the Esplanade, and the profile of the canyon becomes that of the Kanab division,—the view of the canyon westward from Bass Camp discloses a broad expanse of Esplanade for fifteen miles, through which the inner gorge sweeps in two great meanders almost from wall to wall. In the center of the Shinumo area the Esplanade is rather more dissected than in the Kanab division farther west, but its identity as a topographic feature is already well established.

The floors of the Esplanade and Tonto platforms, like the surfaces of the plateaus, are structural surfaces developed everywhere at the same horizon on the underlying formation. In conformity with the dip of the rock system they likewise slope to the southwest at the rate of about 200 feet to the mile.

Another topographic contrast is presented in the difference in dissection of the two sides of the Grand Canyon, a feature which is characteristic of the entire pathway through the Kaibab. The north rim lies three times as far back from the river as the south rim; the great amphitheaters with their limiting promontories extending 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 simple aspect: the side gorges rarely extend back into the rim of the canyon, there are few buttes and outliers, and the great amphitheaters are wholly lacking. Compared with the fantastic topography of the north side, the scenic effect of the south wall is precipitous and somber.

The Colorado River enters the area in the southeast corner, flows northwestwardly to the center of the area, and turns sharply west at the point where it is joined by the Shinumo. The Shinumo is the only living tributary in the area, and is the master stream that drains the Shinumo amphitheater of the north wall. It is a stream of clear water of the same order of magnitude as Bright Angel Creek twenty miles east, and is in striking contrast to the muddy Colorado.

The topography of the 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 to the southwest; 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 the Shinumo amphitheater the lateral gorges have become the dominant feature, so that the main axis of the amphitheater trends to the northwest at right angles to the course of the master stream

and parallel to the course of the Colorado River. The greatest lateral gorge extends entirely across the 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 the Shinumo; 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 is called the "Muav Canyon"; the eastern part extending from the Shinumo 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 Creek Canyon." This remarkable linear depression is situated upon the line of the West Kaibab fault and has been conditioned by erosion in that line of fracture. Two smaller lateral gorges cross the heart of the amphitheater parallel to the "Muav-Flint Creek Canyon"; these are situated upon minor lines of fracture.

It may be noted here that Tapeats amphitheater to the westward, in the Kanab division of the canyon, is characterized by similar topographic features where it is crossed by the West Kaibab fault.

In general the surface of the Kaibab plateau at the rim of the canyon is about 1000 feet higher than that of the Coconino plateau directly opposite. But since the surfaces of the plateaus and of the platforms within the canyon are structural surfaces, elevations diminish progressively southwestward in all parts of the area in accordance with the dip of the underlying rock structure. For example: the elevation of the Kaibab Plateau at the head of the Shinumo amphitheater is 8000 feet; at the end of the promontory of Point Sublime, four miles southward, it is 7500 feet. The elevation of the Coconino Plateau at the end of Havasupai Point is 6750 feet; at Bass Camp, a mile southwestward, 6652 feet. The eastern end of Powell Plateau at Dutton Point is 7555 feet; the western end is 6600 feet. Within the canyon the elevation of the Esplanade platform on the north side of the river below Point Sublime is 6250 feet; on the south side of the river below Bass Camp, 5400 feet. In the eastern part of the area the Tonto platform is 3500 feet; in the western part, 2700 feet.

The elevation of the surface of the Colorado River where it enters the area on the east is 2250 feet; where it leaves the area on the west, 2150 feet,—a drop of 100 feet in 10 miles. The river at Bass Ferry is 300 feet wide and 50 feet deep, with a rise of 40 feet at time of high water.

The greatest drops in the shortest linear distance in the area are at Dutton Point, where a drop of 5355 feet to the river is accomplished in a distance of three miles; and at Havasupai

Point, where a drop of 4500 feet is accomplished in a distance of a mile and a half. The latter drop is not equaled elsewhere in the Grand Canyon.

The width of the Grand Canyon in the Shinumo area from Bass Camp to Dutton Point is seven miles; from Bass Camp to the head of the Shinumo Amphitheater it is twelve miles; from Havasupai Point to Point Sublime it is five and one-half miles. The latter is the minimum width of the Grand Canyon in the Kaibab division. Even at this, the narrowest point, the width is over five times the depth.

The differences of climate to be found within the Shinumo area are remarkable. The range in climate between the Kaibab Plateau on the north rim 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 are extremely severe: from November to April the snow lies deep in the woods, often accumulating to a depth of ten feet; even in mid-summer the nights are chilly and days delightfully cool. Within the canyon, however, the snow rarely falls below the level of the Esplanade, while on the Tonto platform a fall of snow is practically unknown. The winters in the depths of the canyon are mild, and freezing temperatures are rare. From April to October the entire canyon below the Red Wall concentrates the solar heat, transforming it into a veritable oven; all day the bare rocks absorb the heat of the sun, becoming so hot as to burn the hand; by nightfall the wind becomes a furnace blast, and until after midnight the rocks radiate their heat, feeding the hot wind, which blows without ceasing. The effect of the heat, however, is not enervating, for the dryness of the warm wind evaporates all moisture from the body and keeps it cool. The climate of the southern, or Coconino, Plateau at Bass Camp is characterized by more open winters than the Kaibab, as well as by warmer summers: the snow in winter rarely accumulates on the surface to a great depth, and as a rule vanishes entirely within three days after a storm; in summer the 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 is chiefly due to its greater altitude. In winter the precipitation takes the form of snow; in summer it comes in the form of showers, which occur through the afternoon and evening. Looking across the canyon from Bass Camp on the south rim, almost any summer evening one may see storm after storm sweeping over the Kaibab surface, usually accompanied by violent electrical display, while the sky overhead and to the westward over the Kanab Desert remains as clear as crystal. Another

phenomenon that contributes to the greater rainfall of the north rim seems to be the presence of the Grand Canyon itself: after every general storm that visits both sides of the canyon alike, there follows on the south rim a day of clearing; but the clouds that rise out of the canyon after the storm sweep back over the north wall and re-precipitate on the Kaibab surface; these secondary storms almost never return over the south rim. The climate of the Coconino Plateau in the area is semi-arid; often no rain will fall for a month at a time. The precipitation is greatest in the winter months and in the month of July. Within the canyon much of the rainfall evaporates before it reaches the greater depths, so that the climate of the lower part of the canyon is more arid than that of the southern plateau.

Powell Plateau, whose higher eastern portion has an altitude equal to that of the Kaibab rim, and whose lower western portion has an altitude equal to that of the Coconino, has an intermediate climate. Its situation as an island in the canyon serves to moderate the cold in winter, for the warm air, rising out of the deep canyons that surround it, acts as a radiator: the snow does not accumulate so deeply on the eastern end as on the Kaibab; and on the western end does not accumulate at all. Its surface is a resort in winter for the game and wild horses that are driven out of the Kaibab by the snow. Its exposed position subjects it to violent gales of wind at all times of the year. The higher eastern end receives an abundant rainfall, while the lower western end is semi-arid.

The variation of the flora in the Shinumo area is as great as that of 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, giving its surface the aspect of a great park; Englemann spruces grow on the north slopes of the washes, and cottonwoods, aspens, and scrub oaks in their bottoms; a minor flora of flowering plants, exceedingly rich in species, covers the floor of the forest. The flora of the plateau surface of the south rim of the canyon differs completely from that of the Kaibab; it is covered with a forest of gnarled and stunted trees of juniper and piñon, with here and there a buckbrush bush; the trees never form thickets, but grow wide apart; while the open stretches are covered with sage brush and mormon tea, with occasional cactus, mescal, and plants of the century family. This difference between the floras of the north and south rim is due to the differences in precipitation and temperature, which vary directly with the altitude. For this reason the floras of the plateaus furnish an almost unfailing index of the elevation. This is beautifully shown on the

southwestward-sloping surface of Powell Plateau, the whole eastern half of which lies at an elevation of from 7000 to 7500 feet and is covered with the open pine forest characteristic of the Kaibab. At about 7000 feet the character of the flora changes, and passes into the gnarled and stunted forests of juniper and piñon characteristic of the southern plateau across the canyon.

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 bushes of juniper and piñon with greasewood as the ground bush in place of the sagebrush of the Coconino Plateau. The cactus, mescal, and plants of the century family are present in greater abundance than on the plateau, but in less abundance and in more stunted development than in the bottom of the canyon. This is due to the fact that the Esplanade level is within reach of the winter snows and frosts.

The flora of the Tonto platform, three thousand 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 in its most characteristic form. The dominant plants are the greasewood bush, the mormon tea, and the cactus. The mescal and the plants of the century family here attain their greatest development and size. The cacti are 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 somber gray. The somber colors and the reduction of leaf surface are apt 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. The only tree is the screw-mesquite, which grows in the beds of those washes that contain living or intermittent streams.

The vegetation in the bottoms of those canyons of the north side in the Shinumo Amphitheater which contain living streams is beautiful beyond description, and in refreshing contrast to the desert flora of the Tonto platform. Tall cottonwoods grow in the lower canyons; the walls are hung with maiden-hair fern in the shady places; and willow thickets border the stream. Grass grows on the banks where there is soil. Higher up in the canyons, oaks, maples, and other deciduous trees come in, and often beds of tall rushes. The most characteristic bush of these upper north-side canyons is the manzanita, which does not grow on the south side of the Grand Canyon.

GENERAL GEOLOGY.

