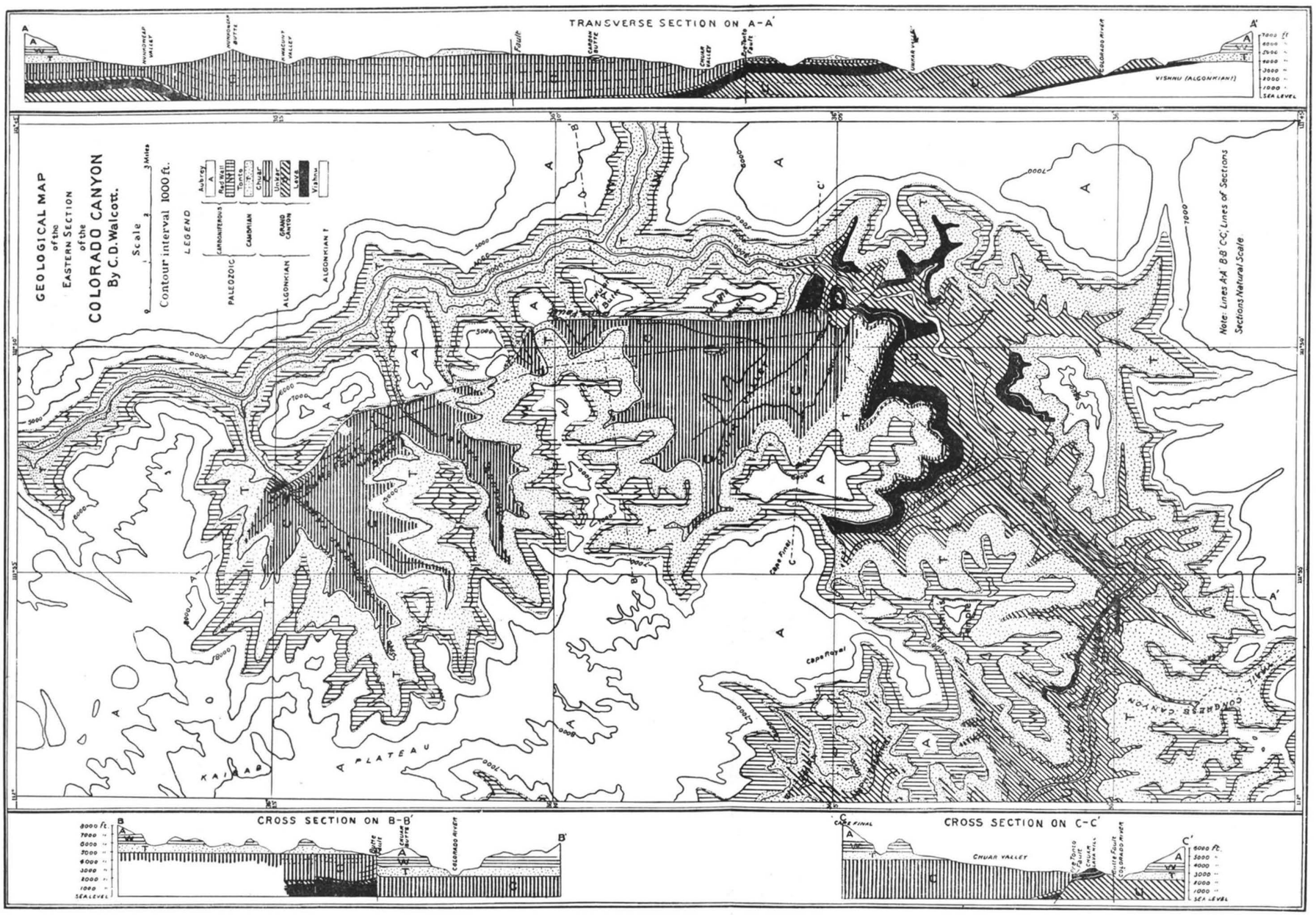
ALGONKIAN ROCKS OF THE GRAND CANYON OF THE COLORADO.

CONTENTS.

INTRODUCTION.

THE Algonkian rocks of the Grand Canyon are unique among the known unconformable pre-Cambrian rocks both of America and of Europe. Nowhere else has the geologist an equal opportunity to study such a series of ancient sediments nearly as they were laid down on the bed of the Algonkian sea. At no other known locality are there such extended and complete exposures of all the beds forming a great series of pre-Cambrian strata, permitting of such certainty in the determination of stratigraphic position and succession.

