THE STRATIGRAPHY OF THE SUPAI FORMATION IN THE CHINO VALLEY AREA YAVAPAI COUNTY, ARIZONA

by

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ILLUSTRATIONS

ABSTRACT

During the summers of 1948 and 1949 a study was made of the Supai formation which is a series of continental red beds and marine limestones of Pennsylvanian (?)-Permian age. Detailed field work was limited to a small area immedeately east of Chino Valley in Yavapai County, Arizona.

The field and laboratory work was supervised by staff members of the Geology Department of the University of Arizona, and the Museum of Northern Arizona. The study was made possible by a generous grant from the Viking Fund Inc. of New York.

Stratigraphic studies indicate that the Supai formation is an ancient delta deposit interbedded with marine limestones. Distribution of well-sorted detrital material over wide areas, studies of primary structures and the relationship of the red beds to the interbedded limestones are the basis for the above conclusion.

The formation has been divided in the area studied into two members, easily recognized in the field. The lower member is 145 to 156 feet thick and consists of a slope-forming unit of red sandstones and siltstones, capped by a cliff-forming unit of cherty limestone. A basal conglomerate is locally present.

The upper member consists of 1060 feet of alternating red sandstones and siltstones interbedded with a few strata of structureless claystone and some of aphanitic limestone. This member forms a cliff and slope type of topography.

Marine fossils collected from the limestones of the lower member are of poor preservation but suggest a Lower Pennsylvanian age for the basal Supai. If further studies bear out the above indications, then it may be established that the basal Supai was deposited by a regressive Pennsylvanian sea.

The contact between the Supai formation and the underlying Redwall limestone of Mississippian age is unconformable. A gradational contact is locally present between the Supai formation and overlying Coconino sandstone of Permian age.

CHAPTER I

Introduction

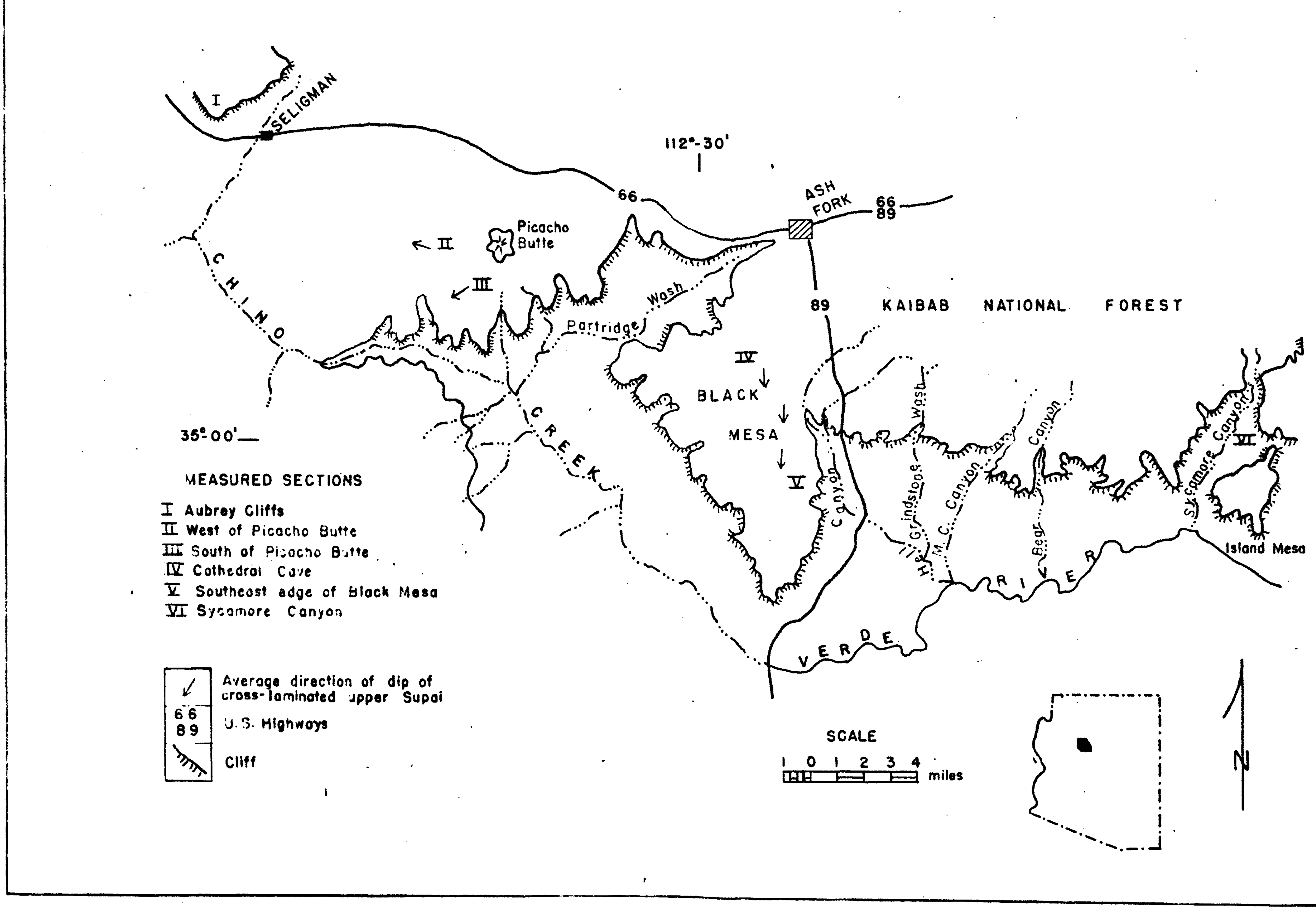
Purpose of investigation. The following report represents the detailed study, of a small part of a formation, which is both marine and continental in origin. The study concerns the stratigraphy of the Supai formation, its age, environment of deposition, and relationship to other formations of Paleozoic time.