ARCHEAN—*Vishnu Schist.*

Name.—The name “Vishnu Terrane” has been given by Walcott (Walcott, c) 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 situated on the Colorado River thirty miles east of the Shinumo area at the base of one of the great buttes called “Vishnu’s Temple,” from which he derives the name.

Distribution in the Kaibab division.—The rocks of the Vishnu series are exposed continuously for a distance of over forty miles within the Kaibab division of the Grand Canyon in the bed of the Colorado River and in the walls of its gorge which is cut beneath the Tonto platform. The Shinumo area is at the western end of this long exposure. The eastern limit of the exposure is determined by the appearance of great thicknesses of overlying strata of the Grand Canyon series dipping northeastward into the bed of the river, in the classic locality described by Walcott. The western limit of the exposure is likewise defined by a structural cause: three miles west of the Shinumo area a southward bend of the river causes it to flow parallel to the gentle southwestward dip of the Paleozoic rock system of the canyon wall, carrying the bed of the stream up out of the schists and into the basal Tonto sandstone of the Cambrian.

Occurrence and distribution in the Shinumo area.—The Vishnu schists are exposed for a distance of three miles in the gorge of the Muav-Flint Creek Canyon. They are exposed in the bed of the Colorado river throughout its course across the Shinumo area. Along the south bank of the river for a distance of four miles, and along the north bank for a distance of seven miles, in the eastern half of the area, sediments of the Grand Canyon series intervene between the Vishnu schists and the Tonto sandstone of the basal Cambrian. Elsewhere the schists are exposed without break in the walls of the river gorge beneath the Tonto sandstone.

No detailed study of these rocks was made in the Shinumo area beyond the general location and determination of the various types represented, since the limited extent of the exposures precludes the possibility of unraveling any general Archean structure from the study of this area alone. They are here a metamorphic complex of quartz, mica, and hornblende schists, invaded by a batholithic mass of quartz-diorite, and injected by veins of pegmatite and aplite.

Five main types of rock are found in this complex within the area :

The first type is a quartz schist, with graduations into mica schist. It comprises the greater part of the Vishnu schists that are exposed in the gorge of the Colorado River west of the cable crossing at Bass Ferry. It is also exposed in the bed of Muav Canyon, and in the bed of Flint Creek above the junction with the Shinumo.

The second type is a quartz schist with gradations into quartz-hornblende schist. It is exposed in that part of the Muav-Flint Creek Canyon that is occupied by the living stream of the Shinumo, 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 "Fault wash," a dry wash which joins the Shinumo just below the mouth of Muav Canyon, and is sharply bounded on both sides by the quartz-mica schist.

The fourth type of rock is a quartz-diorite. So far as observed, it constitutes all of the Vishnu series of the Shinumo area that is exposed in the "granite gorge" of the Colorado River east of the cable crossing. Its western contact is well defined. The eastern limit of the exposure was not located.

The fifth type of rock is a granitic pegmatite which occurs in dikes that cut all the rock types of the Vishnu. These dikes occur in two generations. The older generation is folded with the schists. The younger generation occurs in a great network or mesh of dikes cutting both the quartz-diorite and the schists.

The Vishnu schists have a typical schistose structure. The planes of schistosity have a dip that seldom departs greatly from the vertical. The dominant trend of the schistosity is northeasterly, but varies, from place to place. Locally, the schists are much twisted and contorted.

Lithology.—The less micaceous phase of the *quartz-mica schist* has a dark grey color with a greenish tinge. The cleavage is imperfect and the surfaces have a satin-like luster. The texture is fine-grained and the unaided eye can distinguish no mineral constituents except quartz. The microscope shows the rock to be composed almost entirely of fine interlocking grains of quartz, with occasional small flakes of white mica, arranged in parallel lines. In the extreme quartzose phase the amount of mica is almost negligible, just enough being present to impart a satin-like luster to the rock.

The micaceous phase of the schist has a slight grey color with either a pinkish or greenish tinge on the fresh fracture. Where the rock is weathered, the color becomes red. The

cleavage is rather distinct. The texture ranges from fine to coarse. To the unaided eye both the quartz and mica are visible. Under the microscope the rock is seen to be composed of interlocking grains of quartz, with an almost equal amount of mica. The mica flakes are arranged in parallel lines. The greater part of the mica is muscovite, with occasional flakes of brown biotite.

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

The *quartz-hornblende schist* is dark green in color. The cleavage is imperfect, and the texture fine-grained and uniform. The rock is dense and hard. The mineral constituents cannot usually be distinguished in the hand specimen without the aid of the lens. Under the microscope the rock is seen to consist of about equal proportions of quartz and green hornblende. The quartz is present in interlocking grains. The hornblende tends to form automorphic crystals whose longer axes have a roughly parallel arrangement. No other minerals were present in the slides examined. In some phases of the rock the quartz exceeds the hornblende in amount.

The *hornblende schist* is dark green in color. It is a soft rock, considerably disintegrated, and crumbling under the hammer. The texture is coarse granular. Megascopically the rock appears to consist almost entirely of dark green hornblende. No schistose structure is observable in the mass. The microscope shows the rock to consist almost wholly of large crystals of green hornblende in all stages of alteration. A small amount of interstitial quartz occurs. The quartz granules are strung out in a roughly parallel fashion. The rock is badly altered and the thin section is unsatisfactory.

The *quartz-diorite* found in the river gorge eastward from the cable crossing is a coarse-granular rock of typical granitic texture. It is a hard, resistant rock, which tends to weather into roughly angular blocks, a feature that distinguishes it in the mass from the exposures of the schists. The minerals visible to the unaided eye are white striated feldspar, dark hornblende, and glistening black biotite. The color of the rock is dark grey and the appearance is remarkably fresh. The texture is uniform throughout the exposures observed, and the rock is apparently without contact modifications. No tendency to gneissoid banding was observed.

Under the microscope it is seen to be a coarse-granular rock of granitic texture. The dominant mineral constituents are plagioclase and common hornblende. The plagioclase ranges 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 is present in somewhat less quantity than the hornblende. Titanite and magnetite occur as accessories. Occasionally the quartz is poikilitic in the orthoclase. The feldspathic and ferromagnesian minerals are present in about equal proportions. If it were not for the preponderance of the plagioclase the rock might be classed as a quartz-monzonite or grano-diorite. 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 *pegmatites* are pink in color and usually very coarse in texture. They are composed chiefly of quartz and pink orthoclase. Some of the dikes carry large crystals of silvery-white mica. No other minerals were noted. The dikes usually exhibit the typical comb-structure inward from the walls and the graphic arrangement of the quartz and feldspar. Along the walls of some of the dikes the texture becomes aplitic.

Origin.—There is no clear evidence in the Shinumo area by which the original character of the schists of the Vishnu series can be determined. There is no evidence of a banding that can be clearly referred to original sedimentary bedding, nor is there evidence of any original clastic texture. The mineralogical composition, however, suggests a sedimentary origin for the quartz schists of the mica and hornblende type: either might have resulted from the regional metamorphism of an arkose sandstone or shale. According to the lesser or greater abundance of iron in the original sediments the rock would assume the mica or hornblende type of quartz schist. Certainly the great preponderance of quartz as a constituent of these rocks would seem to weigh against an igneous origin in the balance of probability. The causes operating to produce the schists in their present aspect are conceived to be the processes connected with regional metamorphism, namely, subsidence and deep burial, subsequent folding and mashing, and a slow recrystallization in process of time.

The original character of the *hornblende schist* described as occurring in a narrow outcrop between the schists is not clear. The fact that the rock consists of little else than hornblende suggests that it originally constituted an igneous rock of a basic type. The fact that the microscope discloses a schistose structure is evidence that the rock is at least earlier in age than the period of regional metamorphism that was responsible for the present structural and mineralogical character of the enclosing schists.

The origin of the *quartz-diorite* is reasonably clear. Since

it is a coarse-granular, igneous rock of plutonic aspect occurring over a large area, clearly cutting the schists, and showing no textural modifications at the contact, it is concluded that it represents a deep-seated igneous invasion of considerable size, of the type known as a "batholith." Because of the unaltered character of the rock and the absence of any gneissoid or cataclastic structure, it is argued that the batholithic invasion took place at a time later than the period of regional metamorphism that produced the recrystallization and schistosity of the enclosing schists. The question may arise as to whether the invasion of the batholith was not of itself a partially operative cause in producing this recrystallization and schistosity. The field evidence is against such a conclusion: there is no gradation in the schist away from the contact, either in texture or in mineral composition, nor are the planes of schistosity parallel to the contact.

The *older pegmatite dikes* are folded intimately with the schists. Their injection may have either preceded or accompanied the regional metamorphism.

The *younger pegmatite dikes* cut both the schists and the quartz-diorite. Where they cut the schists they break cleanly across the schistosity. The injection of these dikes is the latest visible event in the igneous activity of Archean time within the area.

Age and correlation.—The rocks of the Vishnu series are rocks which, in the light of present knowledge, can only be conceived to have acquired their present character 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 the consequent lapse of an enormous interval of time,—an interval vastly greater even in events than that represented by the profound unconformity which separates the succeeding Grand Canyon series from the overlying Paleozoic. The Vishnu schists are therefore assigned to the Archean in the usage of the United States Geological Survey; but whether as a group or a complex is as yet undecided. It seems likely, as stated by Ransome (*a*, p. 21), that they are to be correlated with the Pinal Schist of the Globe and Bisbee regions, and "present somewhat different aspects of the fundamental crystalline complex of Arizona."