The first recorded notice of these rocks is that by Major J. W. Powell in the account of his famous explorations of the Colorado River of the West and its tributaries. He says in his report of 1875, page 212, that above the granites there are beds of hard, vitreous sandstone, of many colors, that add but little more than 500 feet to the height of the walls, and yet, owing to their nonconformity with the overlying Carboniferous rocks, they are 10,000 feet in thickness. On page 213 we learn that the rocks unconformably beneath the sandstone series are composed of metamorphosed sandstones and shales which have


TRANSVERSE SECTION ON A-A'
GEOLOGICAL MAP
of the
EASTERN SECTION
of the
COLORADO CANYON
By C.D. Walcott.
Scale
3 Miles
Contour interval 1000 ft.
LEGEND
PALEOZOIC
ALGONKIAN
ALGONKIAN ?
Aubrey
Red Wall
Tonto
Chear
Unkar
Grand Canyon
Lava
Vishnu
Note: Lines A-A' B-B' C-C', Lines of Sections
Sections Natural Scale
CROSS SECTION ON B-B'
CROSS SECTION ON C-C'
KAIBAB PLATEAU
COLORADO CANYON
Cape Final
Cape Royal
Chuar Valley
Vishnu (Algonkian?)
Colorado River
SEA LEVEL

been folded so many times, and so squeezed and heated, that their original structure as sandstones and shales is greatly obscured or entirely destroyed. Further, after these beds were deposited, after they were folded, and after they were deeply eroded, they were fractured, and through the fissures came floods of molten granite, which now stands in dikes, or lies in beds, and the metamorphosed sandstones and shales and the beds of granite present evidence of erosion subsequent to the periods just mentioned yet antecedent to the deposition of the nonconformable sandstones.

In a report on the geology of the eastern portion of the Uinta Mountains, etc., 1876, page 70, Major Powell's summary of the Grand Canyon Group is as follows:

> The Grand Canyon Group rests conformably upon the crystalline schists. The evidence of this is complete, for the lower sandstones and conglomerates first filled the valleys and then buried the hills of schistic rocks, and these conglomerates at the base of the group are composed of materials derived from the metamorphic hills about; and hence metamorphism was antecedent to the deposition of the conglomerates.
>
> The plane of demarkation separating this group from the Tonto Group is very great. At least 10,000 feet of beds were flexed and eroded in such a manner as to leave but fragments in the synclinals. Then followed a period of erosion during which beds of extravasated material were poured over the fragments, and these igneous beds also were eroded into valleys prior to the deposition of the Tonto Group.
>
> Fossils have been found at the base of the Grand Canyon series, but they are not well preserved and little can be made of them. Still, on geological evidence, I am of the opinion that these beds should be considered Silurian.

The subjacent Grand Canyon schists are referred to the Eozoic. This is followed by a statement that the grouping should be considered merely tentative; that it may need some modification, or possibly radical changes.

When describing the unconformity between a horizontal series of rocks forming the upper 4000 feet of the canyon walls and the subjacent unconformable series, Captain C. E. Dutton stated, in his Tertiary History of the Grand Canyon District, 1882, page 179, that the thickness of the lower series must be very great—at least 6000 feet, that Major Powell's estimate of 10,000 feet is

apparently justified, and that the age of the series is probably Silurian; also that Devonian beds may be found in its upper part, but all that he could say then was that they are pre-Carboniferous. He called attention to some layers among the higher beds of the series which he did not hesitate to pronounce volcanic rocks—basalts or diabases. They are coal black and interbedded with the Upper Silurian (?) strata, but whether they are intrusive sheets or contemporaneous coulées outpoured while the rocks were accumulating, he could not say.

During the winter of 1882–83 I studied in detail the Grand Canyon series of Powell, and found that it was, as stated by the latter, unconformably beneath the Tonto sandstone. The lava beds, however, were found to be interbedded and contemporaneous with the deposition of the Grand Canyon terrane and 6000 feet below the summit of the series. In a preliminary note published in 1883, the Grand Canyon series of Powell is divided into a lower or Grand Canyon group and an upper, the Chuar group.[1]

As traces of fossils were found in the Chuar terrane, it and the Grand Canyon terrane were referred to the Lower Cambrian. The subjacent unconformable strata were referred to the Archean, and by reason of stratigraphic position they were tentatively correlated with the Keweenawan group of Wisconsin.[2]

In 1886 the Grand Canyon and Chuar terranes were referred to a pre-Cambrian series of rocks;[3] and in 1890, in describing the Butte fault, a diagrammatic section[4] and several detailed sections that included portions of the Chuar and Unkar terranes were published.[5]

In his correlation paper on the Archean and Algonkian rocks,[6]

[1] Pre-Carboniferous strata of the Grand Canyon of Colorado: Am. Jour. Sci., Vol. XXVI, 1883, p. 440.

[2] *Loc. cit.*, p. 441.

[3] Am. Jour. Sci., Vol. XXXII, 1886, p. 144; Bull. U. S. Geol. Survey No. 30, 1886, p. 41.

[4] Tenth Ann. Rept. U. S. Geol. Survey, 1890, p. 551.

[5] Bull. Geol. Soc. Am., Vol. I, 1890, pp. 51–56.

[6] Bull. U. S. Geol. Survey No. 86, p. 507.

Professor C. R. Van Hise gives a summary of the Algonkian rocks of the Grand Canyon of the Colorado, based upon the observations of Powell, Dutton, and Walcott.

GEOGRAPHIC POSITION AND DISTRIBUTION.

