

# CONTRIBUTIONS TO GRAND CANYON GEOLOGY

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Grand Canyon Natural History Association

May, 1936

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National Park Service  
Grand Canyon National Park

Grand Canyon Natural  
History Association

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This bulletin is published by the Grand Canyon Natural History Association as a project in keeping with its policy to stimulate interest and to encourage scientific research and investigation in the fields of geology, botany, zoology, ethnology, archeology and related subjects in the Grand Canyon region. This number is one of a series issued at irregular intervals throughout the year.

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# Preliminary Report on the Tonto Group of the Grand Canyon, Arizona

By Russell B. Wheeler\* and Albert R. Kerr\*

## Introduction

A systematic study of the Cambrian rocks of Grand Canyon has been started by the writers. Although the results of the first field season are just beginning to take shape, it seems desirable at this time to present a statement of the nature of the work, a summary of the results to date, and a suggestion of the problems which may be worked out as a result of the program.

The sections studied by the writers to date lie within the Grand Canyon and represent the Tonto group: 1) near Pierce's Ferry, which is at the extreme western end of Grand Canyon; 2) in the small canyon directly below Yavapai Point, in the Kaibab division of the Grand Canyon; and 3) in Tanner Canyon, near the extreme eastern end of Grand Canyon (See Fig. 1). It is fully realized that the study of many more sections is necessary before a final report can be made regarding Tonto conditions. The measurement and study of these additional sections are included within the writers' future plans for the completion of the project.

## Areal Extent

THE Tonto group probably underlies the greater part of the plateau area of northern Arizona and southern Utah. Its definite limits are unknown, however, due to its low stratigraphic position which prevents it from being exposed except where intense erosion has cut deeply into the plateau, or where it is exposed due to uplift on the periphery of the plateau.

As far as can be determined at present the northern limit of exposure of the group is in the Grand Canyon, extending

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from the foot of Marble Canyon westward to the Grand Wash Cliffs (See Fig. 1). The actual western limit of exposure is in certain of the isolated ranges beyond Grand Wash Cliffs.

Southeastward from the lower end of the Grand Canyon the group is exposed along the face of the plateau - a continuation of the Grand Wash Cliffs - along Chino Wash, in Cross and Juniper Mountains, and along Black Mesa. The most southern as well as the most eastern exposures known occur in the Tonto Basin, where only the Tapeats (basal) sandstone formation of the group is exposed\* - the overlying Bright Angel and Muav formations having disappeared in the lower part of Chino Valley.

### General Description of Formations

**W**ITHIN the Grand Canyon the Tonto group consists of from 900 to 1000 feet of conformable Cambrian strata. It forms the lowermost group of the horizontal formations and, as seen in the Kaibab division of the Canyon, extends from immediately above the Inner Gorge upward to the base of the precipitous Redwall cliff.

Roughly, the Tonto group has a three-fold lithologic division, (See Fig. 2) grading upward from coarse-grained resistant sandstones at the base (Tapeats sandstone), through fine-grained, thin-bedded, lenticular sandstones and shales in the middle portions (Bright Angel formation), to fine-grained sandstones, limestones, and dolomites at the top (Muav formation). It is due to these differences in lithology that the group gets its characteristic and easily recognized profile features of two cliffs separated by a long sweeping slope.

### Sedimentation

#### PRE-TAPEATS EROSION SURFACE:

**T**HROUGHOUT most of the Grand Canyon, the Cambrian Tapeats sandstone lies horizontally upon the bevelled surface of the nearly vertical, highly deformed, and intensely metamorphosed Archean Vishnu schists and associated granite intru-

\* According to Dr. C. E. Resser this sandstone formation is of Devonian age, however, Professor A. A. Stoyanow states that both Tapeats and Devonian sandstones are present in the Tonto Basin.