Up to the present time no detailed study of these rocks has been made in the Grand Canyon region, and their internal structural relations are unknown. It is not unlikely when such a study is made of their exposures in the Kaibab division of the canyon, in the Shivwits division to the west, and along

Colorado in the eastern end of the Kaibab division and the mouth of Tapeats Creek some 80 miles below in the eastern end of the Kanab division, where the strata of the Grand Canyon Series are exposed between the crystalline schists of the Archean and the basal Tonto sandstone of the Cambrian. The location of these exposures is shown on the map accompanying this article. 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.

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

The third locality lies along the north side of the Colorado river at the mouth of Bright Angel Creek opposite the railroad terminus and hotels of the Santa Fe Railroad. About 1000 feet of the basal portion of the Unkar group are there represented and the areal extent of the exposure is about three square miles. This locality has been briefly described by Ransome (Ransome, *a*). It lies about 10 miles west of the type locality.

The fourth locality comprises a limited exposure of basal Unkar strata which lies in the depths of the Hindu Amphitheater on the north side of the Colorado river about three miles up Crystal Creek from its mouth. It is situated some 20 miles west of the type locality. The areal extent of the exposure is about one square mile. It is as yet undescribed.

The fifth locality lies about the mouth of Shinumo Creek about 30 miles west of the exposures of the type area. It comprises about 12 square miles in areal exposure and represents nearly the entire thickness of the Unkar group. It is hitherto undescribed in geological literature and is the subject of the succeeding pages of this article.

The sixth locality is situated on the Colorado river just above the mouth of Tapeats Creek in the eastern end of the Kanab division of the Canyon, about 12 miles northwest of the mouth of the Shinumo in a direct line and about 25 miles down the river in its actual course. The length of the exposure is about three miles in the bed of the river and in its narrow gorge beneath the Tonto sandstone. About 4,000 feet of the basal portion of the Unkar group are exposed, striking N.W.-S.E. and dipping about 15° N.E. This locality is

structurally a unit with the exposures of the Shinumo area. It is unmentioned in geological literature.

In the western end of the Kanab division in a section across the Grand Canyon at the foot of Toroweap valley, 50 miles west of the Shinumo area, Dutton figures "rocks of Silurian and Archean unconformable" in the bed of the river beneath the basal Tonto sandstone of the Cambrian (Dutton, *a*, p. 88). It is probable that these "Silurian" rocks there represent the Grand Canyon series.

Whether these rocks appear at places in the Shivwits division between the Vishnu schist and the Tonto sandstone is not at present known.

Stratigraphic position, structure, and distribution in the Shinumo Area.—Two unconformities determine the stratigraphic position of the sediments of the Grand Canyon series in the Shinumo Area: they are separated from the underlying Vishnu schists of the Archean by a profound unconformity which represents a base-leveled surface of erosion, and from the overlying Tonto sandstone of the Cambrian by an unconformity which represents a similar base-leveled surface above.

The strata of the Grand Canyon series here constitute a wedge-shaped mass whose apex lies along the south side of the Colorado river parallel to its northward course in this part of the area. The mass as a whole constitutes one great tilted block, which in turn consists of a great number of minor tilted and rotated blocks pitching at successively greater angles northeast away from the apex of the wedge, until at a distance of three miles from the Colorado river the whole mass is dropped by a profound fault which brings up the underlying Vishnu schist from a great depth,—a structure which strikingly resembles that of the area of similarly faulted Triassic blocks of the Connecticut valley. The strike of the strata is N. 40° W. The dips are variable: in general the strata of the fault blocks near the apex of the wedge dip 10°–15° N.E.; near the center of the wedge the dips average 25° N.E.; while in proximity to the line of the great limiting fault on the northeast they are completely reversed by the "drag" along the fault plane. The truncation of this pre-Cambrian structure by the unconformity at the base of the Tonto sandstone is absolute.

The great pre-Cambrian fault that limits the wedge upon the northeast represents the exposure in the basement rocks of the line of displacement of the West Kaibab fault and displays in the most spectacular manner a phenomenon analogous to that described by Walcott upon the line of the East Kaibab monocline (Walcott, *a*). Upon the line of the ancient fault in the Shinumo area two later displacements have taken place after

the deposition of the entire Paleozoic series of the Canyon wall and probably later strata. The first of these is a monoclinical flexure which reverses the throw of the pre-Cambrian fault, while the second is a still more recent fault superimposed upon the line of the monoclinical flexure.

The strata of the Grand Canyon series are exposed beneath the Tonto sandstone in all that part of the inner gorge of the Muav-Flint Creek canyon which is on the south side of the great pre-Cambrian fault,—a distance of about three miles. They are exposed for three miles in the gorge of the Shinumo Canyon; for seven miles along the north side of the Colorado river; and in all the inter-canyon valleys within that distance which are eroded below the base of the Tonto sandstone. The two largest of these inter-canyon valleys are the "East Wash," a mile east of the Shinumo, and the "Asbestos Canyon," three miles to the west.

The gorge of the Colorado river has everywhere been trenched to a depth sufficient to expose the Vishnu schists along the river beneath the overlying strata of the Grand Canyon series. This is due to the fact that the course of the river lies close along the southern apex of the wedge.

The exposures on the south side of the river are more limited, due to the thinning out of the wedge in that direction and the lack of inter-canyon valleys trenched beneath the Tonto sandstone. The strata are exposed for two miles above and one mile below a point opposite the mouth of the Shinumo.

A southwestward bend in the river in the western part of the area carries it beyond the apex of the wedge, below which point the Tonto sandstone caps the Vishnu schists which lie in the river gorge. Southeastward up the river, in the eastern part of the area, a similar relation obtains.

The hard middle members of the Unkar resisted the erosion which preceded the deposition of the Cambrian sandstone and stood as an island in the Tonto sea.

This long monadnock of quartzite runs across the area in a N.W.—S.E. direction parallel to the general strike of the strata of the wedge, and a narrow outcrop of these quartzites is exposed along the Tonto platform on the north side of the river just at the base of the Redwall cliff, running for a distance of about five miles beyond the main areal exposures about the mouth of the Shinumo and uniting with the limestones of the upper Tonto group to form the lower part of the great cliff of Redwall limestone. In the eastern part of this exposure the quartzite monadnock projects 700 feet above the base of the Tonto sandstone. Westward from the exposures about the Shinumo the prolongation of the monadnock along the strike of the quartzites exposes them in a narrow outcrop upon the Tonto platform one mile west of the Shinumo.

The total areal exposure of the Grand Canyon series in the Shinumo area is about 12 square miles.

In following up the Shinumo from its mouth to the point where it leaves the lateral gorge of the Muav-Flint Creek canyon, a traverse is made of the total exposed thickness of the Unkar group from the unconformity at the base to the highest member that is limited by the profound fault on the northeast. There can hardly be a more magnificent illustration of details of geological structure than is here revealed. Along the entire western side of the Shinumo canyon, in cliff faces a thousand feet above the bed of the stream, is displayed every detail of the structure beneath the basal Tonto sandstone. Westward down the Colorado river the intersection of the two great unconformities forming the apex of the wedge is seen in the cliff face above the river bank, below which point the river narrows in its somber gorge in the Vishnu schists. From here northeastward, in the cliff faces along the western wall of the Shinumo canyon, bed after bed of the Unkar strata appears, wedging out southwestward beneath the plane of the unconformity beneath the Tonto sandstone. Every detail of the successive fault blocks of the great wedge is clearly shown,—their increasing tilt northeastward, the dips of the fault planes that bound them, and the occasional down-dropped wedges. Above runs the plane of the pre-Tonto unconformity, revealing in cross section the monadnock in this peneplain which existed as a rocky island during the inroads of the Tonto sea, the debris from its wave-cut cliffs being incorporated and preserved to the minutest detail in the Tonto sandstone. In the background, bed above bed in conformable succession, lies the horizontal Paleozoic section in the wall of the mile-deep Canyon. After traversing a thickness of 5800 feet of Unkar strata in a distance of three miles dipping northeastward into the bed of the stream, the traveler crosses the line of the great pre-Cambrian fault of more than 5800 feet and comes once more into the Vishnu schists on the farther side of the Muav-Flint Creek canyon.

Here again is an instance of the simplicity with which the geological structure is revealed in this wonderful country. Along the whole northern wall of the lateral gorge lie the Vishnu schists below the Tonto sandstone cliff. On the southern side, at the same level, lie the upper sandstones of the Unkar, their beds dragged up sharply against the fault line, which lies in the bed of the stream. The whole Paleozoic system on the northern side of the gorge has been dropped 500 feet by the torn monocline of the West-Kaibab fault, reversing the throw of the pre-Cambrian fault on the same line in the basement rocks. Looking westward up the Muav Canyon, the beds of the Paleozoic are seen bending down

against the fault line in a graceful arc. Far up the canyon at its head under the Muav Saddle, the more recent fault has reversed its throw and restored the throw of the monoclinial flexure. There is not a detail of this structure that may not be seen at a glance.

SEDIMENTS OF THE UNKAR GROUP.—LITHOLOGY.