That portion of the Grand Canyon of the Colorado in which the Unkar and Chuar terranes and the typical section of the Vishnu terrane of the Algonkian (?) series or rocks are exposed, is situated in northern Arizona, between 36° and 36° 17′ N. latitude and 111° 47′ and 112° 05′ W. longitude. Most of this area is in the valley portion of the canyon, between the mouth of Marble Canyon and a point south of Vishnu's Temple, a little west of where the Colorado River changes its course from south to northwest. It is wholly within the greater depths of the Grand Canyon, east and southeast and south of the Kaibab plateau. The inter-canyon valleys of this portion of the Grand Canyon extend back from three to seven miles west of the river, and are eroded in the crest of the monoclinal fold that forms the eastern margin of the Kaibab plateau. All of the valleys have small lateral canyons that lead into them from the high margin of the plateau. The Chuar terrane is confined almost entirely to the inter-canyon valleys of Nunkoweap, Kwagunt, and Chuar, as shown on the map (Pl. VI.). About four miles below the mouth of the Little Colorado the Unkar strata rise above the river, and rapidly expand so as to form the inner-canyon beneath the Tonto sandstone for a distance of eleven miles down the westward bend of the river, south of Vishnu's Temple. A small outcrop also occurs on the line of the Butte fault, at the lower end of Nunkoweap Valley. In going down the river the Vishnu rocks are first seen south of Vishnu's Temple (36° N. lat., 111° 55′ 30″ W. long.), and they appear to extend down the river to the southwestern side of the Kaibab plateau, nearly to Surprise Valley (lat. 112° 33′). Whether the pre-Tonto rocks near the mouth of the Grand Canyon are a portion of the Vishnu terrane is unknown.

NOMENCLATURE.

The name "Grand Canyon Group" was given by Major J. W. Powell to the series of strata beneath the Tonto sandstone and above the "Grand Canyon Schists." The latter were referred tentatively to the Eozoic,[1] and the 10,000 feet of the "Grand Canyon Group" to the Silurian. Captain Dutton regarded the series as of pre-Carboniferous age, and probably Silurian.[2]

In 1883 I referred the Grand Canyon series of Powell to the Lower Cambrian, and divided it into a lower and an upper group —the "Grand Canyon" and "Chuar," respectively,[3] the name "Chuar" being proposed by Major Powell.[4] In 1886 the reference to the Lower Cambrian was changed to a pre-Cambrian series of rocks,[5] and correlations were made with the Keweenawan series of the Lake Superior region.[6] In a section of the strata of the Grand Canyon District published in 1890, the pre-Tonto strata were referred to the Algonkian group, under the names Chuar, Grand Canyon, and Vishnu, the latter including the strata unconformably beneath the Grand Canyon group.[7]

At the present time it appears to be necessary to return to Major Powell's name, Grand Canyon,[8] as applied to the entire series of strata between the Tonto and the "Grand Canyon Schists," and to give to the lower series the name Unkar, from the valley in which its finest exposures occur. The name Vishnu is retained for the unconformably pre-Unkar strata. The classification, from the Tonto down, will then be:

[1] Geology of the Eastern Portion of the Uinta Mountains, 1876, p. 70.

[2] Tertiary History of the Grand Canyon District, 1882, p. 180.

[3] Am. Jour. Sci., Vol. XXVI., 1883, p. 439.

[4] *Loc. cit.*, p. 440.

[5] Bull. U. S. Geol. Survey No. 30, 1886, p. 41.

[6] Am. Jour. Sci., Vol. XXXII., 1886. pp. 144, 153–157.

[7] Bull. Geol. Soc. Am., Vol. I., 1890, p. 50.

[8] Changing the spelling of "Cañon" to Canyon, in conformity with the decision of the Board on Geographic Names.

CAMBRIAN.	Tonto.	
	Unconformity.	
ALGONKIAN.	Grand Canyon.	Chuar.
		Unkar.
	Great Unconformity.	
ALGONKIAN (?)	Vishnu.	

STRATIGRAPHIC RELATIONS.

The stratigraphic relations of the Cambrian, Algonkian, and the doubtful Vishnu beds are indicated by the preceding tabulation, and are clearly shown by section A—A′ of the map. Within the Algonkian series there is no recognized interruption in sedimentation between the base of the Unkar terrane south of Vishnu's Temple and the summit of the Chuar terrane at Nunkoweap Butte, with the exception of a slight unconformity by erosion at the summit of the Unkar terrane. At the base of the Unkar terrane there is a bed of conglomerate that rests unconformably on the eroded edges of the indurated sandstones, micaceous schists, and granitic dikes. The unconformity is absolute. (Fig. 1).