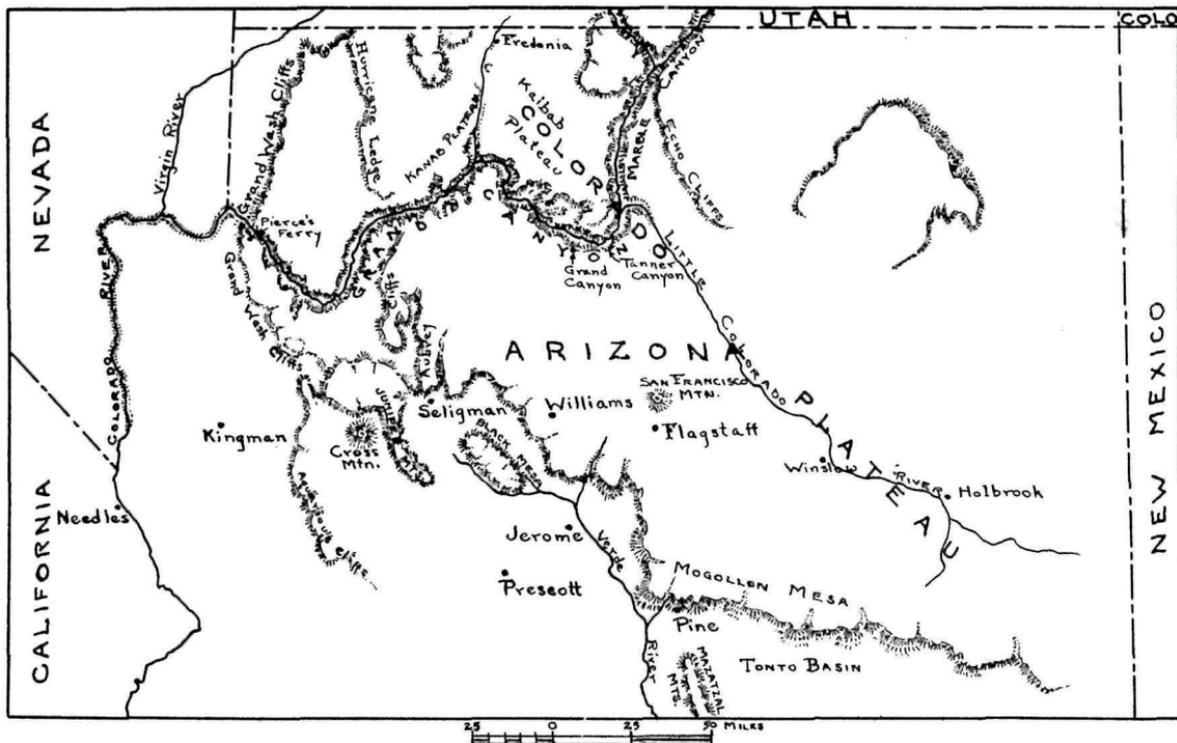


Fig. 1 - Index Map of Northern Arizona

sives. In a number of scattered localities in the eastern half of the Canyon, however, the Tapeats overlies tilted blocks of Algonkian sediments which have been down-faulted into the Archean crust and also bevelled to a flat surface. Elsewhere hills and ranges of both Archean and Algonkian rocks rise into or through the Tapeats. This profound unconformity of both dip and erosion separating the Tapeats from the Algonkian sediments and Archean metamorphics is probably one of the clearest and most spectacular examples of geologic discordance in the world.

The Ep-Archean surface has been base-leveled by erosion before deposition of the Algonkian sediments took place, and from the exposures now present within the Grand Canyon, it is known that at least 12,000 feet of these sediments were deposited upon the Ep-Archean surface. Later the region was uplifted and these sediments were profoundly tilted and faulted to form a series of high fault-block mountains which probably resembled our basin-ranges of today.

A long period of erosion which removed most of the Algonkian sediments followed the forming of mountain ranges and left only huge blocks, parts of which had been down-faulted into the Archean (See Fig. 3). Hinds<sup>1</sup> has stated that this Ep-Algonkian surface, although it possessed somewhat greater relief than the Ep-Archean surface, was nevertheless, a peneplain; and Noble<sup>2</sup> states that it "represents a surface base-leveled by erosion". McKee, however, is of the opinion that the fault-block mountains of Algonkian sediments exhibited too much relief, as the Tonto sea began its invasion of the region, to allow this surface to be termed a peneplain. This latter is also the view held by the writers.

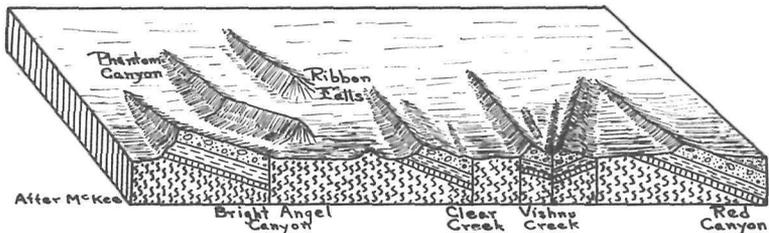


Fig. 3 - Landscape of a portion of Grand Canyon region at close of Algonkian Era.  
(West-East section along Colorado River)

Noble<sup>2</sup> reports a height of 600 feet for an Algonkian monadnock in Monadnock Amphitheater; and another one which, although not measured, must be nearly 800 feet high since it projects almost to the top of the Muav formation, is located at the base of Cheops Pyramid on the north side of the Colorado River directly north of El Tovar Hotel. Various others throughout the eastern part of Grand Canyon project through the Tapeats. Not only size but also abundance of "ranges" as seen in eastern Grand Canyon argues against the existence of a peneplained surface.

In considering the nature of the Ep-Algonkian erosion surface it should be realized that Algonkian remnants which were 600 and 800 feet in height at the time they were buried by Tonto sediments must have had a much greater relief at the beginning of Cambrian deposition, for while the Tonto sediments were being deposited erosion was still wearing away the remaining mountains of the region. In brief, the time that it took to deposit 600 and 800 feet of Tonto sediments was the length of time that erosive forces were acting upon these mountains and wearing them down from the higher elevations which they had had at the beginning of Tonto deposition. Thus it is seen that erosion of the Algonkian mountains was in part coincident with Tonto deposition and, consequently, the remnants of the mountains as now exposed represent their least possible relief, and certainly not the true relief at the beginning of Tonto time.

Figure 3 shows the Algonkian remnants exposed in the Grand Canyon from just west of Bright Angel Canyon to Red Canyon - a distance of but twelve miles. Certainly there must have been many such mountains upon the Ep-Algonkian surface in this region, for it is most illogical to assume that these mountains formed only in the limited area which was to later become the Grand Canyon - there must be many more which have not been exposed to view by erosion.

In view of the above reasoning, it is the opinion of the writers that this area at the beginning of Tonto time, although not what would be termed a mountainous region, was, nevertheless, dotted with a considerable number of prominent ridges and could not be correctly referred to as a peneplain.