Preliminary Outline.—The pre-Cambrian sedimentary rocks of the Shinumo area represent the greater part of the Unkar group of the Grand Canyon series of Algonkian age. The upper, or Chuar, group is not represented in the area. Although these sediments present no more evidence of alteration or metamorphism, aside from local igneous contact phenomena, than the overlying beds of the Paleozoic, they are destitute of fossils or decisive evidence of life. In the absence of fossils the natural basis for dividing the group into component members is the lithology. On this basis the Unkar group in the Shinumo area is divisible into five members, succeeding each other in conformable stratigraphic succession. It is not intended that the importance of this division should be greatly emphasized. Its chief value lies in the fact that it furnishes a basis for comparing the lithological 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 basis for 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 series,

Synopsis.

Tonto Group		
Unconformity.		
	5. Micaceous shaly sandstone (exclusive of 36 feet of intrusive rock).....	2297
	4. Sandstone and quartzite.....	1564
Unkar Group.	3. Argillaceous and arenaceous shale (exclusive of 950 feet of intrusive rock).....	580
	2. Calcareous shale and limestone.....	335
	1. Basal conglomerate.....	6
	Total	4782 ft.
Unconformity		
Vishnu series.		

is a thin conglomerate. This constitutes the basal member of the Unkar. Overlying the conglomerate is a series of limestones and calcareous shales. These grade upward into argillaceous and arenaceous shales which are intruded by a thick sill of diabase, and are succeeded in turn by great thicknesses of sandstone and quartzite. The uppermost exposed member of the group in the area is a thick series of micaceous shaly sandstones.

It has been shown that these strata lie in a wedge-shaped mass inset in the Vishnu schists, and that this wedge is composed of a great number of smaller titled fault blocks. It is apparent from this relation that nowhere in the Shinumo area can the thickness be measured in one unbroken section. Since, however, the lithological characters of the strata are constant and easily recognized, and since the throw of the faults that bound the titled blocks seldom exceeds 100 feet, the restoration of a section showing the unbroken sequence is not a matter of great difficulty.

Detailed sections were made upward from the base of the Unkar through each fault block until its limiting fault was reached. The highest bed measured was then located in the next block to the northeast, and the measurement resumed at that point. Except in the fifth, or highest member of the group, all sections were measured with a tape along the nearly vertical wall faces of the box canyons of the Shinumo and other washes that cut across the strike of the strata. In the fifth, or highest member of the group, the strong drag of the great fault on the northeast has flexed and contorted these shaly sandstones in such a manner that accurate measurement with the tape alone was impossible. Their thickness was computed by the aid of trigonometric formulæ, using the combined data afforded by the use of the tape, the topographic map, and observations of the varying strike and dip.

The section incorporated in this article was made in two places. The greater part of the total thickness was measured in a traverse up the Shinumo. This section includes all the strata above the diabase sill which is intruded midway in the "arenaceous and argillaceous shales" which comprise the third member of the Unkar. It would have been perfectly possible to make a complete section of the group in a traverse of the entire course of the Shinumo from the basal unconformity at the mouth of the creek to the great fault three 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 the canyon of the East Wash 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° N.E. The section of the basal members of the group was measured in this locality, where the sequence is unbroken by faulting.

Detailed Section.

First Member.—Basal Conglomerate. The surface represented by the upper unconformity that separates the Unkar group from the basal Cambrian is a striking enough example of a base-leveled surface, although monadnocks rise in places to a height of 700 feet above the base of the Tonto sandstone. But the surface represented by the lower unconformity that separates the Unkar group from the Vishnu is an almost perfect plane: nowhere in the seven linear miles exposed in the Shinumo area can a difference in relief be observed that exceeds 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.

The basal conglomerate is an arkose conglomerate varying in thickness from 1 to 6 feet in the Shinumo area. It is composed of angular or subangular fragments of the rocks of the underlying Vishnu series, cemented by a matrix of red arkose mud which usually contains small fragments of pink feldspar. Occasionally the matrix contains small rounded grains of quartz.

The degree of induration of this conglomerate presents all variations from a hard, dense, siliceous rock, which fractures across matrix and enclosed rock fragments alike, to an easily disintegrated rock in which the matrix crumbles away from the enclosed fragments. This phenomenon, however, does not depend upon original cementation, but upon metamorphic effects produced by the diabase sill that is intruded in the overlying rocks, the degree of induration depending upon how far the conglomerate lies below the contact of the sill.

The matrix is usually of the same composition everywhere in the area. The character of the enclosed fragments, however, is sharply localized by the character of the underlying rock. The rock which underlies the conglomerate in the East Wash is the quartz-diorite of the batholith previously described. For three feet below the conglomerate the diorite is weathered along the joints into roughly angular blocks. These joints are filled with the red arkose material of the matrix. Above follows a layer of the conglomerate one foot in thickness, composed of weathered fragments of the diorite cemented with the red arkose material. Then follows a layer six inches thick composed of small rounded quartz pebbles and

fragments of chert of the same character as that contained in the overlying limestones. The whole is cemented with the red mud. The conglomerate is very little indurated in this locality. Although the contact of the diorite with the mica-schists in the underlying Vishnu is not two hundred yards distant, there is not a fragment of the mica-schist to be observed in the conglomerate.

In the Asbestos Canyon, four miles to the west of the East Wash, 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 degree of induration is here very great, and the rock fractures across the grains like a hard, dense quartzite. This is due to the fact that the lower contact of the diabase sill lies only 150 feet above this basal conglomerate in the Asbestos Canyon, while in the locality in the East Wash it lies 550 feet above.

Two important features characterize the basal conglomerate of the Unkar in the Shinumo area; the arkose nature, and the lack of sorting and transportation of the component fragments.

Second Member.—Calcareous Shales and Limestone. The section was measured on the west side of the canyon of the East Wash. This and all the following sections read from the base upward, *a.* 1 being the bottom bed, overlain by *a.* 2, etc.

CHARACTER	THICKNESS
<i>a.</i> <i>Basal white limestone.</i>	
1. White, nodular, cherty limestone. The chert occurs in nodules with a roughly concentric structure somewhat suggestive of the structure of <i>Cryptozoön</i>	1' 6"
2. 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 a cubic habit.....	4' 6"
Total.....	6'

CHARACTER	THICKNESS
<i>b. Argillaceous and calcareous red shale and limestone.</i>	
1. Soft, purple shale	6"
2. Purple, cherty limestone	1'
3. Purple shale with occasional bands of purple calcite	4'
4. Purple, crystalline limestone	1'
5. 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 they are mottled with light-colored spots which are usually circular or elliptical in form and of all sizes	5' 6"
6. Blue limestone, white for 1" at the base and showing dendritic markings	5"
7. Red shale	1' 5"
8. Blue limestone	4"
9. Red shale	3' 10"
10. Purple limestone	6"
11. Calcareous, red shale with three thin bands of purple limestone	9' 10"
12. Red, crystalline limestone	1'
13. Red shale	1'
14. Red, crystalline limestone	1'
15. Red shale	11'
16. Blue limestone	3"
17. Red shale	1'
18. Blue limestone	2"
19. Pink limestone	1'
20. Red shale	4' 4"
21. Cherty, white limestone	4"
22. Compact, red shale forming a cliff	8'
23. Alternating layers of buff and red shale	13' 6"
24. Dense, purple, calcareous shale carrying bands of pink calcite and forming a cliff. Contains occasional thin bands of chert	9' 6"
25. Blue, calcareous shale with an onion-like concretionary structure on a large scale	5'
Total	85' 5"

c. White limestone.

1. 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. Dendritic markings are present	2'
2. Nodular, white, cherty limestone. The chert is present in irregular nodules of no definite shape.	

CHARACTER	THICKNESS
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. Dendritic markings are present	2'
3. Dense, homogeneous, white, crystalline limestone, forming a cliff. The upper part is thin-bedded	3' 8"
4. Homogeneous, thin-bedded, white, crystalline limestone containing occasional thin bands of chert and nodules whose character suggest the structure of <i>Cryptozoön</i>	8' 6"
5. White limestone carrying a large amount of chert in undulatory and gnarled bands	2' 4"
6. Lumpy and gnarly, white limestone carrying chert in large irregular nodules. Crumbles to a white powder	2' 6"
7. Purple shale	
8. Layers of undulatory-banded, bluish chert	1' 10"
9. Soft, purple shale	5"
10. Layer of gnarled and twisted chert nodules in a matrix of white talc. The surface of the talc is covered with dendritic markings	2'
11. Thin-bedded, white limestone crumbling to white powder or weathering into thin plates like a shale	2'
12. Soft, purple shale	1'
13. Thin-bedded, crystalline, white limestone	3' 10"
14. Soft, purple shale	1' 10"
15. Dense, blue, crystalline limestone forming a small cliff	3'
16. Homogeneous, thin-bedded, white limestone, crumbling to a white powder and weathering into plates like a shale	15'
17. Dense, crystalline, blue limestone	4"
18. Purple shale	3' 3"
19. Layers of undulatory-banded, nodular chert in a matrix of earthy white limestone	3' 10"
20. Thick-bedded layers of pure, homogeneous, white marble, forming the strongest cliff in the second member of the Unkar	6' 8"
21. Same in thinner beds	6' 6"
22. Undulatory-banded, cherty limestone becoming crystalline above	10'
23. Red shale below and purple shale above, separated by a thin layer of chert	5'
24. Thick-bedded, crystalline, white limestone of the same character as 20, forming a strong cliff	3' 6"