Location and accessibility. The area studied lies within and along the northern boundary of the Prescott National Forest in Yavapai County, Arizona. It is bounded to the north by U.S. Highway 66, to the west and south by Chino Valley, and to the east by U.S. Highway 89 (Fig. 1). The area is completely surrounded and also bisected in a north-south direction by good roads. Numerous ranch roads and trails lead to nearly any desired locality.

Local industry. Cattle raising is the only large industry in the area studied. The major problem of this industry is the obtaining of water for stock use. This need is met in the mountain areas by the construction of earth dams (tanks) in ravines to impound rain water. In the larger valleys the water is furnished by wells.

Figure I.

INDEX MAP of AREA STUDIED



Stone quarrying is carried on in various localities. The Coconino sandstone which is exposed along the west side of Picacho Butte in T. 21 N., R. 5 W. (Fig. 1) and along the cliffs east of Black Mesa in T. 19 N., R. 1 and 2 E. is an excellent building and architectural stone. The thin-bedded sandstone is easily split along its bedding planes and the silica cement makes the stone very resistant to weathering. The largest quarry in the area is situated along Grindstone Wash in T. 19 N., R. 1 E. (Fig. 1). Exposures of the Coconino sandstone are plentiful and in the last named locality exceed 800 feet in thickness. The owners report receiving $15.00 a ton for the flagstone delivered to the railroad at Drake, Arizona (T. 19 N., R. 1 W.). The stone sold under the name of "Arizona flagstone" in Pacific coast cities at prices up to $85.00 a ton during 1948-1949.

Secondary deposits of calcium carbonate along the large fault within Black Mesa have been quarried with minor success. The rock formed is known as "Mexican or California Onyx" and is used for interior decoration. One such quarry is situated in Sec. 21, T. 20 N., R. 3 W. (Plate I) but has not been worked for several years. The "onyx" material is confined to the down-thrown block of the large fault in the fractured siltstones and sandstones of the Supai formation. Small outcrops of the "Mexican onyx" were noted in many localities other than that along the major fault.

Acknowledgements. Many people and organizations contributed to the field work and writing of this report. The writer wishes to thank the Museum of Northern Arizona for library and laboratory priviledges, and the Viking Fund of New York for financial assistance toward field and laboratory expenses. E. D. McKee, Assistant Director of the Museum of Northern Arizona supervised the project and gave the writer much assistance in the field, and he reviewed the manuscript. Others who aided this study are members of the Geology Department of the University of Arizona, Dr. H. Wanless of the University of Illinois, Mr. Dave Brodie and Mrs. P. W. Hughes.

CHAPTER II

Geography

Physiography. The area described in this paper lies along the border of the Basin-Range and Colorado Plateau Provinces as described by Fenneman[1]. The Supai formation was studied in two adjoining localities, the larger being Black Mesa (Fig. 1 and Plate I), lying south of Ashfork, Arizona and east of Chino Valley. The locality, which includes the other exposures, lies eight miles to the northwest of Black Mesa (Fig. 1 and Plate VII fig. 1) and is separated from it by lava flows and probably also by some faulting. The Supai exposures at the second named locality have a northwest trend parallel to Chino Valley.

Black Mesa is one of six localities in the State of Arizona[2] having the same name. It received its name in 1853 from Whipple[3], "because it was dark or black with Juniper trees." From the topographic map (Plate I) the

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1. Fenneman, N. M., Physiographic Provinces of Western United States, McGraw-Hill Book Co., 1931.