## DEPOSITION OF THE TAPEATS SANDSTONE:

THE prominent cross-bedding of the Tapeats is one of its most characteristic features, and, because of the rather limited range of general conditions which give rise to cross-lamination, this structural feature has proved to be most useful in attempting to determine the conditions under which deposition of the formation took place.

No attempt will be made in this article to give a thorough discussion of the criteria of each of the general conditions or environments which give rise to cross-lamination. It is considered by the writers, however, from an analysis of field evidence in elimination of certain possible origins of cross-bedding, that the features of the Tapeats sandstone were produced by the seaward extension of the profile of equilibrium. The encroachment of a shallow epicontinental sea over the region was responsible for the deposition of the Tapeats sandstone as the beach phase of this invading sea which gradually deepened and became more quiet until the finer sediments of the Bright Angel and Muav formations were later deposited above the Tapeats.

At least locally, it seems apparent that Tapeats deposition began as valley fills composed principally of fragments derived from nearby hills of pre-Cambrian rocks. A rather thick and generally fine-textured regolith was then worked over by the encroaching Tapeats sea, and was gathered into the Tapeats formation with but little transportation and assorting. The principal constituent of these sediments was quartz in the form of sands and pebbles, although other minerals were present.

As the invading Tapeats sea continued its advance, the water became deeper and more quiet, and the materials became better assorted and finer-grained so that, just before Bright Angel time, the deposition of alternating layers of sandy shale and fine-grained sandstones in the upper Tapeats foretold the coming change of deposition.



## DEPOSITION OF THE BRIGHT ANGEL FORMATION:

**E**ROSION during Tapeats time further reduced the Algonkian fault-block mountains, and the sands of the Tapeats sea had covered many of the monadnocks by Bright Angel time. The lands supplying sediments to the Bright Angel sea were somewhat lower than they were during Tapeats time and they contributed much fine material in the form of muds and fine sands, which later consolidated to form the shales and fine-grained sandstones of the Bright Angel formation.

The abundant and well-preserved trilobite and brachiopod faunas of the Bright Angel show conclusively that this formation was deposited in a shallow sea. Although the presence of ripple-marks and of some slightly cross-bedded sandstone lenses containing broken fragments of brachiopod shells indicate current and wave action to some extent, still, the Bright Angel sediments were apparently deposited in water which was farther from shore and much more quiet than that in which the underlying Tapeats sands were laid down.

The occurrence of glauconite in some parts of the Bright Angel is quite characteristic and where present, it is closely associated with ripple-marked beds and also with broken fragments of brachiopod shells. According to Twenhofel<sup>3</sup> this mineral is not known in non-marine sediments, and "the environments best suited for its development seem to be marine bottoms on which deposition is extremely slow and on which the sediments deposited are subjected for a long time to the wash of waves and currents and the action of the sea water".

Of the intimate relationship between glauconite and organic matter - indicated by the close association of the mineral with fragments of brachiopod shells - Twenhofel<sup>4</sup> has stated: "Most sediments of inorganic character seem to owe their origin to a rather narrow range of environmental factors. Thus glauconite, for example, seems to require a rather nice relation of organic matter to other sediments deposited. Other unknown factors probably are concerned, but it seems that under conditions of small organic matter iron remains in or changes to the oxidized form, when organic matter is large the iron changes to the carbonate or sulphides, but under some intermediate condition glauconite forms".

As to the green color of the shales of the Bright Angel formation, reference is again made to Twenhofel<sup>3</sup> who states that, for the most part, "green muds derive their color from the presence of finely divided glauconite and to some extent from glauconite of the magnitude of sand grains".

From the above data concerning glauconite in the Bright Angel, it is seen that it probably has more importance in the interpretation of the history of this formation than has any other single feature. It gives further evidence that the deposit is of marine origin; it explains, in part at least, the green color of the sediments; it shows that a close relationship of the proportion of organic matter to other materials of the sediments existed; and it indicates that the land-derived sediments were small in amount and that deposition was slow.

#### DEPOSITION OF THE MUAV FORMATION:

BY the end of Bright Angel time, the relief of the present Grand Canyon area must have been quite low due both to erosion of the pre-Cambrian monadnocks and to deposition of the Tapeats and Bright Angel sediments around their remains. This is shown by the fact that, as Muav time was ushered in, the epeiric sea received less and less mud and fine sand, but more solution materials which were precipitated to form the present limestones of the Muav formation. This predominance of solution materials over clastics would also suggest that the rivers supplying the sediments were probably long.

Of the deposition of the Muav formation Schuchert<sup>5</sup> has stated: "It is an interesting shallow-water, near-shore, marine deposit. This is shown in the great abundance of annelid burrows, in the intraformational conglomerates, and in the variable nature of the calcareous deposits". This is further proved by the presence of trilobite casts found within the formation. The exact processes of development of the limestones, however, are indeterminate at this time for, as Twenhofel<sup>3</sup> has pointed out: "It is obvious that any limestone may have had various processes contribute to its development, and it is probable that two or more processes have contributed in the formation of every limestone. The determination of the contributions of the various agents or processes is not yet possible, except for that fraction derived from shell and similar matter, and in this case only the minimum is determin-

able. Before a complete restoration of the environment of deposition of most ancient limestones is possible, this determination of contributions must be approximated".

The mode of formation of the dolomites of the Muav formation is another point which must remain unexplained until more detailed work has been done on these beds.