CHARACTER	THICKNESS
25. Thin-bedded, crystalline, white limestone	5' 6"
26. Gnarled and nodular, white, cherty limestone ..	7'
27. Very hard, dense layer of flint forming small cliff	5"
Total	105' 2"
<i>d. Blue slate and white limestone.</i>	
1. Soft, purple shale	3' 6"
2. Hard, blue slate forming small cliff	1'
3. Fissile, blue slates with fine partings	7'
4. Thin-bedded, purple, crystalline limestone	1' 2"
5. Dense, purple, crystalline limestone forming a small cliff	7"
6. Same as 4	2' 2"
7. Same as 5, forming small cliff	8"
8. Thin-lamellar, spotted, blue slate	6' 6"
9. Gnarly layers of fine-lamellar, blue calcareous slate with a very coarse concretionary structure. Irregular nodules of chert occur in the middle portion	33'
10. Dense, blue, crystalline limestone forming small cliff	2' 3"
11. Thin-bedded, platy, white limestone	2' 6"
12. Very thin-lamellar, fissile, blue slate	3'
13. Calcareous, blue slate forming a cliff	3'
14. Thin-bedded, platy white limestone	4' 6"
15. Fissile, blue slate	7'
16. Dense, lumpy, white crystalline limestone	2'
17. Pinkish-green, fissile, siliceous slate of a jaspery appearance forming a cliff	5'
18. Layers of dense, white, crystalline limestone separated by thin bands of pale-green, talcose material	10'
19. 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"
20. Layers of dense, white, crystalline limestone separated by bands of pale green, talcose material	2'
Total	108' 2"
<i>Synopsis of second member of the Unkar.</i>	
a. Basal white limestone	6'
b. Argillaceous and calcareous red shale and limestone	85' 5"
c. White limestone	105' 2"
d. Blue slate and white limestone	108' 2"
Total thickness	304' 9"

When the specimens of these rocks were examined in the laboratory it was found that all the limestones were more or less dolomitic. The limestones of division "c" were found to be entirely dolomites.

Thin sections were cut from specimens from twenty separate beds in the second member. 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 the nodules and from the limestone itself, for the purpose of ascertaining the exact mineralogical character of these rocks, and in the forlorn hope that they might reveal traces of a structure that could be referred to something organic. No minerals other than calcite and quartz were revealed by the microscope in any of the slides. The silica of the chert bands and nodules was found to exist in the form of interlocking grains of quartz. None of the grains were rounded and there was no suggestion that the quartz grains of the chert bands represented an inwashed sand. Nor was there any trace of an organic structure 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 found to consist of mixtures of quartz and calcite in all proportions. The greater part of the limestone was of this impure character. The shales were found to consist of a fine impalpable ferruginous or calcareous mud, containing occasionally a minute grain of quartz.

Several features of interest are shown in the lithologic section of the second member of the Unkar as a whole.

Ripple marks and sun cracks appear for the first time in the shales in stratum No. 18 of division "d," just below the highest limestone stratum at the summit of the member.

The increasing intensity of metamorphic phenomena in the section from the base upward may also be noted. This is due to the approaching proximity to the lower contact of the diabase sill which is intruded in the member above. The metamorphic action is manifested in the shales by their change upward both in color and in degree of induration: the shales of division "b" are almost entirely red; from the summit of this division upward the color changes to purple and blue. Below division "d" the shales are soft and crumbly; within this division, however, they become dark blue slates, while in the upper part they become extremely hard, siliceous jaspers.

The vertical succession of the strata is seen to be broadly characterized by continual and rapid alterations of limestone and shale. According to the dominance of either type of rock the four divisions *a*, *b*, *c*, and *d* are separated: division "*a*" is

entirely limestone, “*b*” is alternating limestone, and “*d*” predominantly shale. Thus there are four major cycles of oscillation upon which the minor cycles are superimposed.

A comparison of the above section in the East Wash with a section measured in the Asbestos Canyon, four miles to the west, is of interest. In the Asbestos Canyon the “basal white limestone” (*a*) has a thickness of 30 feet contrasted with a thickness of 6 feet in the East Wash. The lower stratum of “nodular, cherty limestone” is there 7’ 9”, contrasted with 1’ 6” in the East Wash. The upper stratum of “parallel-banded, cherty limestone” is 22’ 3” in the Asbestos Canyon, containing in the middle an intercalated layer of purple shale, and near the top a thin layer of rather fine arkose conglomerate. The “argillaceous and calcareous red shales and limestones” of division “*b*” have a thickness of 88 feet in the Asbestos Canyon contrasted with 85’ 5” in the East Wash. They do not have the red color that characterizes them in the East Wash, but are purple and blue, and much indurated. This change of color and difference in degree of induration is due to their closer proximity to the diabase sill in the Asbestos Canyon.

The correspondence in lithographical character and vertical succession of these two sections four 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 (*a*).

Third Member.—Argillaceous and Arenaceous Shale.

Section measured at East Wash in continuation of the preceding section.

a. Cliff-forming jasper.

1. Dense, hard layer of blue-black jasper mottled with red spots and showing no banding in the mass, forming with the three following layers a strong perpendicular cliff. This is the most resistant rock in the Unkar. Where the under surface shows beneath the overhang of the cliff it is sun-cracked on a large scale and in several generations.	28'
2. Same general character as 1, but showing a banded structure. The lower 2 ft. are slaty and weather out, giving the cliff an overhang.	19'
3. Same as 2 with a soft slaty layer at the base. ...	14'
4. Same as 2 and 3 with a soft layer at the base.	12'
Total	73'

b. Calcareous blue slate.

1. Slaty, black jasper, sun-cracked throughout...	12'
2. Pink, crystalline limestone.....	1' 6"
3. Slaty, blue jasper with small red spots.....	4' 6"
	<hr/>
Total	18'

c. Cliff-forming jasper.

1. Dense, hard layer of blue-black jasper mottled with red spots, forming with the following layer a strong cliff.....	14'
2. Same as 1 with a soft slaty layer at the base which weathers out, giving the cliff an overhang.	3' 6"
	<hr/>
Total	17' 6"

d. Sandy quartzitic jasper.

1. Slaty, blue, spotted jasper.....	4'
2. Fine-grained, pink quartzite, ripple-marked ...	5'
3. Slaty, blue, spotted jasper.....	12'
4. Fine-grained, pink quartzite.....	4'
5. Slaty, blue, spotted jasper with sun-cracks.....	6'
6. Fine-grained, pink quartzite, ripple-marked...	1'
7. Pink, quartzitic jasper.....	5'
8. Fine-grained, pink quartzite.....	4'
9. Fine-grained, pink, sandy jasper, sun-cracked..	11'
	<hr/>
Total	52'

e. Red and blue jasper.

1. Banded, blue jasper with curious spots. Sun-cracked throughout	22'
2. Red and black banded jasper	9'
	<hr/>
Total	31'

f. At this horizon is intruded a sill of diabase, whose thickness varies from 650 feet on the Shinumo to 950 feet or more in the Asbestos Canyon.

The remainder of the section was measured in a traverse up the Shinumo, starting with the upper contact of the diabase sill.

<i>g.</i> Blue slate and quartzite forming a cliff.....	20'
<i>h.</i> Blue slate forming a slope.....	100'
<i>i.</i> Red, argillaceous shale — sun-cracked throughout. The rock is very soft and forms a slope together with the underlying blue slate.....	91'
<i>j.</i> Alternating, vermilion, argillaceous shale and sandstone.	

The alternations in this series occur with remarkable regularity. The sandstone is white in color and is compact and

fine-grained. It 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 beautifully preserved sun-cracks. The shales are fine-grained, fissile, and argillaceous.

The succession in this alternating series is as follows :

No.	Bed	Thickness	S. S.—Sh. cycle
1.	Sandstone.....	4' 2"	
2.	Shale.....	3' 10"	8'
3.	S. S.....	2'	
4.	Sh.....	3'	5'
5.	S. S.....	1'	
6.	Sh.....	2'	3'
7.	S. S.....	7'	
8.	Sh.....	10' 6"	17' 6"
9.	S. S.....	5'	
10.	Sh.....	3'	8'
11.	S. S.....	6'	
12.	Sh.....	2' 6"	8' 6"
13.	S. S.....	6'	
14.	Sh.....	3' 6"	9' 6"
15.	S. S.....	6'	
16.	Sh.....	3' 6"	9' 6"
17.	S. S.....	7' 6"	
18.	Sh.....	4'	11' 6"
19.	S. S.....	3' 6"	
20.	Sh.....	6"	4'
21.	S. S.....	2'	
22.	Sh.....	1'	3'
23.	S. S.....	3' 10"	
24.	Sh.....	2' 6"	6' 4"
25.	S. S.....	2'	
26.	Sh.....	6' 6"	8' 6"
27.	S. S.....	3'	
28.	Sh.....	4'	7'
Total,		109' 4"	Ave., 7' 10"

k. Alternating, vermilion, arenaceous shale and sandstone.

