



Precambrian rocks of northern Arizona

John F. Lance

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PRECAMBRIAN ROCKS OF NORTHERN ARIZONA

by JOHN F. LANCE
University of Arizona

INTRODUCTION

The two systems of Precambrian rocks exposed along the bottom of the Grand Canyon have been studied by geologists since the early days of scientific exploration in the west, and have been used as text-book examples for the interpretation of Precambrian structural, stratigraphic, and erosional history. The Vishnu schist, and associated intrusive bodies, and the Grand Canyon series, consisting of sedimentary and volcanic rocks, have been assigned to the Archean and Algonkian, respectively. Non-committal terms, older and younger Precambrian have been used by recent authors. The older and younger Precambrian rocks are separated by one of the most pronounced unconformities known in the geologic column, and an erosion surface of lesser, but still impressive, magnitude divides the two older sequences from the Paleozoic strata.

Within the Grand Canyon the relationships of the Precambrian rocks to each other and to the overlying Paleozoic section is, for the most part, clear. In central Arizona the Yavapai schist and the Apache group represent the presumed equivalents of the Vishnu and the Grand Canyon series. In southern Arizona the older Precambrian Pinal schist is overlain by the younger Precambrian Apache group. Crystalline rocks, including granite, schist, and gneiss in western, southwestern, and parts of southeastern Arizona have been assigned to the older Precambrian, mostly without any compelling evidence.

The core of the Defiance uplift contains rocks of presumed Precambrian age. Known outcrops include quartzite in Bonito Canyon, west of Ft. Defiance, and granite and metavolcanic and metasedimentary rocks near Hunters Point. In both areas the overlying rocks are Permian redbeds currently assigned to the Supai formation. Regional relationships suggest an older Precambrian age for the granite. The quartzite in Bonito Canyon is shown as Algonkian on the geologic map of Arizona. Correlation of the crystalline rocks of the Defiance uplift with other units is not certain. As the age of these rocks has not been solved, a review of the lithology and age relationships in other parts of northern and central Arizona may be useful in assessing some of the possibilities.

A fairly satisfactory generalized history can be developed for the Grand Canyon area and the margins of the Colorado Plateau. Both the Vishnu and Yavapai schists consisted originally of thick sequences of sedimentary and volcanic rocks, which can be separated into individual units by detailed mapping in some areas. A major orogeny, termed by Wilson (1939) the Mazatzal revolution, compressed the rocks into northeast-trending mountains, and was accompanied and followed by intrusions of large granitic batholiths and associated pegmatites. A period of erosion, the Ep-Archean, produced a surface of remarkably low relief in the Grand Canyon area and parts of central and southern Arizona. The younger Precambrian Grand Canyon series in northern Arizona and the Apache group in east-central and southern Arizona were deposited on this surface. Both consist of sandstone, shale, and limestone, with basalt flows, and both have been intruded by diabase. The Grand Canyon disturbance, which followed deposition of the younger Precambrian rocks of the Grand Canyon, formed fault-block mountains with dominantly northwest trends. An erosional period, the Ep-

Algonkian, produced a surface of very low relief across the tilted wedges of younger Precambrian and the crystalline masses of older Precambrian before the encroachment of the Paleozoic seas into the area. The details of younger Precambrian orogeny in central Arizona are not well known. West-central and northwestern Arizona contain no rocks of known younger Precambrian age.

PRECAMBRIAN OF THE GRAND CANYON Vishnu Schist

The crystalline complex forming the inner walls of the Granite Gorge of Grand Canyon has been recognized as of Archean age since the early observations by Powell. Walcott called it the Vishnu terrane, and Noble (1914) applied the term Vishnu schist, recognizing, in the Shinumo quadrangle, a complex of quartz, mica, and hornblende schist, intruded by massive quartz diorite and granitic pegmatite and aplite. The pegmatites, typically pink, were assigned to two generations, the older one being folded with the schist, and the younger one cutting both the schist and the quartz diorite. Noble suggested that the older rocks now represented by the Vishnu included originally both sedimentary and igneous types.