From the base of the Unkar terrane south of Vishnu's Temple the strata dip 10° to the northeast, and then, as shown on the map (Pl. VI. and the accompanying section), they flatten out on the line of the divide between Unkar and Chuar Valleys, dip 25° to the north in the heart of Chuar Valley, and thence extend in low, broad undulations to the syncline of Nunkoweap Butte. North of the Butte the strata rise, the dip being from 20° to 25° southeast. The summit of the series is at Nunkoweap Butte, between Kwagunt and Nunkoweap Valleys. From the point south of Vishnu's Temple to where the strata of the Chuar terrane pass beneath the basal beds of the Tonto sandstone, on the north side of Nunkoweap Valley, there is a marked unconformity between the strata of the Grand Canyon series and the superjacent

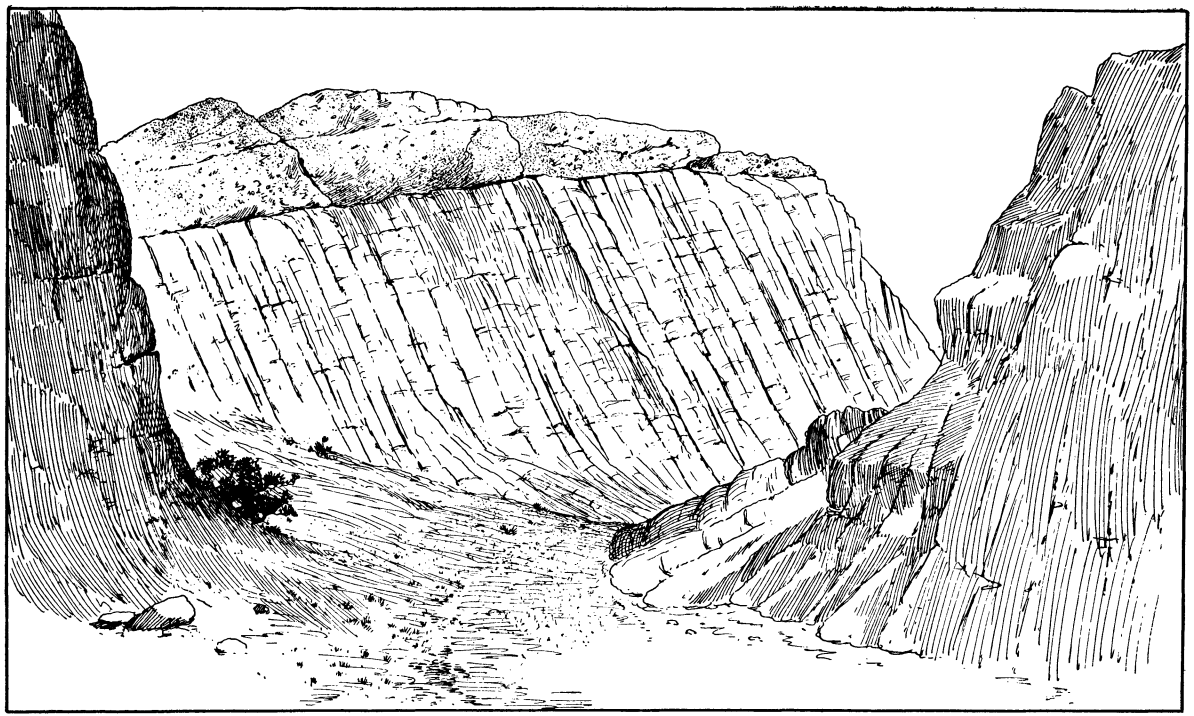


FIG 1. Unconformity at the Base of the Unkar Terrane. Conglomerates resting on the upturned, eroded Beds of the Vishnu Terrane.

Cambrian sandstone. The former were planed off to a baselevel before the deposition of the latter.

CHUAR TERRANE.

The first division of the Chuar terrane is from the summit of Nunkoweap Butte, on the divide between Nunkoweap and Kwagunt Valleys, down the south side of the butte to the base of a massive belt of reddish-brown sandstone. The latter stratum was traced to Chuar Valley, where it caps the lower division of the terrane on the north side of the valley. The lower division terminates in argillaceous shales resting on a massive magnesian limestone south of Chuar Brook.

Section from the Summit downward.

UPPER DIVISION.

	Feet.	Feet.
1. *a.* Massive reddish-brown sandstone, with irregular layers of similar color and containing numerous fragments of sandstone-shale of lighter color	125	
b. The sandstones of 1 become shaly near their base and pass into a reddish, sandy, and then argillaceous shale, with a few thin, compact layers of sandstone in the shale	75	200
2. Black, fissile, argillaceous shale, that crumbles on exposure to the weather		225
3. Compact gray limestone in massive layers; buff on weathered surface		50
4. Shale similar to 2		60
5. Gray limestone similar to 3		50
6. Black argillaceous shale, similar to 2 and 4		140
7. Hard buff limestone, with irregular oölitic, cherty bands that at times constitute most of the stratum		4
8. *a.* Black argillaceous shale, with compact layers 2 or 3 inches thick	30	
b. Dark, earthy limestone	1	
c. Black shale	2	
	—	33
9. Gray, Stromatopora[1] (?) limestone		8
10. Black argillaceous shale, with variegated shales below, containing more or less arenaceous matter in the form of arenaceo-argillaceous shale and thin layers of sandstone.		