The sandstone 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 :

1. Sandstone.....	9' 4
2. Arenaceous shale.....	21' 1"
3. Sandstone.....	9'
4. Arenaceous shale.....	11' 8"
5. Sandstone.....	2'
6. Arenaceous shale.....	24'
7. Sandstone.....	1'
Total	78' 1"

Synopsis of third member of the Unkar.

a. Cliff-forming jasper.....	73'
b. Blue slate with calcareous band.....	18'
c. Cliff-forming jasper.....	17' 6"
d. Sandy quartzitic jasper.....	52'
e. Red and blue jasper.....	31'
f. (Intrusive diabase)	
g. Blue slate and quartzite.....	20'
h. Blue slate.....	100'
i. Red argillaceous shale.....	81'
j. Alternating vermilion argillaceous shale and S. S.....	109' 4"
k. Alternating vermilion arenaceous shale and S. S.	78' 1"
Total thickness	579' 11"

Thin sections were cut from several specimens of the jaspers. The slides were unsatisfactory, however, 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 it to have been a somewhat arkose sandstone indurated to a siliceous quartzite. It was seen to be 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 one of the sandstone layers in the "alternating argillaceous shale and sandstone" of division "j." 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 lithologic section of the third member given above. This metamorphic action is manifested in three ways:

1. Induration by silicification,—jaspers.
2. Induration by baking,—slates.
3. Decoloration,—red to blue and black.

It was noted in the summary of the features of the second member that the shales became successively slates and jaspers above, while their color changed from red to blue. In the third member the shales are represented entirely by jaspers and quartzites. Just below the contact the induration is very great, and the jaspers are tough and vitreous; the 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 upward into the original red shale.

The metamorphic effects above and below the contact differ in degree of intensity as well as in kind: above the contact the induration and decoloration characterize only about 100 feet of strata; below the contact this action extends through 300 feet. Above the contact the strata are characterized by baking and decoloration only, changing the red shale into a blue slate; below the contact there has been a considerable addition of silica, transforming the red shales into blue and black jaspers; added to this are the effects of baking and decoloration.

It may be said in summary that the third member is characterized by argillaceous shales in the lower portion, which grade upward into arenaceous shales and sandstones through the interesting series of alternations described in division "j." There is hardly a stratum in the entire member that does not bear marks of shallow water origin, manifested by either sun-cracks, ripple-marks, or cross-bedding.

Fourth Member.—Sandstone and Quartzite.

Section on the Shinumo.

- a. Purple-brown sandstone of fine grain containing locally an occasional lense of fine conglomerate and sometimes a thin local bed of red or purple shale. The sandstone is cross-bedded throughout 406'
- b. Compact, white quartzite of fine and uniform grain, displaying a faint cross-bedded structure. This quartzite is the most resistant rock in the fourth member. 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 lense the under surface displays well preserved mud-cracks. The face of the cliff is stained magenta by the ferruginous cement of the shale lenses in the overlying sandstones, which washes down from above 119'
- c. Purple-brown sandstone of the same character as a 353'
- d. Banded, white quartzite, stained magenta on the exposures, and forming a cliff 120'

e.	Fine-grained, purple sandstone with a white band in the middle. The white band is constant and presents a conspicuous feature by which this purple sandstone can be distinguished at a distance of several miles. The rock is cross-bedded and sometimes displays a "twisted and gnarled" structure	150'
f.	Compact, cliff-forming, white quartzite of the same character as <i>b</i> , though not so massive in structure ...	250'
g.	Banded white quartzite	20'
h.	Irregularly bedded sandstone	
	1. "Curiously twisted and gnarled layers," of fine-grained white sandstone containing large red spots of a 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 deposition. It gives the rock an appearance which suggests that the original sand was moist and plastic and once flowed by rolling over and over in the form of a quicksand.	105'
	(It may be noted that a bed of this character is described by Walcott in his section in Unkar Valley. (Walcott <i>b</i> , page 511.) It occurs at the same horizon as the bed described above, and contains the same red spots.)	
	2. Banded, purple sandstones	20'
	3. Green, cross-bedded sandstone	21'
		<hr/> 146'

The total thickness of the fourth member of the Unkar is 1564 feet.

Slides were cut from several specimens of the sandstones and quartzites. All were found to consist of small rounded quartz grains, the size of which seldom exceeds 0.7^{mm}. This extreme fineness and roundness of the grains, as well as the cleanness of the sorting, is remarkable. The cement is usually siliceous, sometimes slightly ferruginous. A slide was made from a specimen taken from one of the small conglomerate lenses in division *a*. The conglomerate was found to consist of small rounded quartz pebbles, lying in a fine arkose matrix. Occasional large angular fragments of orthoclase and microcline were revealed.

In summary it may be said that the fourth member is characterized by great thicknesses of pure, fine-grained sandstone of a uniform character. All divisions of the member are resistant to the weather and form cliffs. Ripple marks and cross-bedding occur throughout.

Fifth Member.—Micaceous Shaly Sandstone.

Section measured in Fault Wash, west side of Shinumo Canyon.

<i>a.</i> Gray-green, pinkish-green, and brown micaceous shaly sandstones, cross-bedded and ripple-marked, varying in character only through gradations in color. Frequent arenaceous and argillaceous shaly partings occur, causing the rock to weather like a soft sandy shale. The shale partings are usually green. Some of the sandy layers near the base show the "gnarled and twisted structure."	1100'
<i>b.</i> The green, gray, and brown beds of <i>a</i> pass upward through change of color into red and vermilion beds of the same general character. These are likewise 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	1197'
Total	2297'

The summit of the Unkar section is obliterated in the beds of division *b* by the plane of the pre-Tonto unconformity. The highest beds of this division lie at the upper end of the Fault Wash, dragged against the Vishnu schist on the north by the great pre-Cambrian fault previously described, and the whole overlain by the Tonto sandstone.

In the uppermost part of division *b* are four thin sills of rotten basaltic rock, weathering green and crumbling to small fragments. They occur between the beds of vermilion sandstone and shale. Their intrusive character is shown by the fact that they have baked and decolorized the vermilion beds for a few inches both above and below the contacts, changing the color to purple. The rock is too badly weathered to allow a petrographic determination in thin section.

In summary the fifth member of the Unkar may be characterized as a series of micaceous shaly sandstones of uniform character, varying only in color, and bearing marks of shallow water origin throughout.

Comparison with the type section in Unkar Valley.—A comparison of the above section of the Unkar group with that described by Walcott (*d*) in the type locality 30 miles to the east reveals the fact that the correspondence between the two sections is very close, both in thickness and in lithological succession; only in the lower portions 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 much limestone in the members which correspond to the second member on the Shinumo; the deficiency in limestone is made up by greater thickness of arenaceous and argillaceous shale. Proceeding upward in the section there is a somewhat greater

proportion of sand in that division of Walcott's section which corresponds to the third member on the Shinumo. The succeeding members correspond closely in character and thickness even to the minor divisions; an example of this is the "gnarled and twisted layers" previously cited.

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

DIABASE INTRUSIVE IN THE UNKAR.

Occurrence.—The diabase occurs in the form of an intrusive sheet or sill which occupies three separate stratigraphic horizons in the Unkar sediments in different parts of the Shinumo area. On the west side of the Asbestos Canyon three miles west of the Shinumo it is intrusive in the limestones of division *c* of the second member of the Unkar at a horizon 15 feet above their base. On the east side of the Asbestos Canyon it ascends out of this horizon and breaks across the overlying limestones and shales in an eruptive contact. Most of the lower, and part of the upper, sections of the eruptive contact are beautifully displayed in the walls of this canyon, but the complete exposure is obliterated above by the truncating unconformity at the base of the Tonto sandstone. Between the exposures in the Asbestos Canyon and the main areal exposures about the mouth of the Shinumo, the pre-Cambrian structure is hidden beneath the sandstone of the Tonto platform. Where the diabase reappears in the exposures about the Shinumo it is found to lie intruded midway within the shales of the third member of the Unkar at a horizon 400 feet above that which it occupies in the Asbestos Canyon. This is the stratigraphic position which it holds in all the exposures of the central part of the Shinumo area. Eastward up the river from the East Wash the diabase again disappears beneath the pre-Tonto unconformity. But directly under Havasupai Point, about three miles farther east, limited outcrops of the basal portion are exposed in small inter-canyon valleys on both sides of the river. Here the lower contact of the diabase lies just at the top of the "white limestones" of division *c* of the second member of the Unkar.

The thickness of the sill is approximately 650 feet on the Shinumo and 950 feet on the west side of the Asbestos Canyon. Eastward from the Shinumo the outcrop is considerably

thinned by a strike fault, precluding the possibility of measuring the thickness in that direction.

PETROGRAPHY.

Megascopic.—The fresh specimens characteristic of the greater part of the mass show it to be a tough, heavy, holocrystalline rock of medium to coarse grain and of a grey 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 of a coarser grain and different texture than that of the mass of the rock and are more resistant to the processes of disintegration. These lumps and balls can be seen to consist of coarse ophitic intergrowths of augite and plagioclase. The diabase weathers by mechanical disintegration to a greenish-olive sand in which are innumerable lumpy kernels of all sizes derived from the ophitic masses described above. The rock has no typical columnar structure, but usually displays a rough vertical jointing such as is characteristic of granite.

Microscopic.—The slides examined show the typical rock to consist primarily of plagioclase feldspar (near labradorite) and olivine in about equal amounts, with a subordinate quantity of augite and brown biotite. A very little magnetite is present. 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 chiefly confined 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 them to be composed entirely of augite and feldspar. The augite is enclosed within the feldspar, displaying beautiful examples of ophitic texture. Several of the magnetite crystals were observed to 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 are of two kinds. The first type occurs in the ophitic intergrowths of augite and plagioclase in the lumps and balls described above, and is a segregation phenomenon character-

izing the mass as a whole; sometimes this texture becomes very coarse, the separate crystals of augite or plagioclase attaining an inch in length. The second type occurs in typical pegmatite dikes cutting the diabase in many places and varying in width from a few inches to several feet. The minerals are plagioclase and augite and the texture is usually ophitic, although not always so. In some of these dikes crystals of plagioclase exceeding three inches in length were observed.