Noble and Hunter (1917) examined the older Precambrian rocks along a 40-mile stretch of the river near the eastern end of Grand Canyon, in what is known as the upper Granite Gorge. They estimated that 50 percent of these rocks are gneiss, 30 percent are mica schist, 10 percent basic intrusive rocks, and 10 percent are pink siliceous intrusive granite, aplite, and pegmatite. They suggested that at some future time the gneiss might be separated from the Vishnu schist and a new name or names be applied.

Several interesting points concerning the age and structural relationships of the various rocks were discussed by Noble and Hunter. One of these relates to the origin and relative ages of the gneisses, the tentative suggestion being advanced that some of the granitic gneiss represents the original basement upon which the sedimentary sequence, now metamorphosed to schist, was laid down, with a long and complex history of subsequent intrusions before, during and after the deposition of the sedimentary rocks. Petrographic study showed that some of the gneiss was originally quartz diorite and granite, intrusive into the sedimentary sequence before the regional metamorphism. This regional deformation, which Noble and Hunter stated to be the most obvious event in the Archean history of the area, produced foliation and schistosity with predominant northeast strike and nearly vertical dip, indicating compression from either southeast or northwest. A generation of pink granite and pegmatite, visible from many localities along the rim of the canyon, is clearly later than the regional metamorphism, and cuts all of the other older Precambrian rocks. The pegmatite bodies, in general, conform closely to the direction of schistosity.

Campbell and Maxson (1938) gave preliminary results of work aimed at distinguishing the original rock types in the Vishnu and at interpreting the details of older Precambrian history. They proposed that the name Vishnu series be used for a sequence of 25,000 feet of metasedimentary rocks, originally fine-grained argillaceous sandstone and sandy shale, now metamorphosed to quartzite, sericite quartzite, and quartz mica schist. No name was

Vishnu Series

proposed for a considerable, but unknown thickness of amphibolite, probably originally basaltic lava and tuff, as shown by relict pillow and amygdaloidal structures.

Final results of the studies by Campbell and Maxson have not been published, but they have given a preliminary interpretation of the older Precambrian history of the Canyon. The first event was the deposition, on a "virtually unknown terrain," of thousands of feet of sediment, dominantly sandy clay, but including quartz sand and ferruginous beds. No limestone appears to have formed although some beds were slightly calcareous. Basalt flows, some submarine, were intercalated toward the top of the sedimentary sequence. **Sedimentation is interpreted as having been in a shallow, subsiding geosyncline.**

The second event was a period of major volcanism, with extravasation of hundreds or thousands of feet of basaltic lava. Sandstone and argillite was deposited during this period. The volcanic centers presumably coincided with the axis of the geosyncline. Third was an intensive orogenic disturbance, folding and considerably metamorphosing the volcanic and sedimentary rocks and forming great northeast-trending mountain ranges. Quartz-mica schist, quartzite, and amphibolite were formed, respectively, from the sandy shale, sandstone, and basalt. Metamorphism that formed rocks such as garnet sillimanite schist is interpreted as the result of contact processes resulting from later intrusions.

The fourth event, closely related to the third, was the intrusion of granitic magma. Rocks related to this episode include bodies of pink and gray massive granite and related types, granitic gneiss, and aplite and pegmatite dikes. Massive, coarse-grained, gray, homogeneous granite, relatively free of schist, forms large bodies in the lower Granite Gorge near Lake Mead. In the upper end of the Canyon, in the Bright Angel quadrangle, the igneous bodies appear to be more closely related to the structure of the schist, and are perhaps more diverse in type. Campbell and Maxson have applied the name Zoroaster granite to a red, microcline-rich, coarse-grained granite, and "Phantom migmatite" to a body of mixed granite, schist, and amphibolite. The massive quartz diorite and hypersthene gabbro described by Noble, and Noble and Hunter in the Shinumo quadrangle have not been formally named. The Zoroaster granite and the quartz diorite appear to be batholithic bodies later than regional metamorphism.