[1] Probably a species of Cryptozoon.

		Feet.	Feet.
	On the slopes light-drab, pea-green, vermilion, chocolate, maroon, and buff-colored shales of various shades alternate		740
11.	Massive stratum of concretionary limestone		10–25
12.	Reddish-brown, sandy shale		25
13.	*a.* Thick-bedded, dark reddish-brown sandstone	70	
	b. Same, thinly bedded	70	
		—	140
	Total thickness of upper division		1700

The last two beds form so strongly marked a horizon in the shaly beds that it is taken as a rough division line in the terrane, the strata beneath containing a different character of limestone that serves to distinguish them.

LOWER DIVISION.

		Feet.	Feet
1.	Brown sandy shales, passing below into chocolate and dark argillaceous shales that alternate with brown and greenish, sandy shales. Near the summit a layer of oölitic iron ore occurs		300
2.	*a.* Alternating sandy and argillaceous shales, with thin belts of limestone from 6 inches to 4 feet in thickness	310	
	b. Stromatopora limestone	4	
	c. Dark shaly limestone	3	
	d. Dark argillaceous shale	6	
	e. Dark-gray shaly limestone in massive layers	2	
		—	325
3.	Chocolate-brown, dull and yellowish-green, sandy and argillaceous shales, with sandstone in narrow bands, and 21 feet of limestone in thin layers near the middle and base of the stratum		625
4.	*a.* The sandstone and sandy shales become less prominent, the argillaceous and calcareous strata replacing them, 54 feet of limestone occurring in 500 feet of strata	500	
	b. Dark clay-shale	4⅓	
	c. Dark shaly limestone	1	
	d. Dark argillaceous shale	4	
	e. Gray limestone, having a tendency to break up into shaly layers; strongly bituminous near the base	5⅔	
	f. Friable, rather coarse, gray to buff sandstone	5	
	g. Compact lead-colored limestone	2	
		——	522

	Feet.	Feet.
5. Black argillaceous shale, with chocolate and greenish, sandy and argillaceous shales beneath, carrying hard layers of sandstone. In a few localities white and pink gypsum occurs in masses a few feet in diameter, or as seams in the upper, black shales		100
6. Three feet of compact, mottled, buff limestone interbedded in 15 feet of brown sandy shale		18
7. *a.* Black and chocolate, sandy and argillaceous shales, with three thin layers of limestone near the base	180	
b. Black and brown argillaceous shale, with interbedded layers of a somewhat friable sandstone	180	
c. Chocolate, green, maroon, drab, argillaceous shales, with thin layers of brownish sandstone interbedded, and, toward the base, sandy shales	360	
d. Brown sandstone, in layers 8 to 18 inches thick, passing below to sandy and argillaceous shales, with layers of buff and chocolate sandstone	55	
e. Drab argillaceous shale, passing down into brown, sandy, ripple-marked shales	55	
		830
8. *a.* Massive band of irregular, thinly bedded limestone, gray and buff except near the chocolate-colored upper stratum. A variety of limestone occurs.		
b. Chocolate-colored, compact layers, with a smooth, partially conchoidal fracture.		
c. Evenly bedded, thin layers, hard, lead-colored.		
d. Thin, shaly, gray layers.		
e. Very irregular and concretionary layers.		
f. Compact, gray, bituminous layers.		
Total		50
9. Dark argillaceous shale, with a strongly marked band of a deep-maroon color; drab, yellowish-green, and dark or brownish-black shales continue below to a dark-chocolate band that is superjacent to 100 feet of drab and greenish shales. The shales are largely argillaceous, with arenaceous matter scattered through the section as sandy shales, thin-bedded sandstone, and arenaceo-argillaceous shales. In one locality a band of fine-grained gray limestone, 6 inches thick, occurs in the shales 3 inches above the base of the Chuar terrane		450 to 650
Total thickness of lower division		3,420

	Feet.
Total thickness:	
Upper division	1,700
Lower division	3,420
	5,120
Limestone in upper division	138
Limestone in lower division	147
	285

UNKAR TERRANE.

The line of outcrop of the massive magnesian limestone below the base of the Chuar terrane extends south, in the face of the cliffs, to the north side of Unkar Valley. The section was taken from this point south across Unkar Valley and along the walls of the inner canyon of the Grand Canyon to a point south of Vishnu's Temple, where the sandstones and conglomerates rest unconformably upon the sandstones, schists, etc., of the Vishnu terrane and the gneisses, schists, etc., of the Archean. The section is characterized by a great thickness of reddish-brown sandstones.

Section from the Summit downward.