The contact facies of the diabase are frequently fine-grained or glassy, but never for more than a few inches from the contact. The slides typical of this zone reveal a hyalopilitic arrangement of glass with skeleton crystals of magnetite between badly altered crystals of feldspar.

For about a half-mile east and west of the Shinumo there occurs in the upper part of the diabase sill along the upper contact a pink holocrystalline rock of medium grain. The contact of this rock with the overlying blue slates is sharp and well-defined. Downward it appears to grade into the normal diabase, and no definite line of contact can anywhere be observed. Unfortunately the writer did not collect transition specimens, but took only one specimen from the middle of the pink mass. The slide from this specimen when examined under the microscope showed it to be a granular rock of medium texture, consisting of rather fresh crystals of orthoclase, with subordinate quartz and a somewhat altered ferromagnesian mineral which was made out 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. But a more complete set of specimens across the apparent transition zone must be collected before such a conclusion can definitely be established.

In the Asbestos 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 badly altered.

Ransome, in his report upon the "Geology of the Globe Copper District, Arizona" (Ransome *b*, p. 80 ff.) describes a diabase of post-Carboniferous age occurring in thick sills in the pre-Carboniferous sedimentary rocks of that region. This diabase closely resembles the Algonkian diabase described above, both in mineralogical 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 occurring within the diabase sills of the Globe district as a possible segregation phenomenon within the diabasic magma.

Contact metamorphism.—Since the diabase sill occupies relatively different horizons in the Unkar strata upon the Shinumo and in the Asbestos Canyon, and since in the former locality the strata between which the sill is intruded lie in undisturbed sedimentary contact in the latter locality, and vice versa, the study of the respective contact effects upon the invaded strata could be made with great facility.

The contact effect upon the shales which lie above and below the diabase along the Shinumo has already been described in the detailed section of the Unkar: there the shales were shown to be altered to jaspers by baking and silicification. It was shown that 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 the Asbestos Canyon these rocks lie in undisturbed sedimentary contact and are there unaltered red shales.

The contact effect upon the limestones can be studied in the Asbestos 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 layers of the same character 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 *c* of the second member of the Unkar. They overlie the red shales of division *b*, which are here baked to blue slates.

<i>Section below diabase contact</i> (reading upward from the base)	
Dense, purple, calcareous slate (<i>b</i> , 24 of second member of Unkar)	9'
Soft, blue slate (<i>b</i> , 25)	3'
Nodular, cherty limestone (<i>c</i> , 1, 2)	4'
Banded, crystalline limestone with bands and nodules of serpentine (<i>c</i> , 3, 4,)	10'
Serpentinous, nodular and banded layer carrying veins of asbestos	1'
White, crystalline limestone with bands and nodules of serpentine	2'
Pure, white, crystalline limestone	1' 6"
Layer of green serpentine	2'
Diabase.	

Above the upper contact of the diabase the limestones contain several alternating layers of green serpentine and narrow

veins of asbestos occur at several horizons in proximity to the contact.

The geological occurrence of the asbestos is fully described by Diller in "Mineral Resources of the U. S. for 1907" (Diller, *a*), and again by the same writer in "Mineral Resources for 1908" (Diller, *b*). The contribution of the writer of the present article consists of the further data afforded by a microscopic study of the rocks associated with the asbestos in this locality. A microscopic study was made of 25 thin sections cut from the limestones, the bands and nodules of serpentine, and across the veins of asbestos. Aside from the serpentine and asbestos no other minerals were revealed in the limestones beyond the dolomitic calcite and interlocking grains of quartz already described in the slides cut from the limestones of the same horizon in the section on the East Wash, where the same strata lie in undisturbed sedimentary contact. The texture of the limestones is entirely that of marble. The serpentine of the bands and nodules shows no trace of an alteration structure which might indicate a derivation from pyroxene, hornblende, or olivine. The slides cut across the veins of asbestos showed them to be later than the serpentine in which they are usually enclosed. A great number of veins of asbestos of microscopic size was revealed in some of the slides where their presence was unsuspected. Some of these veins were observed cutting across both the serpentine and the limestone in the same slide.

The asbestos which occurs in the larger veins is commercially of high grade and the fiber is of great tensile strength. It is pronounced by Diller to be the best in quality yet found anywhere in the United States. (Diller, *b*, p. 11.) Locally the crossfiber is 4 inches in length. The horizon of the larger veins is confined, so far as is known, to the limestones which lie beneath the lower contact of the diabase sill. The veins above the contact, although more widely distributed through the limestones, are usually of smaller size. The horizon below the contact is not absolutely constant in stratigraphic position and may lie anywhere from 3 to 15 feet below the contact. The width of the veins within this horizon varies greatly from place to place, so that a vein of three inches in width 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.

Conclusions.—The serpentine and asbestos occur in the limestones only where these strata are invaded by the diabase sill; where the diabase lies between shales there is no development of these minerals within the invaded strata. In no place in the area are they developed within the diabase itself. It is therefore clear that they are a contact metamorphic

phenomenon conditioned by the invasion of the limestones by the diabase. It seems probable, as suggested by Diller (*a*, p. 72), that the serpentine which encloses the veins of asbestos is derived from some mineral in the limestones and not from the diabase. The limestones themselves are magnesian, and locally siliceous in the form of chert bands and nodules. In another part of the area the conversion of the shales to jaspers where they are in contact with the diabase is evidence that the fumarolic action accompanying the injection of diabasic magma was manifested by aqueous and probably siliceous emanations and was fairly intense. It seems possible that the operation of the fumarolic action upon the elements already present in the magnesian limestones might have been sufficient to convert the more siliceous portions into serpentine. The occurrence of the asbestos in veins that cut both the nodules of serpentine and the limestones is evidence that the formation of the cross-fiber asbestos was itself a somewhat later phenomenon.

Age and Correlation.

The Grand Canyon series is referred to the Algonkian in the usage of the United States Geological Survey and is tentatively correlated with the Keweenawan series of the Lake Superior region and with the Llano series of Texas, following the conclusions established by Walcott (*b*, p. 518). In the Shinumo area the profound nature of the unconformity which separates these strata from the basal Tonto sandstone is even more striking than in the area described by Walcott, while the certainty of their stratigraphic position is in its clearness and spectacular character probably unparalleled in the world.

GEOLOGIC HISTORY.

Outline.

The following sequence of events may be distinguished :

1. Deposition of the Vishnu sediments, source unknown.
2. Regional metamorphism.
 - a.* Subsidence and profound burial.
 - b.* Orographic movement of folding and compression resulting in recrystallization and schistosity, accompanied or preceded by injections of pegmatite.
 - c.* Elevation, accompanying or succeeding the orographic movement.
3. Batholithic invasion of quartz diorite.
4. Later pegmatitic injections.
5. Long cycle of erosion carried through to a featureless peneplain of no relief, which truncates the very roots of the Vishnu structure.

6. Sudden incoming of the shallow Unkar sea.
7. Deposition of the Unkar sediments and succeeding strata of the Grand Canyon series in shallow water (or upon land?)
8. Intrusion of diabase sills.
9. Orographic movement of block faulting and tilting accompanied or succeeded by elevation.
10. Long cycle of erosion carried through to a peneplained surface of small relief.
11. Incoming of the Tonto sea, succeeded by the deposition of the Paleozoic strata of the wall of the Grand Canyon.

The earliest event which is decipherable in the geologic history of the Shinumo area is found in the blurred and mangled record of the Vishnu schists. Far back in the dark ages of geologic time a thick series of more or less arkose sands and muds was accumulating upon a subsiding floor. So much may be reasonably inferred from the mineralogical character of the quartz schists of the mica and hornblende type. So dim and vague is the record that the base of this series, the floor upon which it was laid down, the thickness, and the location of the land mass from which it was derived must, perhaps, remain forever unknown. Following the long accumulation and burial of these sediments came an orographic movement which wrote across the older manuscript in a newer and bolder hand, blurring the ancient writing with the stamp 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, followed by folding and compression, which engraved upon them the characters of recrystallization and schistosity in slow process of time, and accompanied by their elevation into lofty mountains. Somewhat later the cores of these mountains were intruded by great masses of igneous rock, here in the form of quartz diorite, followed by pegmatitic injections. Perhaps while this orographic movement was still in progress the forces of erosion were already at work. Then followed a tremendous cycle of erosion carried through to the very end, planing away the ancient mountains to the basal roots, and reducing hard and soft rocks alike to an utterly flat and monotonous level. Such was the completion of the cycle of this vast unknown and unnamed æon of time.