Campbell and Maxson stated that no evidence was found for more than one major period of intrusion in the area. They postulated a replacement origin for much of the granite, gneiss, and pegmatite.

Although some of the gneiss might represent the original basement on which the Vishnu sedimentary and volcanic rocks were deposited, and some might represent pre-Mazatzal revolution intrusions, as suggested by Noble, all bodies of gneiss, granite, and pegmatite are truncated by the Ep-Archean erosion surface. All the crystalline rocks of the Grand Canyon area and those along the western and southern edges of the Plateau in Arizona appear to be of older Precambrian age.

Grand Canyon Series

The Grand Canyon series consists of nearly 12,000 feet of sandstone, shale, and limestone, separated by unconformities from the Vishnu below and the Cambrian Tapeats sandstone above. Two divisions of approximately equal thicknesses were recognized by Walcott (1883, 1895), the Unkar group below and the Chuar group above. The Chuar has been identified only in the area near Chuar,

Unkar, and Nankoweap Canyons, near the confluence of the Little Colorado. The Unkar appears at several places downstream from the Little Colorado to Tapeats Creek, west of the Shinumo quadrangle. The largest exposure is that in the eastern end of the canyon, but exposures showing the structural relationships to older and younger rocks can be seen from observation points near Grand Canyon village.

The Grand Canyon series is preserved in a series of fault blocks, tilted to the northeast. Open folds in the strata near the eastern end of the Canyon have been noted by several workers. The Ep-Algonkian erosion surface bevels the sedimentary wedges and the underlying crystalline rocks and the Tapeats sandstone rests on the surface. These relationships are pointed out at several observation stations set up by the National Park Service.

Walcott measured 6830 feet of Unkar and 5120 feet of Chuar rocks in the eastern area of exposures. Noble (1914) studied the 4000 feet of Unkar group in the vicinity of Shinumo Creek and recognized five formations; in ascending order, the Hotauta conglomerate, Bass limestone, Hakatai shale, Shinumo quartzite, and Dox sandstone. These divisions have been extended into the eastern exposures. Van Gundy (1937) proposed that about 400 feet of sandstone and limestone near the top of Walcott's Unkar be designated the Nankoweap group. The Nankoweap beds overlie basalt flows interbedded with the upper part of the Dox. A magnesian limestone above the Nankoweap, originally included by Walcott in the Unkar, was reassigned to the Chuar group. According to Van Gundy, the Nankoweap group is bounded above and below by erosional unconformities which represent the most important breaks in the entire Grand Canyon series.

The Unkar has diabase intrusives which are responsible for asbestos deposits in the Bass limestone. The asbestos deposits are similar to those in the Mescal limestone of the younger Precambrian Apache group in central Arizona and have been used as one line of evidence for a postulated correlation between the Unkar and Apache groups.

A younger Precambrian age for the Grand Canyon series is certain from the structural relationships, although early workers considered it to be early Paleozoic. Walcott reported fragmentary fossils from the lower shale and limestone of the Chuar, identifying them as possibly remains of mollusks, trilobites, and stromatoporoids. Van Gundy and others have reported casts of jelly-fish from the Chuar and the Bass limestone. **Algal structures are common in the Bass.**

Following deposition of the Grand Canyon series, the Grand Canyon disturbance formed tilted fault-block mountains along faults with predominant northwest strikes. Gentle folding in the eastern end of the Canyon has been described. No intrusive activity seems to have accompanied the faulting, and Noble (1914) and others have noted that beds of the Grand Canyon series are not metamorphosed.