#### POST-TONTO EROSION INTERVAL:

**T**HROUGHOUT most of the Grand Canyon the Muav formation is directly overlain by the Redwall limestone of Mississippian age. At several scattered localities, however, pockets of Devonian sediments occur between these two formations, in eroded hollows in the Muav surface. These probably represent Devonian river channels.

The surface which separates the Muav formation from the Redwall limestone, or from the Devonian remnants where they are present, is one of erosion but not of angular discordance. The hiatus represented by it, although of considerable magnitude, is easily recognized only where strong relief is exhibited in the eroded surface, and such a condition has been observed only where the Devonian remnants were found. Since these are comparatively few in number the unconformity is not a prominent feature of the Canyon walls.

One of the Devonian pockets occurs on the side of a large promontory just west of the writers' type section below Yavapai Point, where it is plainly visible from the Tonto Trail. This pocket was measured as being 66 feet deep and 164 feet in length. Near pockets of this type the line indicating unconformity exhibits slight irregularity, but elsewhere it is quite level.

After the retreat of the Tonto sea, the Muav was exposed to erosion which presumably continued throughout the Ordovician and Silurian periods since rocks of these two periods are lacking from the Grand Canyon. The pockets of Upper Devonian rocks in shallow depressions on the Muav surface indicate that deposition in Late Devonian time took place on the Muav surface at least locally. Whether or not these Devonian sediments entirely covered the Muav and were for the most part eroded away in a period of pre-Redwall erosion, has not yet been determined. At any rate, subsequent invasion of this

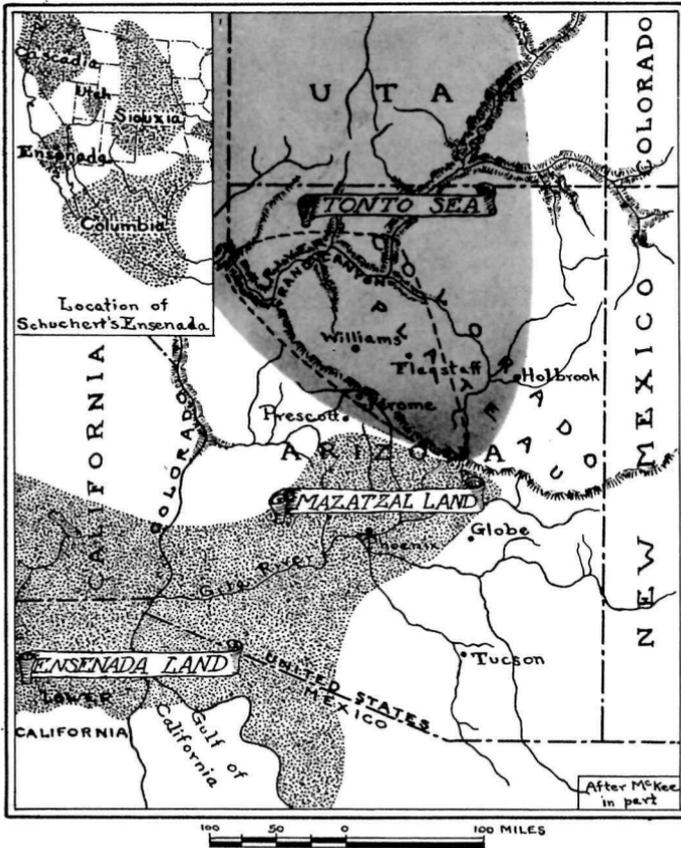


Fig. 4 - Map showing probable areas occupied by the Tonto Sea and Mazatzal Land during Tonto time.

(Dashed line includes known area of Tonto formations)

area in Mississippian time by the Redwall sea caused the deposition of limestone over a strikingly flat surface of Muav and Devonian limestone.

### Fauna

#### TAPEATS SANDSTONE:

ALTHOUGH a few structures resembling worm burrows are present near the top of the Tapeats sandstone, no determinable fossils were found by the writers within this formation.

#### BRIGHT ANGEL FORMATION:

IN addition to various trilobite tracks, annelid burrows, and fucoïdes thought to be of seaweed origin, many well-preserved trilobite and brachiopod fossils are to be found within the Bright Angel formation.

In the Grand Canyon, the Bright Angel formation has yielded two distinct Cambrian faunas - the one at the western end of the Canyon being Lower Cambrian, while to the east in the Kaibab division of the Canyon and in Tanner Canyon, the fauna is of Middle Cambrian age.

Following is the list of fossils collected by the writers and identified by Professor B. F. Howell and Mr. John F. Mason:

#### Pierce's Ferry:

Olenellus cf. fremonti

Hyalithes sp. undt.

? Eocystites sp. undt.

#### Yavapai Point:

Alokistocare althea

Glossopleura mckeeii

Anoria tontoensis

Kootenia sp.

Obolus chuarensis

Hyalithes sp. undt.

#### Tanner Canyon:

Alokistocare althea

Obolus chuarensis

Lingulella lineolata

Concerning these fossils, Mr. Mason<sup>6</sup> writes: "All the faunules from below Yavapai Point and from Tanner Canyon are of Middle Cambrian age, presumably dating from the lower half of that epoch as represented in the Cordilleran region. The collections from near Pierce's Ferry are of Lower Cambrian age".