2. Barnes, W. C., Arizona Place Names, Univ. Ariz. Gen. Bull. No. 2, pg. 51, 1935.

3. Barnes, W. C., op. cit.

area may be seen to be in the youthful cycle of erosion, with many V-shaped canyons cutting headward toward the center of the Mesa. A distance of four and one-half miles separates the lowest point of elevation along Chino Valley (Plate I) in Sec. 30, T. 19 N., R. 3 W. (4500 feet) from the highest point on Black Mesa, in Sec. 10, T. 19 N., R. 3 W. (6100+ feet). The Paleozoic formations exposed on the Mesa are horizontal or, locally, dip at low angles. The most prominent physiographic feature is a northwest-trending fault which divides the Mesa as regards both drainage and geology.

To the west of Picacho Butte (Fig. 1) the Paleozoic formations are exposed in a west-facing cliff. The beds dip gently to the east forming a monocline which in the vicinity of the butte (Fig. 1) passes under flows of Tertiary basalt.

Drainage. Along the western slopes of Black Mesa all drainage is toward Chino Valley. Most of the intermittent stream gullies flatten out and disappear before reaching Chino Wash. Rain waters from the slopes of the Mesa sink into gravels and sands along the margins of the Valley without reaching the through drainage of Chino Wash.

In the central part of Black Mesa the drainage is controlled by a northwest-trending fault. A drainage divide along the fault is located at the eastern edge of Sec. 34, T. 20 N., R. 3 W. Water flowing northwest along the fault line enters Partridge Creek north of the area mapped and then into Chino Wash in Sec. 18, T. 20 N., R. 4 W. Along the southeastern side of the drainage divide, surface waters enter Hell Canyon (Fig. 1) approximately nine miles to the southeast. All drainage of the eastern slopes of the Mesa also is gathered in Hell Canyon.

Flora and Fauna. The climate of the area studied is that of the Upper Sonoran Zone. The flora and fauna of the area has been discussed by McKee[4].

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4. McKee, E. D., The Inverted Mountains, Vanguard Press, 1948.

CHAPTER III

General Geology

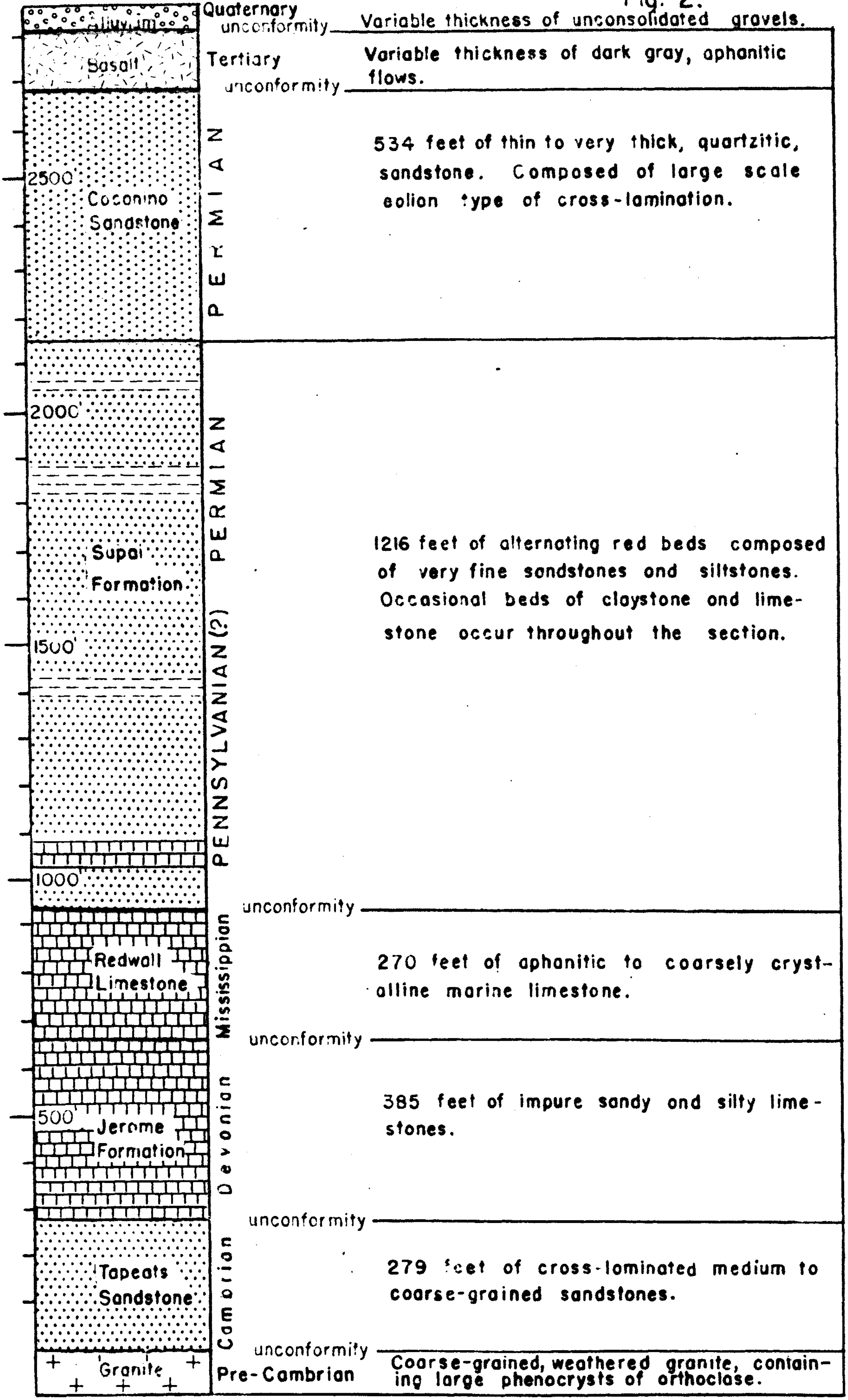
Summary. With the exception of Recent alluvium, the sedimentary rocks exposed within the area studied (Plate I) belong to the Paleozoic Era. Beginning with the Cambrian, all of the Paleozoic systems extend into the Permian with the Ordovician and Silurian systems being absent. The total thickness of Paleozoic deposits is relatively small (Fig. 2) throughout northern Arizona but increases westward towards the Cordilleran geosyncline which existed throughout the entire Paleozoic era.