Ep-Archean and Ep-Algonkian Erosion Surfaces

The two Precambrian erosion surfaces exposed for many miles along the Grand Canyon have been described by a number of writers. According to several authors, the maximum relief of the Ep-Archean surface is less than 50 feet. The surface is exposed only where blocks of the Grand Canyon series have been preserved by downfaulting into the older Precambrian, but the exposures extend for more than 50 miles along the canyon. The maximum relief noted by Sharp (1940) was only 20 feet. The surface is so flat that some geologists have considered it as prob-

ably formed by marine erosion, but Sharp and others who have made very detailed studies believe that it was formed by subaerial processes and that it was only slightly modified by marine action.

The Ep-Algonkian surface in the Canyon is exposed for more than 200 miles. It also is remarkably flat. Sharp estimated that at least 95 percent of the surface has a relief of less than 150 feet. Monadnocks of massive granite and Shinumo quartzite as much as 800 feet above the general level remained to form islands in the advancing Tapeats sea. Other rocks, particularly the Bass limestone, were resistant enough to remain as somewhat lower hills on the old surface. According to Sharp, at least 95 percent of the rocks beneath the exposed surface are older Precambrian.

Both surfaces show signs of weathering which Sharp interprets as largely of the chemical type. He reports a maximum depth of weathering of 10 feet below the Ep-Archean surface and of 50 feet beneath the Ep-Algonkian surface, with only the upper 5 to 10 feet greatly altered. Both surfaces are overlain in places by regoliths of structureless, fine-grained, ferruginous deposits interpreted as soils. These deposits are more widespread and thicker on the younger of the two surfaces, where they are commonly one or two feet thick.

PRECAMBRIAN OF CENTRAL ARIZONA

Yavapai Schist

The Yavapai schist was named in the Bradshaw Mountains in central Arizona by Jagger and Palache (1905). They described a complex of slate, phyllite, schist, gneiss, and hornfels, intruded by granitic masses. The overlying rocks within the type area are Cenozoic volcanic and sedimentary rocks, some of which are known to be of Lower Pliocene age from fossil evidence. The Yavapai schist has been extended into the Jerome district where the crystalline rocks are overlain by lower Paleozoic sedimentary rocks.

Wilson (1939) pointed out that rocks assigned to the Yavapai schist are only locally schistose and proposed that three formations, designated the Yaeger greenstone, Red Rock rhyolite, and Alder series, in ascending order, should constitute the Yavapai group. The Alder series, some 5000 feet of shale and grit with conglomerate and quartzite, is in fault contact with the other two formations where observed. Three formations, the Mazatzal quartzite, Maverick shale, and Deadman quartzite, were interpreted by Wilson as being younger than the Yavapai group, although he pointed out that they overlie a southward sloping surface eroded on the Red Rock rhyolite and that they could be facies equivalents of the Alder series. The City Creek series, consisting of about 2000 feet of gray, maroon, purple, and green shale with interbedded quartzite, cannot be assigned a definite relationship to the other units, but it is overlain unconformably by the Cambrian Tapeats sandstone north of the Mazatzal Mountains.

Detailed mapping in other parts of central Arizona have also resulted in recognition of a complex sequence of rock units and events within the older Precambrian (Anderson, 1951; Anderson and Creasey, 1958). Certain generalizations appear evident from the various studies. First, the older Precambrian complex includes thick sequences of sedimentary and volcanic rocks that have been intensely deformed. The sedimentary rocks, which vary markedly in abundance from place to place, include sandstone, shale, and locally, as reported by Lindgren (1926), some limestone. Second although there is evidence of

intrusive and tectonic activity during the accumulation of the Yavapai group and other older Precambrian rocks, the major structural event seems to have been the Mazatzal revolution, which involved strong compression acting in a northwest direction and intrusion of large granitic bodies.

Several geologists have argued that the Mazatzal revolution produced a major landmass, termed Mazatzal land, that trended northwest through central Arizona and that limited basins of deposition in younger Precambrian and Paleozoic times were restricted to northwestern and southeastern Arizona. The extent and influence of this landmass have been discussed in some detail by Stoyanow (1942), Huddle and Dobrovolsky (1952), and McKee (1951).