Heretofore the Bright Angel formation was believed to contain only a Middle Cambrian fauna, but with the discovery of the Lower Cambrian Olenellus fossils in the western end of Grand Canyon the problem of the Tonto has become more complex. The presence of faunas of each of these two epochs of the Cambrian period must be explained by one of the following conditions:

1) The Bright Angel formation as exposed in the western part of the Grand Canyon is not continuous with the Bright Angel of the eastern part of the Canyon. This is highly improbable for, so far as is known, there is no such break throughout the length of the Grand Canyon. The Bright Angel at all three sections measured by the writers is identical in general character, lithology, and stratigraphic position. Conclusive proof, however, can only be obtained by a series of measured sections at fairly regular intervals westward from Indian Gardens.\*

2) Deposition of the Tonto group began in Early Cambrian time and continued well into the Middle Cambrian. (If this were true, the Tonto sea must have deposited sediments of Bright Angel type earlier in the area of western Grand Canyon than in the eastern section.) The shore line then would have advanced toward the east. Whether or not this is what took place cannot be determined until more field work has been done on this phase of the problem.

3) Anoria, Glossopleura, Alokistocare, and the associated forms listed above do not constitute a strictly Middle Cambrian fauna, but may indicate Early Cambrian time as well; or

4) Olenellus is not confined to the Lower Cambrian as has

\* Dr. C. E. Resser<sup>7</sup> is of the opinion that the formations near Pierce's Ferry do not belong to the Grand Canyon section but to that of the Muddy Mountains.

heretofore been believed, but may also occur at least in the lower part of the Middle Cambrian.

Whether the Tapeats sandstone and Bright Angel formation are Lower or Middle Cambrian, or both in part, cannot be fully determined until the above problem has been solved.

#### MUAV FORMATION:

**D**ETERMINABLE fossils are scarce in the Muav and, other than fuccidal forms evidently of both plant and animal origin, only one fossil was found in this formation by the writers - this was identified by Mr. Mason as being a *Corynexochid trilobite pygidium*.

Dr. C. E. Resser, in speaking of fossils from the Muav, states<sup>7</sup>: "The Muav limestone has yielded a few Middle Cambrian species belonging to the genus *Kootenia*. It is possible that certain other material from the mouth, or opposite the mouth, of the Little Colorado gotten by Walcott many years ago may also belong to the Muav but the species are still undescribed and I am not sure of their age. You can cite *Kootenia* as the characteristic fossil of the Muav".

All of the Muav fossils so far collected have come from the eastern portion of the Grand Canyon, and in view of the fact that *Olenellus* is found in the Bright Angel formation near Pierce's Ferry, no definite statement as to the age of the Muav as a whole will be made here. It now seems probable, however, that the formation is assignable to the Middle Cambrian epoch.

#### Paleogeography

**T**O the north of the Grand Canyon, the Spence shale and the overlying Howell formation in the House Range, Utah, are reported to contain *Glossopleura producta*. Consequently, it is very likely that the Bright Angel formation, which contains abundant specimens of *Glossopleura*, is to be correlated with these formations.

The Spence and Langston formations in the Wasatch Mountains, Utah, are also reported to contain *Glossopleura*. The Ute formation immediately above the Langston (which in turn

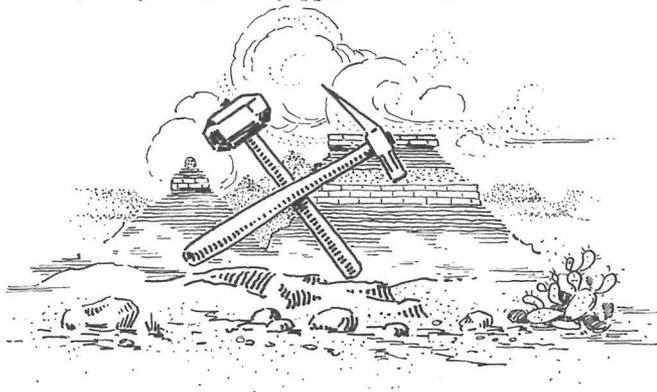
overlies the Spence) is reported to contain *Alokistocare*, which is also abundant within the Bright Angel formation. These genera indicate a relationship between the above mentioned formations of the Wasatch Mountains and the Grand Canyon Tonto group.

The similarities of the trilobite faunules of the Utah formations mentioned above, and the Grand Canyon Tonto group indicate that the two regions were connected by an arm of the Cambrian sea which covered these regions.

It has already been noted that the Bright Angel and Muav formations thin out and disappear to the south of the Grand Canyon region, and that the Tapeats sandstone is the only representative of the Tonto group in the Jerome region and in the Tonto Basin. These facts, together with the correlations noted above, indicate that the waters of the Tonto sea encroached upon the region from the north, becoming shallower as they approached central Arizona, and that the shore line of the sea was near the central part of the state (See Fig. 4).

In central Arizona there is an area in which Cambrian sediments are lacking. In the southern part of the state several Middle Cambrian formations (Troy, Bolsa, Coronado) are present, but fossils in them are of types distinct from those of the Tonto group. These facts indicate that a Cambrian sea also existed in southern Arizona, but that it was separated from the sea to the north by a land barrier. To this ancient barrier between areas of deposition Stoyanow has assigned the name "Mazatzal Land" (See Fig. 4) because it includes the Mazatzal Mountains. This land mass is believed to have existed more or less permanently throughout the Paleozoic era.