The exposed igneous rocks in the area studied include limited outcrops of Pre-Cambrian granite upon which Cambrian sediments were deposited. Basalt flows of local origin (Plate VII Fig. 2) and Tertiary in age are widely exposed to the north and east of the area mapped. One small area of basalt in Sec. 23, T. 20 N., R. 4 W. (Plate I) was mapped.

Both the sedimentary and the igneous rocks of the area mapped are distributed over much of Northern Arizona.

Structure within the area is relatively simple and is limited to high angle normal faulting.

Fig. 2.


Alluvium
Quaternary
unconformity
Variable thickness of unconsolidated gravels.
Basalt
Tertiary
Variable thickness of dark gray, aphanitic flows.
unconformity
P E R M I A N
2500'
Coconino Sandstone
534 feet of thin to very thick, quartzitic, sandstone. Composed of large scale eolian type of cross-lamination.
2000'
PENNSYLVANIAN(?) P E R M I A N
Supai Formation
1500'
1216 feet of alternating red beds composed of very fine sandstones and siltstones. Occasional beds of claystone and limestone occur throughout the section.
1000'
unconformity
Mississippian
Redwall Limestone
270 feet of aphanitic to coarsely crystalline marine limestone.
unconformity
Devonian
500'
Jerome Formation
385 feet of impure sandy and silty limestones.
unconformity
Cambrian
Tapeats Sandstone
279 feet of cross-laminated medium to coarse-grained sandstones.
unconformity
Granite
Pre-Cambrian
Coarse-grained, weathered granite, containing large phenocrysts of orthoclase.

Sedimentary Rocks

Cambrian System.

Tapeats sandstone. The Cambrian System in the Grand Canyon region has been divided into three formations by Noble[5]. They are the Tapeats sandstone, Bright Angel Shale and Muav limestone. The lowermost of these is the Tapeats sandstone.

In the black Mesa area the Tapeats occurs with a variable thickness as it rests upon the uneven erosion surface of Pre-Cambrian granite. The maximum thickness observed is 279 feet of alternating fine- to coarse-grained sandstone and individual grains consist of rounded quartz particles cemented by silica, and in a few places by iron oxide. Exposures have a reddish-brown color and include many cross-laminated beds. The cross-laminated units are similar to the ones described by McKee[6] as "extensive, uninterrupted series of laminae dipping in one direction".

No diagnostic faunal material was obtained from the Tapeats sandstone although fossil worm borings were observed in a number of localities.

This formation has been described[7] as deposited in an "offshore environment".

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5. Noble, L. F., The Shinumo Quadrangle, Grand Canyon District, Arizona, U.S. Geol. Surv. Bull. 549, pp. 61-65, 1914.