Apache Group

The Apache group, consists of about 1000 feet of quartzite, limestone, and shale, and overlies the Pinal schist, the Yavapai group, the Mazatzal quartzite, and granite in southern and central Arizona. The units include, in ascending order, the Scanlan* conglomerate, Pioneer shale, Barnes* conglomerate, Dripping Spring quartzite, and the Mescal limestone. A basalt flow is found above the Mescal in places, and diabase intrusives into the Mescal have localized the asbestos deposits of central Arizona. The Apache group has been considered as probably equivalent to the Unkar group of Grand Canyon. A unit younger than the Mescal, the Troy quartzite, was originally included within the Apache group, but has been correlated with the Bolsa quartzite in recent years.¹ The Bolsa is demonstrably of Cambrian age in southern Arizona, and Cambrian fossils are known from exposures in central Arizona that have been mapped as Troy. The entire Apache group was originally assigned to the Cambrian. At present it appears that the quartzite originally called the Troy and included in the Apache group may actually belong there, at least in the northern areas (Shride, 1958).

The Apache group rests on the older Precambrian rocks with marked unconformity, but the overlying Paleozoic section rests on it in most places with only little or no discordance. The original conditions of deposition of the Apache group have been obscured by the complex structural history of central and southern Arizona. The group thins going north and northwest from the Globe area toward the Mogollon Rim. According to Andrew Shride (personal communication), the basal conglomerate of the group thickens and rises in the section from the Sierra Ancha area to the northwest, and the upper units are progressively beveled by the surface beneath the Troy quartzite. Also, in the northeasternmost exposures of the group, as shown on the State geologic map, the upper part of the Dripping Springs quartzite rests on crystalline rocks, indicating the loss of several basal units. These facts indicate the presence of a younger Precambrian high in central Arizona, but the configuration of the Apache basin and its relationship to the basin of deposition of the Grand Canyon series, and the relationship of the Ep-Algonkian erosion surface in central and southern Arizona to that farther north are not readily discernible.

Precambrian Erosion Surfaces in Central Arizona

The Ep-Archean surface is exposed in central Arizona where the Apache group rests on older rocks. The surface has been described as a peneplain by most workers. In general, this surface in central and southern Arizona does not appear to differ greatly from that in the Grand Canyon, except that it is exposed over a much larger area and that the underlying rocks are perhaps more diverse

* Scanlan & Barnes now considered merely basal conglomerates of the Pioneer & Dripping Springs respectively.

¹ Most of Troy is still in the Precambrian - N. H. of latitude of Globe

in type and resistance to erosion than those in the Canyon. Locally the surface has greater relief in central Arizona, and is overlain in places by thicker and coarser conglomerates than those in the Grand Canyon series. This may be in part related to the fact that a larger area is exposed in central Arizona.

The Ep-Algonkian erosion surface in central and southern Arizona is similar to that in the Grand Canyon except that where the lower Paleozoic rocks rest on the Apache group sedimentary or volcanic rocks they do so with little or no angular discordance. The relationships of the surface to underlying crystalline rocks is much the same as that of the corresponding surface in the Canyon. **Older Precambrian rocks such as the Mazatzal quartzite, locally strongly discordant with the Paleozoic beds, form irregularities on the surface. Relief of several hundred feet has been reported at several places.**

The identity of the Ep-Algonkian surface of the Grand Canyon with that in some parts of northwestern and west-central Arizona can scarcely be doubted. Along the Grand Wash Cliffs and southeastward from Music Mountain along the Mogollon Rim the surface essentially projects out from under the cover of Paleozoic rocks south of Grand Canyon. Structural and stratigraphic complications in the Jerome area and farther east along the Rim did not obscure the picture of the broad relationships because rocks readily identifiable with the Cambrian Tonto group of the Grand Canyon overlie the Precambrian in enough places to establish reasonable control. However, the problem of the extent of Precambrian highlands in Central Arizona south of the area of Tonto group outcrops, and the effect of these highlands on early Paleozoic sedimentary basins, remain as problems not completely solved (McKee, 1951). The basal Paleozoic sediments lying on the Ep-Algonkian surface in east-central and southern Arizona appear to be younger than those in the west-central and Grand Canyon areas.