1. Hinds, N. E. A., "Ep-Archean and Ep-Algonkian Intervals in Western North America", Carnegie Inst. Wash. Publication, No. 463, Aug. 1935, pp. 1-52.
2. Noble, L. F., "The Shinumo Quadrangle, Grand Canyon District, Arizona", U.S.G.S. Bull. 549, 1914.
3. Twenhofel, W. H., "Treatise on Sedimentation", 1926.
4. Twenhofel, W. H., "Environment in Sedimentation and Stratigraphy", Bull. Geol. Soc. Am., vol. 42, Mar. 1931, pp. 407-424.
5. Schuchert, Charles, "The Cambrian of the Grand Canyon of Arizona", Am. Jour. Sci., 4th ser., vol. XLV, May, 1918.
6. Mason, J. F., Personal communication, Jan. 1936.
7. Resser, C. E., Personal communication, Dec. 1935.
8. Stoyanow, A. A., "Notes on Recent Stratigraphic Work in Arizona", Am. Jour. Sci., 5th ser., No. 70, vol. XII, Oct. 1936, pp. 311-324.



# On the Occurrence of Sillimanite and Staurolite in Grand Canyon

By Ian Campbell\*

**A**LTHOUGH much of the early interest in the Grand Canyon region centered around the occurrence, real or supposed, of valuable minerals, the area has never achieved much fame as a "mineralized district". Nevertheless quite a variety of minerals is known to occur within the park limits, and it seems desirable to call attention to the occurrence of two minerals in particular for the sake of their scientific interest.

Visitors to the more accessible parts of the Inner Gorge are familiar with the typical rocks and minerals of the Archean there exposed. There is variety, to be sure, but on the whole a rather monotonous variety, consisting for the most part of granites and granite gneisses and of mica and hornblende schists.

Pegmatites, which are often the "happy hunting grounds" of the mineral collector, because of the great variety and often well-crystallized character of the minerals they contain, are present in great number. But the pegmatites of this section are rather barren of rare or interesting minerals. Locally, especially in some of the pegmatites of Hermit Creek, sizeable crystals of black tourmaline are found; but the more prized colored varieties of this mineral do not occur so far as the writer is aware.

Garnet is one of the more striking minerals found in the Archean here, and its local prominence is testified to in such names as "Garnet Creek" and "Ruby Creek". Large crystals are found also on Phantom Creek, where individuals three centimeters or more in diameter have been measured. In the major-

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ity of these occurrences, the garnet (generally almandite) appears to have been produced by metamorphism of argillaceous sediments.

Of most significance for petrogenic studies, however, is the occurrence of two minerals whose presence in this section has received heretofore only very scant mention. These are sillimanite ( $\text{Al}_2\text{SiO}_5$ ) and staurolite ( $\text{H}_2\text{FeAl}_4\text{Si}_2\text{O}_{12}$ ). Hunter<sup>1</sup> noted the presence of sillimanite in a granite gneiss from Hermit Creek. In this instance the mineral could only be detected under the microscope. No other record of sillimanite in Grand Canyon is known to the writer. Staurolite has been mentioned briefly by the writer<sup>2</sup> in two earlier articles. But in none of these instances has there been any description of the general relationships and the genetic significance of these interesting minerals. It seems worthwhile, therefore, to present a more extended description for the benefit of those interested in the natural history of the park area.

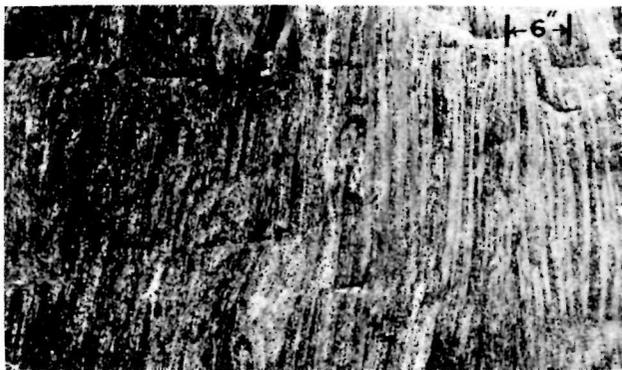


Fig. 1 Vertical beds of garnetiferous mica schist and sillimanite schist interbedded with quartz mica schist. Note erosional etching of the resistant garnetiferous layers. Vishnu Terrane, 250 yds. west of the mouth of Monument Creek, Grand Canyon.

<sup>1</sup> Noble, L. F. and Hunter, J. F., U.S.G.S. Prof. Paper 98-I, p.107, 1916.

<sup>2</sup> Campbell, Ian and Maxson, John H., Some Observations on the Archean metamorphics of the Grand Canyon; Proc. Nat. Acad. Sci., 19, p.807, 1933.  
Field studies of the Archean in Grand Canyon; Grand Canyon Nature Notes, 8, p.146, 1933.