	Feet	Feet
1. *a.* Massive beds of gray to reddish magnesian limestone, passing below into a calciferous sandrock	50–150	
b. Light-gray shaly sandstone	25	
c. Irregular massive beds of yellowish-brown sandstone,	50	
d. Partially cross-bedded, fine-grained, purplish-brown sandstone	50	
e. Reddish-brown sandstone and sandy shales, ripple-marked	200	
		475
2. Lava beds:		
a. Dark-green basaltic rock with a reddish tinge. Breaks into small angular fragments. Upper surface slightly irregular	100	
b. Layers of a reddish-brown sandstone	8–10	
c. Solid, compact lava, of a dark-green and reddish tinge, with a slight tendency to columnar structure	70	
d. A layer of sandstone, 1 foot in thickness, caps a massive flow of dark-green lava, which breaks up and weathers into a fine talus of a lighter green than the rock in place	100	
e. A flow not unlike *d*, and capped by a layer of sandstone 2 feet in thickness	70	

	Feet.	Feef.
A layer of vesicular lava with a thin stratum of sandstone at the summit - - - - - - -	10	
g. Solid, compact lava, of a dark-green and reddish tinge, with columnar structure partially developed in the central portion. This band appears to be formed of three flows in quick succession, as no sedimentary material accumulated on the surface of the two lower; 25, 125 and 25 feet; total - - - - - - - -	175	
h. Reddish-brown sandstone, compact and slightly metamorphosed toward the summit - - - - -	15	
i. On the weathered surface this flow presents a slope of 25° to 30°, rarely forms a cliff, as do the flows above, and the rocks crumble into a rather light olive-green, coarse sand. Thin beds of reddish-brown sandstone occur in several places, and one, 125 feet from the base, is quite persistent in its horizontal extension. The upper surface of the flow is slightly undulating and more or less nodular - -	250	
	——	800
3. Sandstones (upper):		
a. Shaly, vermilion, rather fine-grained sandstones, with intercalated bands of a greenish-gray, followed below by 700 feet of vermilion beds of a uniform character, and massive beds with arenaceous, shaly partings, the massive beds breaking up into shale and sandstone on the talus slopes. Ripple-marks and shrinkage-cracks characterize the upper, shaly beds - - - - - -	1,730	
b. The vermilion sandstones of *a* pass into chocolate-colored sandstones, that for 125 feet down unite in the general slope of the beds above. Below, a cliff is formed of five massive bands of chocolate-colored, slightly micaceous sandstone, separated by shaly sandstone partings of a greenish color below and a chocolate color above -	925	
c. Reddish-brown to chocolate, more or less shaly sandstone, 125 feet, underlain by 300 feet of friable sandstone and arenaceous and micaceous shale - - -	425	
d. Irregularly bedded, compact sandstone:		
Curiously twisted and gnarled layers - - - 15		
Massive, grayish layer - - - - 10		
Light-gray layer with reddish spots, friable, shaly in places - - - - - - 125		
	—— 150	
	——	3,230

	Feet.	Feet.
4. Sandstones (lower):		
a. Compact, quartzitic, gray sandrock, 25 feet, with 65 feet of hard, compact sandstone	90	
b. Massive, compact, cliff-forming, brown, buff, and purplish-brown sandstone	1,200	
c. 1. Reddish-brown to vermilion, friable, shaly sandstone — 200		
2. Brick-red shaly sandstone — 250		
3. Brown, friable, shaly sandstone, ripple-marks and shrinkage-cracks — 300		
4. Same in more massive layers, with fine, siliceous conglomerate (10 feet) at the base — 80		
—	830	
—	—	2,120
5. *a.* Light-gray limestone, with interbedded laminæ of quartzitic shale	8	
b. Brown sandstone, with a bed of siliceous conglomerate, 2 feet	30	
c. Reddish, cherty limestone	10	
d. Reddish-brown limestone	2	
e. Dark reddish-brown slate,	5	
f. Light-gray, compact, shaly limestone	14	
—	—	69
6. Dark, compact, basaltic lava in one massive flow		80
7. Light-gray, compact, shaly limestone with pinkish tinge between the laminæ; it is a little cherty near the base, or with thin, hard, interbedded layers of sandstone		26
8. Siliceous conglomerate, formed largely of pebbles derived from the upturned edges of the pre-Unkar strata, upon which it rests unconformably		30
Total thickness of the Unkar terrane		6,830
Total thickness of the Chuar terrane		5,120
Total thickness of Grand Canyon series		11,950

VISHNU TERRANE.

The strata of the Vishnu terrane on the north side of the Grand Canyon, due south of Vishnu's Temple, consist of micaceous schists and quartzite, with dikes and veins of reddish colored granite cutting across the plicated bedding of the schists, etc. I examined this series at one point only, and do not feel warranted in discussing its general characters. On the south

side of the canyon the strata occupying the same relative position beneath the base of the Unkar terrane have been considered to be of Archean age.

SEDIMENTS AND CONDITIONS OF DEPOSITION.