In much of central Arizona the older Precambrian rocks are exposed at the surface, or are overlain by Cenozoic sedimentary and volcanic rocks, some of which have been dated as Pliocene. The crystalline rocks in mountain ranges such as the Mazatzals and Bradshaws in central Arizona, and the Hualpais and Cerbatos in western Arizona are 4000 to 5000 feet above the top of the Precambrian basement in the Grand Canyon. Also, the crystalline rocks now exposed in these ranges must be a considerable distance below the old Ep-Algonkian surface. Ransome (1926) estimated at least 3000 feet for this distance in the top of the Bradshaw Mountains.

PRECAMBRIAN ROCKS OF THE DEFIANCE UPLIFT

General Statement

Crystalline rocks of probable Precambrian age are exposed in three areas along the east side of the Defiance uplift. The northern exposures, a few miles west of Ft. Defiance, consist of several small outcrops of quartzite. The first and second major canyons that drain the uplift south of Hunters point contain, respectively, granitic and metamorphic rocks. The quartzite is the only one of these rock types that has been discussed extensively in the literature. The granite and metamorphic rocks were mapped by University of Arizona field camp students in 1952 and have been examined by several geologists since then. The granite was described briefly by Haff and Kiersch (1955). No details have been published on the metamorphic rocks. The account given here is based on my notes and on reports by University of Arizona students,

particularly Roger Y. Anderson, Keith Coke, and Jack Haight.

The exposures of crystalline rocks are all small, and relationships between various rock types are unknown. They are overlain by the Supai formation, so stratigraphic relationships indicate only a pre-Permian age.

Quartzite at Bonito Canyon

Gregory (1917) first described the quartzite exposed in Blue Canyon, then called Quartzite Canyon, a small tributary to Bonito Creek west of Ft. Defiance. He assigned a Precambrian (?) age, considering that the most likely correlation was with the Shinumo quartzite of the Unkar group. He believed that the quartzite represented a monadnock on a Precambrian erosion surface surviving into Permian time. Darton (1925) amplified Gregory's observations, pointing out that some Paleozoic strata may have been deposited in the area and eroded away before Permian.

The quartzite is dark gray to purple, jointed, with numerous sedimentary structures such as cross-bedding, ripple marks, and mud cracks. Mica flakes and flat pebbles of quartzite and phyllitic rocks occur along bedding planes. The pebbles, also present in lenses, have been described as being crushed and flattened. Most accounts discussing the quartzite emphasize the metamorphism that the pebbles seem to indicate.

Granite near Hunters Point

Darton (1925) noted the occurrence of granite beneath the Supai in shallow drill holes at two places west of Ft. Defiance and compared the relationship between the Permian and Precambrian rocks of the Defiance uplift with that in the Zuni uplift. In his series of structure sections across the Defiance Plateau (1925, fig. 31), he showed the core of the uplift as being composed largely of granite. His section through Hunters Point shows considerable prescience in depicting the relationships almost exactly as they are now known to be in the first canyon south.

Pink, coarse-grained granite is exposed for about one-fourth of a mile along the walls of the first canyon south of Hunters Point. It is finer-grained toward the eastern end of the outcrop, where a small area of a few hundred square feet on the north side appears to represent a partially digested xenolith of silicified argillaceous rock which grades into typical granite with no definite boundaries. Bands of fine- and coarse-grained material can be traced through the granite in several places, giving the appearance of aplitic and pegmatitic dikes cutting the main body, but with gradational contacts. Pink orthoclase phenocrysts, some as much as two centimeters in length, are common in the coarser phases, with a finer-grained groundmass of quartz, orthoclase, and biotite.