Below Granite Rapids, the slopes of the Inner Gorge become somewhat less precipitous and it is possible to traverse the south bank of the river at low water stage all the way to the mouth of Hermit Creek. About a half mile downstream from the mouth of Monument Creek, there occurs a series of beds, totalling 75 feet in thickness, which are noticeable because of the abundance of garnets they contain. The outcrops below high water stage are particularly striking because the garnets, being more resistant to erosion, stand out like raisins and plums on the surface of a pudding. The bedded character of this series is very clear, being brought out by differences in size and amount of the garnets, and in variations in the accompanying minerals of which in some cases the principal one is biotite, in others, largely hornblende. See Fig. 1. One bed is very noticeable because of the abundance of long narrow



**Fig. 2** Photomicrograph of sillimanite schist. Spec. No. 270, magnification = 60x, plane polarized light. The elongated white crystals are sillimanite. The slightly transparent mineral, occurring in irregularly shaped flakes, is biotite. The black areas are magnetite. The colorless matrix is chiefly quartz. Garnet occurs in the rock, but is not well illustrated in this particular section.

white crystals of high luster. These are sillimanite and give the rock in which they occur a unique appearance. The sillimanite crystals are small, only a millimeter or less in diameter; but some attain lengths of over a centimeter. A photomicrograph of a thin section of this sillimanite gneiss shows the minerals and their relationships in this rock. See Fig. 2. Sillimanite occurs partly as the well-developed prisms illustrated and partly in exceedingly fine, almost hair-like crystals, closely grouped in fluxional arrangement. This latter is the variety known as fibrolite.

The importance of sillimanite is as an indicator of geologic conditions. Students of metamorphism are agreed that the development of this refractory aluminosilicate connotes high intensity of metamorphism. Thus Harker<sup>1</sup> places sillimanite as the index mineral of his sixth (the most extreme) zone in the progressive metamorphism of argillaceous sediments.

One of the major problems in connection with the Archean rocks of the Grand Canyon is whether or not their metamorphism is of regional or contact type. Now, one of the distinguishing features of regional metamorphism (implied, indeed, in the name) is that over a wide area such metamorphism should exhibit approximately equal intensities. In contact metamorphism, on the other hand, considerable variation in intensities is to be expected within relatively short distances.

Before going farther with this argument, let us examine the occurrence of staurolite in Lone Tree Canyon. The relatively slight degree of metamorphism of the Archean rocks found here was remarked on by Noble<sup>2</sup> and confirmed by the writer. The sericite phyllites in which cross-bedding and other sedimentary features are so strikingly preserved are evidence of comparatively feeble stages of metamorphism. Yet a few hundred yards downstream and only a few hundred feet apart, stratigraphically, are found garnet-staurolite schists indicative of much greater intensities. The two minerals (garnet and staurolite) stand out as prominent porphyroblasts in this rock, which is illustrated in Figure 3. The garnet here is again the variety almandite. The staurolite occurs mostly as rather stout brownish-red prismatic crystals, not

<sup>1</sup>Harker, Alfred, *Metamorphism*. London, 1932, pp.227-229.

<sup>2</sup>Noble and Hunter, *op. cit.* pp.108-109.



Fig. 3. Drawing of staurolite  
schist, Spec. No. 226  
Approximately natural size

The porphyroblasts in this specimen are chiefly staurolite; the small black flakes are biotite; the matrix is largely sericite and quartz.

always readily distinguishable from garnet, which it strongly resembles both in color, hardness and luster. However, the fact that staurolite possesses one good cleavage while garnet lacks any, will serve to separate the two in those cases where the external crystal form is not sufficiently well developed in orthorhombic prisms or in the very characteristic cruciform twins for which this mineral is known. The limits of these garnet-staurolite schists cannot be determined with any certainty, due to the present impossibility of making a traverse across their strike. Along their strike they are found as far as the mouth of Lone Tree Canyon, and a somewhat similar rock occurs again in Clear Creek, on the north side of the Colorado. It appears that there is a rather thick sedimentary series here,

in which certain beds have suffered relatively high degrees of metamorphism, others much less.

Just what intensities of metamorphism are here represented? In the scale given by Harker<sup>1</sup>, the sericite phyllites would fall in zone one, while the staurolite rock would be in zone four. (Six is the highest zone). Such a rapid and considerable change in intensity is surely not indicative of a dominantly regional metamorphism. Recall, too, that much farther to the west are found the sillimanite bearing rocks of zone six; but that closely associated with these in the field are quartzites and micaceous quartzites representing stages comparable to the sericite phyllites of Lone Tree Canyon. Indeed, in one instance a ripple mark has been preserved on a quartzite<sup>2</sup> whose stratigraphic position is within less than 1000 feet of the sillimanite gneiss.

These observations strongly suggest (although they do not prove) that the extreme cases of recrystallization and most of the cases of newly developed minerals in these rocks are more probably to be attributed to contact than to regional effects. Such a conclusion is of the utmost importance as regards the possibility of interpreting the Archean history of this area. If metamorphism is not uniformly severe everywhere, it means that somewhere there may even be opportunity of finding evidence of the most primitive forms of life. In fact in Norway, the Alps and elsewhere fossils have been recorded as surviving even up to the intensities of the garnet zone (zone three). Only a foot by foot examination of the Archean outcrops can hope to turn up such a treasure; but in view of the indicated character of the metamorphism, such a search would seem to be worth making.