Over the eroded, upturned beds of the Vishnu terrane a bed of siliceous conglomerate, composed largely of pebbles derived from the beds below, indicates the old sea-beach formed during the period preceding the deepening of the water. In this sea sand and a few beds of calcareous mud accumulated prior to the spreading of a flow of basaltic lava which now forms a massive bed 80 feet in thickness. In the period of quiet following the lava-flow, a few alternating beds of calcareous and arenaceous mud and sand were deposited prior to the deposition of 5350 feet of sandy beds, which now form rather fine-grained, vermilion, chocolate, brown, buff, and parti-colored sandstones. With the close of this epoch of arenaceous deposition the sea-bed and the strata beneath were fissured by crevices which extended down into the Archean, and flow after flow of basaltic lava poured out through these over the sea-bed. In the intervals between the flows the deposition of the sand continued, and we now find, between the massive lava-flows evenly distributed beds of reddish-brown sandstone. With the last of the six principal flows the sea deepened, and a thick deposit of calcareous mud was accumulated, which now forms a magnesian limestone, passing below into a calciferous sandrock, the whole varying from 50 to 150 feet in thickness. This was the closing deposit of the Unkar terrane. Its upper surface shows slight traces of erosion, and, as the sediments of the succeeding Chuar terrane are unlike those of the Unkar, it is probable that the source from which the sediments were derived changed from one that had contributed a vast amount of sand to one that yielded great quantities of argillaceous matter and sand of a still finer character. It is not to be understood that this implies a change of source of sediment, but rather a change of conditions, produced by progressive erosion that lowered a somewhat elevated area

toward a baselevel before the close of the known upper limit of the Chuar terrane.

The lithologic characters of the Unkar terrane are rather uniform in the upper portion, the strata consisting of reddish-brown and greenish sandy shales, and of layers of a medium-grained sandstone, varying from 2 inches to 3 feet in thickness. In the more thickly bedded portion there is a tendency to form cliffs that resemble the Triassic sandstones of the Vermilion Cliffs of southern Utah, and the shaly portions are much like those of the Trias. As a whole the prevailing color is a reddish-brown, much like that of the Carboniferous Lower Aubrey sandstone cliffs in the canyon wall, 2000 feet above. Traces of life are as yet unknown; ripple-marks, fine and coarse mud-cracks, and all the markings of quiet, shallow water and a low shore-line that was frequently exposed to the action of both water and air, are abundant.

The sandstones of the Unkar group are exposed directly in the Grand Canyon, below the mouth of Chuar Valley; and the rocks of the Chuar terrane occur in nearly all of the canyon valleys between the eastern side of the Kiabab plateau and the six great buttes that form the west side of the lower portion of Marble Canyon.

As indicated by the section, the Chuar terrane was formed and calcareous muds, uniformly spread over a relatively level sea-by the deposition of a great series of argillaceous, arenaceous, bed. The strata now succeed one another as fine sandstones, shales and limestones, the lithologic characters resembling those of the Cretaceous, as seen in the cliffs a few miles to the north. In places the limestones and shales may be compared with the Trenton limestone and the Utica shale of the Lower Palæozoic of the East. The parti-colored shales, in one belt 700 feet in thickness, recall the friable Permian clays. In fact, there is no more evidence of metamorphism throughout the 12,000 feet of the Grand Canyon series than there is in the evenly bedded strata of the Permian, Triassic, and Cretaceous groups of the Plateau Province of northern Utah.

Midway of the lower portion of the shales and limestones of the Chuar terrane the presence of a fauna is shown by a minute discinoid or patelloid shell, a small Lingula-like shell (which may be a species of Hyolithes), and a fragment of what appears to be the pleural lobe of a segment of a trilobite belonging to a genus allied to the genus Olenellus, Olenoides or Paradoxides. There is also a Stromatopora-like form that is probably organic.

The paucity of the fauna in both the Unkar and Chuar terranes demands some explanation, for the strata were apparently deposited under conditions most favorable to the development of abundant life. I find in my field-notes a suggestion that the sediments were deposited in a great inclosed basin, or mediterranean sea, and that during the greater part of the period of their deposition no connection existed by which any fauna then existing outside of this sea could obtain ingress.

The sediments of the Unkar and Chuar terranes, as measured, give a total thickness of 11,950 feet. How much more was planed away by the sea in which the next terrane (the Tonto) was deposited was not determined. With the close of the epoch of the Chuar terrane a period of orographic movement ensued, during which the strata of the Vishnu, Unkar, and Chuar terranes were elevated, broken by faults, and more or less flexed. The summit of the series is now found in a knoll on the divide between Nunkoweap and Kwagunt Valleys. It may have been a remnant left by the sea as the latter cut away the Algonkian land, or a hill remaining above the baselevel of erosion that planed away a section of the entire thickness of the pre-Tonto strata. The surface upon which the sandstones of the lower Tonto were deposited was nearly level. Here and there a hard stratum caused ridges to be left in the Tonto sea, and the fragments broken from them are scattered among, and mixed with, the sands of the Tonto.