6. McKee, E. D., Cambrian History of the Grand Canyon Region, Carnegie Inst. Wash., Publ. 563, pg. 43, 1945.

7. McKee, E. D., op. cit. pg. 49.

The Cambrian formations that lie above the Tapeats sandstone in the walls of Grand Canyon (Bright Angel shale and Muav limestone) are not found in the Black Mesa area. Whether this was an area of non-deposition or extensive post-Cambrian erosion is not known to the writer.

Devonian System.

Jerome Formation. Devonian strata of central Arizona were named the Jerome formation by Stoyanow[8.] in 1936.

The contact of the Tapeats sandstone with the overlying Devonian limestone is sharp. At no place was any evidence of an erosional surface observed in the area studied, making difficult the realization that deposits of Ordovician and Silurian periods are entirely lacking here.

The Jerome formation along the western front of Black Mesa is composed of 385 feet of impure sandy and silty limestone. It is dark gray in color and forms an alternating cliff-and-slope type of topography. Tests in the field revealed that some of the units are dolomitic and when struck with a hammer give off a petroliferous odor. Probably the most distinctive feature of the Jerome formation is that because of included impurities of sand and silt, the limestone cliffs weather to rough and very sharp surfaces.

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8. Stoyanow, A. A., Correlation of Arizona Paleozoic formations, Bull. Geol. Soc. Amer., Vol. 47, p. 495, 1936.

A search was made by the writer in a number of localities for fossiliferous material but none was found. The sandy, dolomitic limestones probably represent a depositional environment which was unfavorable to marine fauna, or the fauna were destroyed by dolomitization.

Mississippian System.

Redwall Limestone. The maximum known thickness of the Redwall limestone within the area studied is 275 feet. This thickness is believed to represent nearly all of the Redwall limestone that existed at the beginning of Supai deposition. A section measured by Gutschick[9.] at Black Mesa in Sec. 31, T. 19 N., R. 2 W. shows 275 feet of Redwall underlain by the Jerome formation and capped by large blocks of residual Supai material.

The Redwall limestone was named by Gilbert[10.] in 1875 and included both Mississippian and Devonian deposits. In 1923 Noble[11.] redefined the Redwall to include only those rocks of Mississippian age. Recent work[12.] has revealed that

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9. Gutschick, R. C., The Redwall Limestone (Mississippian) of North Central Arizona, PhD. Thesis (unpublished), Univ. of Ill., pp. 18-26, 1942.

10. Gilbert, G. K., U.S. Geog. and Geol. Surveys W. 100th Mer. Rept., Vol. 3, pp. 161, 162, 177, 178, 185, fig. 82, 1875.

11. Noble, L. F., op. cit.

12. Gutschick, R. C., personal communication, 1949.

the Redwall limestone is composed of rocks of the Kinderhook and Osage groups.

At its base the Redwall is, in general, finely crystalline to aphanitic and resembles the underlying Jerome formation. Beds of chert are common in the lower portions of the Redwall formation. The upper part of this limestone is predominately coarsely crystalline and forms massive cliffs.

The base of the Redwall limestone rests upon the Jerome formation unconformably. The exact boundary is difficult to ascertain in this area as the two formations are similar near the contact. The boundary is located by the author along a gently undulating surface of limestone which has a reddish tinge due to included silts.

Pennsylvanian (?) and Permian Systems.

Supai Formation. The type locality of the Supai formation is in Havasu Canyon which is located in the Central Grand Canyon region. This formation was named by Darton.[13]

A pronounced unconformity exists between the Supai formation and the underlying Redwall limestone. Locally (S.E. ¼ Sec. 4, T. 20 N., R. 3 W.) an unknown thickness of conglomerate of the Supai formation lies upon the Redwall. The cobbles and pebbles of this conglomerate consist of Redwall limestone (Fig. 3 and Plate VIII fig. 2).

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13. Darton, N. H., A Reconnaissance of parts of Southwestern New Mexico and Northern Arizona, U.S. Geol. Surv. Bull. 435, pg. 25, 1910.

A single, complete section of the Supai formation is lacking in the Chino Valley area. A thickness of 1216 feet was obtained from a composite section of several localities.

The Supai formation consists of two members. The basal one is 145 to 156 feet thick and is composed of slope-forming beds of sandstone and siltstone capped by thick beds of cliff-forming cherty limestone. Thin beds of red siltstone are interbedded with the cherty limestone units.

The upper member of the Supai formation consists of siltstones and sandstones of various shades of red which form alternating cliffs and slopes. Scattered beds of claystone and aphanitic limestone are found in the upper member. The maximum known thickness of the upper member is 1060 feet.