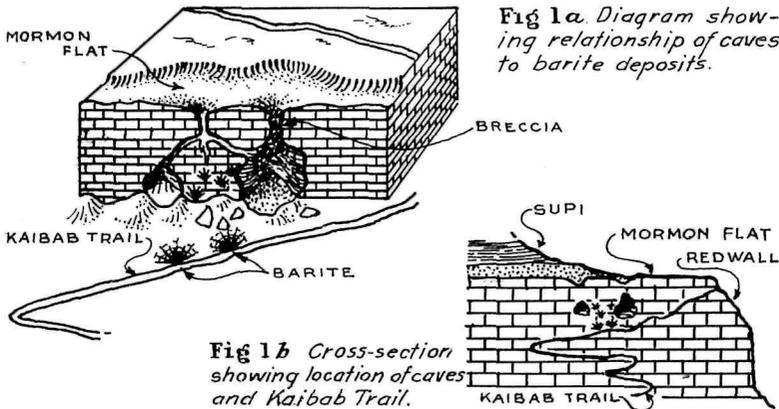
<sup>1</sup> Maxson, John H., and Campbell, Ian, Archean ripple mark in Grand Canyon, Amer. Jour. Sci., 28, p. 298-303, 1934.

<sup>2</sup> Harker, op. cit., p. 227

# Barite Deposits in the Redwall of Grand Canyon

By Joseph J. Bryan

**A**S one goes down the Kaibab Trail from the South Rim of the Grand Canyon, crosses Mormon flat, and begins the descent of the great Redwall cliff, one's attention is attracted to two shallow caves just above and to the right of the trail (Fig. 1).



The larger of the two caves narrows at the top to a short channel or opening six or seven feet in length and three to four feet in width. This opening is partially filled with a coarse breccia, composed almost entirely of angular fragments of chert and flint, cemented by a friable, buff-colored, coarsely crystalline limestone (Fig. 2). The angular fragments of chert and flint measure anywhere from an inch to several feet in length and width. The walls of this cave are honeycombed with smooth irregular channels and openings which are doubtless the result of solution work along joints and bedding planes. The floor of the cave, too, exhibits smooth channels and grooves probably worn by waters percolating through small openings in the limestone.

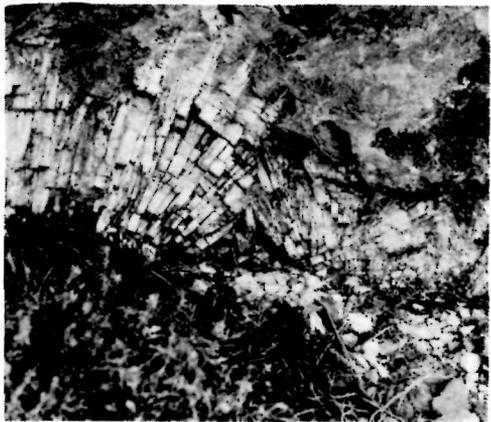


Fig.2 Cave breccia in Redwall limestone ...

The smaller cave dwindles in the back to a narrow opening which is practically filled with an irregular mass of white coarsely crystalline limestone and small scalenohedrons of calcite.

These small caverns are about twenty feet apart, and the intervening limestone is full of enlarged cracks, joints, and solution channels filled with intimately mixed, coarsely crystallized calcite and barite. In this limestone between the caves, the writer noticed one small crack over twelve inches in length and about one quarter of an inch in width, which was completely filled with barite.

Just beside the trail to the right and a few feet below the caves are several large radiating masses of tabular barite crystals (Fig. 3). The barite cuts and emmeshes fragments of the limestone which it seems to have replaced.



Barite crystals in Redwall.

Fig. 3.

Nearly all the barite is white to colorless, although in places small amounts of it have a reddish, and sometimes a greenish tinge. Blowpipe tests fail to reveal any trace of strontium, perhaps the most common impurity in barite.

In crossing Mormon Flats, one gradually enters the top of the Redwall limestone, and can hardly help but notice the abundant lenses of chert and flint which characterize that part of the formation.

In many places in the Grand Canyon the Redwall is noted for its natural caverns and solution channels. Especially notable are the caverns in this formation just below Grandview Point. In Cataract Canyon also, the Redwall has large solution channels through it, many of which contain small deposits of galena, sphalerite, and vanadinite. From the porch of Yavapai Station, many visitors observe a small cavern in the top of the Redwall just north of O'Neill Butte. In size and

form this cave is very similar to the ones described in this article.

The angular fragments of chert and flint in the breccia which nearly fills the opening in the larger cave are of the same color and character as the chert and flint which occurs in lenses and layers in the top of the Redwall limestone above the present roof of the cave.

None of the angular fragments in the breccia are of the Supai formation, which everywhere throughout the Canyon, overlies the Redwall. As there is a great unconformity or erosion interval (probably equal to all of Pennsylvanian time as well as Upper Mississippian) between the top of the Redwall limestone (Lower Mississippian) and the base of the Supai formation (Permian), the shallow caves are probably a remnant of a pre-Supai sinkhole in the Redwall. It is believed the eastern portion (probably a major part) of the sinkhole has been eroded away during the formation of the Grand Canyon, and that the present caves represent only the ends of minor side passages or solution channels.

The origin of the barite in these old sinkholes presents a very interesting problem. Samples of the limestone surrounding the caves were tested for barium, but none of them yielded a trace. Yet it is believed that the underground waters carried barium in solution, probably as the bicarbonate, and these solutions mingling with sulphate waters caused the very insoluble  $BaSO_4$  to be precipitated. A very thorough analysis of the surrounding limestone might reveal the presence of barium. Another possible source would be the upper portion of the Redwall limestone which was removed before the Supai sediments were deposited.

At any rate the coarse crystallizations of calcite and barite indicate that they were deposited by solutions following channels and openings in the massive limestone, and that in the large radiating masses of barite we have a case of replacement of the limestone.