The next event is the beginning of another great cycle of sedimentation resulting in the deposition of the Grand Canyon series of Unkar and Chuar strata, ushered in by the sudden invasion of a shallow sea which swept over the featureless desert surface of the Vishnu plain, depositing the basal conglomerate of the Unkar. The clue to the inferences as to the character of this incoming sea, of the rock mantle which it

found covering the plain, and of the climate of the time is preserved for us in the basal conglomerate described in a previous part of this article. It was there noted that the weathering below the surface of the peneplain was slight, and the product of physical disintegration rather than of chemical weathering; that the matrix of the conglomerate is red in color and arkose in nature; that the pebbles are angular and show no evidence of transportation and sorting. We may therefore conclude that the conglomerate represents the soil in place which covered the Vishnu plain. All the evidence points to an arid climate,—the lack of chemical weathering, the freshness of the arkose feldspar, and the red color of the matrix, all indicating a lack of vegetation and abundant moisture which could decompose the soil and reduce the iron which imparts the red color. It is therefore not unlikely that the Vishnu plain was a vast desert at the incoming of the sea. The absolute lack of transportation, sorting, and rounding of pebbles indicates that the incoming sea had little chance to rework the soil mantle by its waves. It seems impossible to account for this phenomenon except by a sudden invasion of the sea across the Vishnu desert. If we interpret the past in the light of the present our only guide is to seek to picture some present condition on the earth which parallels that preserved in the geological record. A possible clue may lie in the conditions about the Caspian Sea to-day. There is in that region a desert about the shores of the Caspian which lies below the present level of the Black Sea; a sudden rise in the level of the ocean might cause the latter to overflow the low barrier which separates it from the Caspian, and in this way a sudden inundation of the desert would be accomplished. It is now thought that wind erosion may carry the surface of an old desert to a level below that of the sea if the cycle is continued to extreme maturity. Such forces might have been active in the last stages of the Vishnu peneplain.

The deposition of the alternating limestones and shales of the second member of the Unkar seems to have taken place in a permanent water body into which mud was frequently washed. It may be noticed from the section of this member that the alternations are almost innumerable. The exact cause of this is speculative. Possibly the alternations are due to climatic oscillation: a movement from an arid to a semi-arid climate would load the rivers with sediment, while arid intervals would retard their flow, if not dry them up entirely, resulting in a temporary clarifying of the sea and a deposition of limestone. Whether the limestones are the result of organic agencies or of purely chemical precipitation is also a matter of speculation, since in regard to decisive evidences of life the

geological record is silent. It is believed that the water body was for the most part shallow, since sun-cracks appear in the shales in the upper part of the member below the highest limestone strata. What the polygonal cracks and the small cubic depressions in the banded cherty layers of the basal limestones mean the writer does not know. The cracks are suggestive of sun-cracks and the depressions strongly resemble salt hoppers.

The most striking feature of the third member is the great abundance of sun-cracks throughout the shaly strata and of ripple-marks and of cross-bedding in the sandstones. The researches of Professor Barrell have made it clear that extensive sun-cracking is a feature which has a maximum chance of preservation on broad flood plains or deltas in an arid climate. (Barrell, *a*, pp. 524-568.) In the opinion of the writer of the present paper, the extreme abundance of these cracks in this member of the Unkar is hard to account for except by postulating wide delta flats or flood plains. Furthermore, the bright red color of the shaly strata in connection with the mud cracks seems to bespeak an arid climate with little or no vegetation to reduce the iron. It is at least certain that all this part of the Unkar 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 member is the series of alternating shales and sandstones already described in detail: as may be seen from the sections, the alternations are frequently as regular as clockwork. The sandstone layers are composed of fine, cleanly sorted and rounded quartz grains, ripple-marked and cross-bedded, while the shales are a fine red mud. It is thought that the clean character of the sandstone layers of this alternating series is a mark of climatic oscillation: a climatic movement towards a wetter climate, if increasing the ratio of run-off to erosion, causes the rivers to flow on a lower grade and sweep seaward the piedmont deposits of sand and gravel; as the clay was largely sorted from those deposits when they were first laid down, their redistribution accompanied by a secondary sorting on a delta surface or seabottom would be marked by extreme cleanness.

Great thickness, clear sorting, and extreme fineness and roundness of grain are the characters which distinguish the fourth member, which is composed entirely of sandstones and quartzites. All strata are characterized by cross-bedding and ripple-marks, bespeaking shallow water. The origin of these great thicknesses of sandstone is a puzzle. The clean sorting seems to indicate long transportation: it is not impossible that the rivers carrying this material might have flowed through a great desert of dune sands, picking up and carrying material

such as is deposited in the Indus delta to-day from a similar source. Occasional lenses of fine conglomerate within some of the strata suggest scoured and filled stream channels.

The upper member of the Unkar again bears all the marks of shallow water origin: mud-cracks, ripple-marks, and cross-bedding characterize the entire thickness. The addition of micaceous material and of some feldspar gives a slightly arkose character to the rock; possibly a crustal movement rejuvenating the land mass supplying the sediments was responsible for the change in character. Here again are marks of aridity, seen in the vermilion color and the vast development of mud-cracks.

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 Tonto Sandstone.

In summary it may be said that the evidence obtainable from the lithologic record of the Unkar sediments in the Shinumo Area points probably to an arid climate, and almost surely to deposition in shallow waters; first in a permanent body of water and later in deltas or on flood plains. Which of the latter conditions prevailed the writer is not competent to say.

The predominance of clastic sediments instead of limestones in the basal portion of Walcott's section, 30 miles east, suggests that that area was nearer to the shore line of the early shallow sea. The close correspondence of the stratigraphic succession and lithology in all higher members in the two areas suggests uniform conditions over at least that distance.

The next event which can be read from the geologic record is the invasion of the Unkar strata by a thick sill of diabase in the lower members, and by four thin sills of basaltic rock in the upper part of the section.

Following this came an orographic movement of block faulting and tilting, accompanied or succeeded by elevation, breaking the strata of the Grand Canyon series into great crustal blocks, and throwing them into high ranges of mountains which in character and aspect were probably not unlike the faulted ranges of the Great Basin or the desert ranges of Arizona.

Then began a second vast interval of erosion, gnawing slowly but surely into these faulted mountains, reducing them in slow process of time through stages of youth, maturity, and old age, and finally planing away all except the very hardest strata of their cores to form the broad monotonous expanse of a base-leveled surface. The monotony of this surface was broken only by an occasional monadnock of hard Unkar quartz-

ite, resisting the forces of erosion in that ancient plain by virtue of the terrific hardness which causes the same strata to-day to 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 which have weathered repeated cycles of erosion. It is probable that this cycle of erosion was not finally completed until well along in lower Cambrian time.

The next event is the incoming of the Tonto sea. Although this chapter belongs to the Paleozoic history recorded in the horizontal strata of the walls of the Grand Canyon, that part which is involved with the distribution of the Unkar strata upon the pre-Tonto surface may properly be anticipated here.

It is not unlikely that this invading sea transgressed a surface which 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 Paleozoic strata, and above which stand occasional monadnocks of quartzite. The story of the invading sea is written in the Tonto Sandstone, locked up in which is a record of marine transgression which on account of the vertical sections and absence of soil is clear beyond belief. When the Tonto sea came in over the surface of the ancient peneplain the monadnocks stood out as islands which were gradually overwhelmed and buried in the sands of the deepening sea. The long ridge of the quartzites of the middle Unkar in the Shinumo area has already been described. It stood out as a long narrow rocky island whose longer axis extended for an unknown distance northwestward along the strike of the strata. The long southwest face of this island was undercut by the marine planation to form a steep cliff. Every detail of the face of this old sea cliff is preserved in the Tonto sandstone in the cross-sections cut by the present canyons across its face: at its base, huge angular blocks of Unkar quartzite as large as houses are preserved in the Tonto sandstone in the exact position where they fell and lodged; farther out from the base are masses of large boulders, worn and rounded by the pounding of the waves; these become smaller and smaller and finally run out 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.

By far the most impressive feature of this wonderful country is to traveller and geologist alike the mile-deep pathway of the Colorado River of the West across the great plateaus. The stupendous and glaring record of erosion revealed to us

in the cutting of this mighty gorge has almost blinded us to the realization of the immensity of the vastly greater record revealed in its walls. But the story told by the two intersecting unconformities in the bottom of the gorge,—two ancient cycles of sedimentation, uplift, and erosion carried to a finish, separated by hopelessly lost intervals of time, resulting twice in the planing down of lofty mountain ranges to the very core, written vaguely at first on a blurred and time-worn record, and later in an increasingly clearer and bolder hand,—the slow accumulation of the strata of the Canyon wall on the floor of the Paleozoic sea, the subsequently erased record of the accumulation of vast thicknesses of Mesozoic and Eocene strata, separated in turn by great intervals of erosion, and even the “great denudation” which has stripped these later strata back fifty miles to the terraces of Utah—represents a lapse of time compared with which the cutting of the Grand Canyon is but the passing of an afternoon; for in the light of present knowledge it is safe to say that the Grand Canyon was entirely cut since the time when, according to the fossil record, the remains of man first appear on earth.

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Auburn, N. Y., January, 1910.

Map showing the Shinumo area (within double ruled lines) and distribution of Grand Canyon and Vishnu Series. From the Kaibab and Echo Cliffs topographic sheets, U. S. G. S. Contour interval, 250 ft. Scale about $5\frac{1}{2}$ miles per inch.

Faults, — — —. GRAND CANYON SERIES: Chuar Group, cross hatched. Unkar Group, solid black; I, Type area described by Walcott; II, Ottoman area; III, Bright Angel area; IV, Hindu area; V, Shinumo area; VI, Tapeats area. VISHNU SERIES, x x x x.

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