The granite is intensely jointed and badly weathered in places, particularly near the upper contact. Some of the feldspar is kaolinized and alteration products such as chlorite and hematite give a dark-green and dark-red color to some exposures. A quartz vein containing specular hematite cuts the granite but does not extend up into the Supai.

An erosion surface with perhaps 100 feet of relief is cut on the granite. In most places a basal conglomerate about two feet thick lies on the surface, but locally it is absent. The maximum thickness is five feet, at the west end of the outcrop, where the largest fragments in the conglomerate are as much as five inches in diameter. Most of the conglomerate contains fragments between one and two inches in diameter, set in a coarse, silty, dark-red

sandstone that grades upward into the Supai beds. Most of the pebbles in the conglomerate are quartzite and granite, with some volcanic rocks. The quartzite pebbles show better rounding than the granitic or volcanic ones in all exposures.

Metamorphic Rocks near Hunters Point

Metamorphic and sedimentary rocks are exposed in a canyon about two miles south of Hunters Point. Outcrops are discontinuous and no clear picture of any sequence has been established. Rocks on the north side of the canyon are more highly metamorphosed than those on the south side, where shale, sandstone, tuff, and limestone are only slightly altered. On the north side are schist, slightly silicified limestone, low grade slate or phyllite, and greenstone. The relationships between the two sides of the canyon are obscure. A fault or unconformity might be concealed by the alluvium along the canyon floor. A fault is thought to be more likely.

The schist includes several types of metavolcanic rocks, probably originally andesite, basalt, and tuff. The limestone, which appears to overly most of the schist, but which is locally folded into it, is pale reddish brown to gray, very cherty, and somewhat silicified. The rock referred to as slate might be called a phyllite, but has incipient slaty cleavage. It is mostly red, but exposures of greenish and gray rock probably represent part of the same sequence.

The rocks south of the canyon show practically no metamorphism. Most of them strike about N 70 E and dip southeast from 30 to 70 degrees. A section measured by Roger Y. Anderson included about 200 feet of thin-bedded green sandstone, blue, red, and green shale, tuff, and a half-foot bed of green, silicified limestone. A structureless zone of red clay from a few inches to ten feet thick below the Supai grades into the sedimentary sequence and appears to be an old soil.

A dark gray basic dike and a quartz vein, both containing specular hematite, cut the sedimentary and metamorphic rocks. Both appear to be truncated by the pre-

Supai erosion surface.

The basal conglomerate of the Supai in the canyon is much like that in the canyon with granite, but is only two or three feet thick, with pebbles averaging less than an inch in diameter. Locally the conglomerate is absent, and in places lenses of sandstone or pebble conglomerate a few inches thick appear several feet above the base of the Supai.

Age of Crystalline Rocks of Defiance Uplift

The quartzite at Bonito Canyon has been correlated with the younger Precambrian of the Grand Canyon on the State geologic map of Arizona. Allen and Balk (1954) also argued for a younger Precambrian age. Hinds (1936), on the other hand, compared the quartzite with the Mazatzal quartzite of central Arizona. The granite has not been dated, but is almost certainly older Precambrian, because no granites similar to it of other age are known in the whole surrounding area.

Considering the degree of metamorphism of some of the rocks south of Hunters Point and possibly of the quartzite, I would judge that all of the pre-Permian rocks exposed represent a complex similar to those of the older Precambrian rocks in northern and central Arizona, except perhaps in some of those near intrusive bodies. The small dikes and quartz veins hardly seem adequate to account for the amount of metamorphism observed. Huddle and Dobrovolsky (1952) discussed the evidence for a ridge of basement rocks, the Holbrook granitic ridge, trending northeast from central Arizona to the Defiance uplift.

It might be argued that the quartzite and possibly the metamorphic and sedimentary sequence rest unconformably on the granite. This is a possibility, but it seems unlikely that a wedge of younger Precambrian rocks, faulted into the crystalline basement, would be preserved near the crest of the highest structural block known for many miles in all directions, considering the amount of erosion represented by the hiatus between the Supai and the underlying rocks.

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