Only the lower member of the Supai formation is known to be fossiliferous in the area studied. Fragmental remains of marine fauna are to be found in the cherty limestone units of the lower member.

The Supai formation represents an interfingering of marine limestones and detrital sediments of continental origin.

Permian System.

Coconino Sandstone. The sandstones of the Coconino formation were named by Darton[14]. Distribution of this formation is extensive over northern Arizona and southern Utah.

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14. Darton, N. H., op. cit. pp. 21-27, 1910.

The contact between the Coconino sandstone and the underlying Supai formation is gradational (Fig. 4).

Detailed work by others[15.16.] has shown an eolian origin for the Coconino sandstone. Within the area mapped (Plate I) the Coconino has been stripped by erosion, but west of Picacho Butte (Fig. 1), 534 feet of this formation overlies the Supai.

The formation is composed almost entirely of fine- to medium-grained quartz cemented by silica. The individual beds are very thin to very thick and consist almost entirely of cross-laminated wedges dipping in many directions.

In all exposures the Coconino sandstone is a cliff-forming unit. The thickness at its many exposures is variable as would be expected of an eolian deposit.

The bedding planes of the cross-laminated Coconino yield excellent fossil reptile tracks. Rain or hail prints have also been observed.

Cenozoic System.

Recent Alluvium. The unconsolidated to poorly consolidated alluvium which covers the surface of hills and washes alike is composed of gravels having a local origin.

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15. McKee, E. D., The Coconino Sandstone, Carnegie Inst. of Wash. Publ. No. 440, 1934.

16. Reiche, P., An Analysis of Cross-lamination: The Coconino Sandstone, Jour. of Geology, Vol. 46, No. 7, 1938.

Two ages of gravel are recognized; an older that forms gently sloping terraces now being dissected, and a younger is developing from present day erosion of all rock units. The older, weakly consolidated gravels are to be found along the west slopes of Black Mesa (Plate I) and stand at higher elevations than the alluvium now occupying Chino Valley.

The two ages of gravels have been grouped together for the purpose of mapping.

Igneous Rocks

Pre-Cambrian Granite. Along the base of the cliffs of Black Mesa (Plate I) and in the deeper ravines such as Partridge Wash (Fig. 1) outcrops of granite are numerous. The granite is coarsely crystalline with large phenocrysts of pink orthoclase and abundant quartz and biotite. All exposures observed are highly weathered and jointed.

Tertiary Basalt. Thick accumulations of basalt are exposed north and east of the area mapped. Only one outcrop was observed within the area mapped (Sec. 23, T. 20 N., R. 4 W.). The basalt is of local origin and many feeder dikes were observed throughout Black Mesa and Chino Valley. One such dike is shown on Plate VII fig. 2.

The basalts are medium to dark gray and many of them contain phenocrysts of olivine. All of the flows and dikes observed are aphanitic with dense to scoriaceous texture.

Structure

Faulting. The Paleozoic beds of Black Mesa are for the most part horizontal. In most areas (Plate I) where the dips exceed 2°, high angle normal faulting is implied.

Three small normal faults were recognized within the area mapped (Sec. 22, T. 20 N., R. 4 W.; Sec. 9, T. 19 N., R. 3 W.; and Sec. 13, T. 19 N., R. 3 W.). The displacement apparently does not exceed 50 feet along any one of them.

A northwest trending fault which is at least 19 miles in length and parallel to Chino Wash divides Black Mesa into two different geologic units (Plate I). The area to the southwest of the fault is composed of Paleozoic formations of Mississippian age and older. To the northeast of the fault, with exception of one small area of Mississippian limestone (Sec. 16, T. 20 N., R. 3 W.), strata of the Pennsylvanian (?)-Permian System are exposed.

North of the area mapped, the large fault was traced for approximately two miles to where it disappeared under the Tertiary basalts. Southeast of the area this same fault was traced for nine miles to a point where it disappears under Recent alluvium.

The displacement of the larger fault was measured near the northern edge of the area mapped (Sec. 16 and 17, T. 20 N., R. 3 W.) and is believed to be nearly 525 feet in magnitude. The Redwall limestone is exposed on both sides of the fault and is known to be 275 feet thick in this area; therefore the base of the Redwall limestone in Sec. 16, T. 20 N., R. 3 W. should be near an elevation of 5075 feet. On the upthrown block of the fault the base of the Redwall limestone is near the 5500 foot contour.

At its northern edge the fault splits into two components leaving a horst dipping 10° to the northeast between them. The western component of the fault differs from all other observed exposures in that its trend is along a knifelike ridge. The fault zone along the ridge is silicified and therefore more resistant to weathering than the limestones of the Redwall formation or the sandstones of the Supai formation.