Of the duration of the interval of erosion between the deposition of the sediments of the Chuar terrane and the first of those of the Tonto, we can only form a conjectural estimate, based on the sections of Cambrian rocks in northwestern and central

Nevada. The stratigraphic position of the sandstone at the base of the Tonto terrane is that of the Middle Cambrian, a horizon equivalent to that of the lower portion of the St. Croix sandstone of Wisconsin and the Secret Canyon shale of the Eureka District of Nevada. The fauna of the Chuar terrane indicates the presence of life, but it is not of value in stratigraphic correlations. It is probable, almost to a certainty, that it is older than the Olenellus fauna of Nevada. If this be true, the interval between the summit beds of the Chuar terrane and the Tonto sandstone is represented, in Nevada and Utah, by a deposition of 3000 or more feet of limestones and many thousand feet of sandstones and siliceous argillites. With the exception of a few traces at the base of the Tonto sandstone, none of detrital sediments resulting from the erosion of the pre-Tonto land area have been discovered.

GEOLOGIC AGE.

The lower portion of the Tonto terrane, the Tonto sandstone, forms the base of the Palæozoic section in the Grand Canyon District. It is massive-bedded and rather coarse in the lower portion, passing above into shaly, fine-grained, fossiliferous sandstones. The presence of a well-marked Middle Cambrian fauna in its upper portion clearly indicates its geologic age. It is only the absence at the base of the sandstone of the Lower Cambrian or Olenellus fauna that prevents us from carrying the recognized Palæozoic section down to include its oldest known fauna. The period of erosion represented by the unconformity between the Tonto sandstone and the Grand Canyon series is considered to more than equal Lower Cambrian time, and to constitute a well-defined boundary between the Palæozoic and pre-Palæozoic formations. In my earlier work, in 1883, I referred the Grand Canyon and Chuar strata to the Cambrian;[1] but upon further study of the Cambrian rocks and their contained faunas, and in view of the extent of the time-break indicated by the noncon-

[1] Am. Jour. Sci., Vol. XXVI., 1883, p. 441.

formity by erosion, this was changed in 1886, and all the pre-Tonto strata were referred to a pre-Cambrian series.[1]

In the scheme of nomenclature adopted by the Geological Survey in 1888, the clastic rocks beneath the Cambrian and superjacent to the Archean were grouped under the term Algonkian — of equivalent rank to Cambrian, Silurian, etc.[2] In this classification the system name — equivalent to Palæozoic, etc. — was not decided upon; but I am strongly in favor of adopting the name "Proterozoic," proposed by Dr. Irving and accepted by Professor C. R. Van Hise.[3] Under this nomenclature the Grand Canyon series will be referred to the Algonkian system of the Proterozoic group.

There may be a difference of opinion among geologists as to the adequacy of the evidence that the Grand Canyon series is pre-Cambrian. This can hardly be the case with those who have studied the questions of orographic movement and subsequent erosion. The long section on the map shows most clearly that the sediments of the Grand Canyon series were elevated, faulted, and more or less flexed prior to the period of erosion that cut away a section of the entire series and not only reduced to a baselevel the land area formed by the latter, but reduced to the same plane the more resistant subjacent rocks of the Vishnu terrane of the Algonkian, and probably the Archean, to the west. The time required for the orographic movement resulting in elevation and for the subsequent erosion would exceed, in my opinion, the period of Lower Cambrian sedimentation. It is not at all improbable that the sediments of Lower Cambrian time in the Great Basin region of Nevada, Utah, etc., were derived from the Algonkian continent to the east, of which the Grand Canyon series of rocks then formed a part.

CORRELATION.

The Grand Canyon series, the Llano series of Texas, and the Algonkian series of the Lake Superior region afford an opportu-

[1] Bull. U. S. Geol. Survey No. 30, 1886, p. 41.

[2] Tenth Ann. Rept. U. S. Geol. Survey (for 1888–89), 1890, p. 66.

[3] Bull. U. S. Geol. Survey No. 86, 1892, p. 493.

nity of comparing the stratigraphic succession of somewhat similar lithologic series of strata, but a definite correlation can not be made until a more reliable factor is obtained than lithologic resemblance of the various formations. It is quite probable that the Grand Canyon series and the Keweenawan series of Lake Superior represent the same time-interval; also that the strata beneath Packsaddle Mountain, in central Texas, are the equivalent of the Chuar terrane of the Grand Canyon; but until palæontologic evidence is secured it may be said that these correlations are little more than possibilities. The Grand Canyon, Llano, and Keweenawan series may be referred to the Algonkian, as that system of rocks includes the strata of sedimentary origin between the Archean complex and the base of the Cambrian; beyond that any correlation on trustworthy data is impossible. Mr. Iddings's examinations of the specimens of eruptive rocks in the Algonkian of the Grand Canyon series show the basal flows of the Unkar terrane to be a true doleritic basalt, and that the dikes and the upper flows, as exposed in Chuar Butte, etc., are basalts differing but little from the basalts of Tertiary age found in Nevada, Utah, and on the plains in the vicinity of the Grand Canyon. This fact prevents any correlation of the lavas with those of other localities, even though basaltic rocks were found to occur in formations referred to the Algonkian. It is evident that until characteristic fossils are found in the various terranes now referred to the Algonkian it will be impossible to make any correlations that will be more than tentative suggestions.

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