The writer believes the age of the fault to be pre-Tertiary basalt, as the fault disappears under the basalts to the north and they show no visible displacement. This belief is strengthened by the lone outcrop of basalt in Sec. 23, T. 20 N., R. 4 W. (Plate I), which lies several hundred feet above exposures of basalt to the north of the area mapped.

CHAPTER IV

Stratigraphy of the Supai Formation in the Black Mesa Area.

Historical Review. No attempt has been made to review all the voluminous literature pertaining to the Supai formation. Only those works having a direct bearing upon its stratigraphy within the Black Mesa and contiguous localities have been reviewed.

The first geological investigation of northern Arizona was made by Jules Marcou[17] in the year 1853. In the vicinity of the Little Colorado River, Marcou observed a "Magnesium Limestone" (Kaibab limestone) which he correctly identified as Permian in age. This is noteworthy in that it marks the first recognition of Permian strata in the United States at a time only 13 years after Murchison established the Permian system in Russia.

The area in the vicinity of Partridge Wash was visited in 1857-58 by an expedition under the command of Lt. Joseph C. Ives[18]. The geologist accompanying this expedition,

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17. Marcou, Jules, Geology of North America, Zürcher and Furrer, Zurich, Switzerland, 1858.

18. Ives, J. C., Report upon the Colorado River of the West, Ex. Doc., 1st Session of the 36th Congress, U.S, Senate, 1861.

Dr. J. S. Newberry, disagreed with Marcou, stating[19] that no rocks were "more recent than the Carboniferous Epoch" in this region (Northern Arizona).

The controversy arising from the reports of Marcou and Newberry affected geologic thought for many years to follow. Many of the early American geologists were in agreement with Newberry and for this reason the Supai formation was considered much older than it is considered today.

Many papers, written in the late 19th and early 20th centuries concerning the Supai and other Paleozoic formations of Northern Arizona, have been abstracted by Darton[20].

The term Supai formation[21] was introduced by Darton to a series of red sandstones and shales, the type locality being in Havasu (Cataract) Canyon, which drains into the Grand Canyon of the Colorado 85 miles north of Black Mesa. The formation was redefined by Noble[22] in 1922 after detailed studies at Bass Trail in the Grand Canyon. The top 300 feet of red beds was removed from the Supai and made a separate

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19. Newberry, J. S., in Ives, J. C., op. cit., pg. 71.

20. Darton, N. H., A resume' of Arizona geology, Univ. of Ariz., Coll. of Mines Bull. No. 119, 1925.

21. Darton, N. H., A Reconnaissance of parts of southwestern New Mexico and northern Arizona. U.S. Geol. Surv. Bull. 435, pg. 25, 1910.

22. Noble, L. F., A section of the Paleozoic formations of the Grand Canyon at the Bass Trail, U.S. Geol. Surv. Prof. Paper 131-B, pg. 59, 1922.

formation named the Hermit shale. It is described as consisting of a "deep brick-red sandy shale and fine-grained friable sandstone of Permian age." Another change involved "250 feet of a red sandy shale, purplish and gray limestone with red chert and reddish to buff calcareous sandstone of Pennsylvanian age" which formerly had been included with the Redwall limestone, but was added to the base of the Supai formation.

When redefining the Supai formation, Noble was of the opinion that it was entirely of Pennsylvanian age. Darton[23], in a later publication, stated "that most, if not all, of the red strata are of Permian age". Darton[24] believed also that the lower member, added to the Supai by Noble, was of Pennsylvanian age andshould be separated from the Supai "as soon as suitable field work is done to define it".

Longwell[25], in his studies of the Supai in the extreme western part of Arizona states, "fossils of probable Pennsylvanian age at the top of the lower Grand Wash Cliff indicate that the Permian does not extend to the base of the Supai".

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23. Darton, N. H., A resume' of Arizona geology, Univ. of Ariz. Coll. of Mines, Bull. No. 119, pg. 84, 1925.

24. Darton, N. H., op. cit., pg. 79.

25. Longwell, C. R., Geology of the Muddy Mountains Nevada, U.S. Geol. Surv. Bull. 798, pg. 37, 1928.

Recent stratigraphic work by Huddle and Dobrovolny[26] has resulted in an attempt to define more closely the age of the Supai formation. They state, "The formation transgresses time lines and probably varies in age from DesMoines through Leonard".

Evidence for the above statement is based in part on the determination of fossils[27] in the Fort Apache and adjoining areas, nearly 150 miles southeast of Black Mesa.

An interpretation of the Supai appears to be wanting up to 1929. Glock[28] has reported that "all the characteristics of the Supai seem to require a semi-arid climate, shallow shifting waters, and continental conditions, in part at least". White[29] referred to the upper and middle parts of the Supai as "terrestrial deposits -- laid down on an old flood plain". Further evidence as to the type of depositional agent involved, is indicated by the primary structures studied by McKee[30].

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26. Huddle, J. W., and Dobrovolny, E., Late Paleozoic stratigraphy and oil and gas possibilities of central and northeastern Arizona, U.S. Geol. Surv., Oil and Gas Invest. Prelim. Chart 10, 1945.

27. McKee, E. D., Personal Communication, 1950.

28. Glock, Waldo, Geology of the east-central part of the Spring Mountain Range, Nevada, Amer. Jour. of Sci., Vol. 17, pg. 332, 1929.

29. White, David, Flora of the Hermit shale, Grand Canyon, Arizona, Carnegie Inst. Wash., Publ. 405, pg. 10, 1929.

30. McKee, E. D., Three types of cross-lamination in Paleozoic rocks of Northern Arizona, Amer. Jour. of Sci., Vol. 238, pg. 822, 1940.

On the basis of cross-lamination studies made in the Supai and compared with similar studies on modern deltas, McKee considered the Supai formation to be a deltaic or flood plain deposit. Studies by Stoyanow[31] make reference to the early Supai as "broad, shallow brackish and fresh-water bodies."

Lithology of Supai Formation at Measured Sections. Four sections of the Supai formation were measured within the area studied (Fig. 1). Two of these were measured at Black Mesa; one in the southeast corner, and the other along the northern boundary. The remaining two were measured in the vicinity of Picacho Butte which lies approxomately eight miles northwest of the Mesa. No complete section was measured at any one locality. An attempt has been made to correlate these stratigraphic sections with two measured by E. D. McKee, one twenty miles northwest of Picacho Butte at Aubrey Cliffs, the other nearly twenty-five miles east of the southeast corner of Black Mesa in Sycamore Canyon.

A standard procedure was used in recording the data of the measured sections in the hope that correlation could be affected by one or a combination of several techniques. Correlation was attempted (1) upon the basis of similar vertical changes in lithology, (2) by the use of key beds,

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31. Stoyanow, Alexander, Paleozoic paleogeography of Arizona, Bull. Geol. Soc. Amer., Vol. 53, pg. 1275, 1942.

(3) by faunal zones, (4) by comparison of gross units (i.e. cliff and slope forming units), (5) by comparing color of beds and types of cross-bedding. The first three of these techniques were helpful.

Correlation of minor units with those of the Sycamore Canyon section (Plate II) measured by McKee was not possible as the profile and thickness of the individual beds differ greatly in the two areas.

The Supai formation of the area studied has been divided by the writer into two major units based on lithology. These differ from the three member of Huddle and Dobrovolny[32], who base their division primarily upon topographic expression.

The basal member of the Supai formation in the Black Mesa area lies unconformably on the Redwall limestone. This member consists of a slope unit of red siltstone (concealed in most places) overlain by thick beds of cherty limestone alternating with thin layers of red siltstone. Locally, thick beds of angular to sub-rounded conglomerate form the base of the Supai formation and rest directly upon the Redwall limestone. This lower member corresponds in stratigraphic position to the Pennsylvanian calcareous sandstone

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32. Huddle, J. W., and Dobrovolny E., Late Paleozoic stratigraphy and oil and gas possibilities of central and northeastern Arizona, U.S. Geol. Surv. Oil and Gas Invest. Prelim. Chart 10, 1945.

which Noble[33] included with the Supai formation (redefined), and it also corresponds, at least in part, in lithology. The thickness of this lower member as measured in four localities, ranges from 145 feet to 155 feet. Marine fossils collected from two localities indicate a Pennsylvanian age for the lower beds, and these deposits, at least, may be contemporaneous with the limestone in the Grand Canyon section believed to be of Pennsylvanian age.

The upper member of the Supai formation, as recognized in the Black Mesa area, consists of alternating beds of siltstone and very fine sandstone with a few interbedded claystones and sandy or cherty limestones. The detrital sediments are of various shades of red and brown. Individual beds are relatively thin in comparison with those of the well-known sections in Grand Canyon to the north, and also with those of Oak and Sycamore Canyons to the east. Beds are less than 10 feet in thickness and do not have the massive appearance of many in the localities referred to above. This upper member is thicker than the lower, and in the section west of Picacho Butte is nearly 1,000 feet thick. To the southeast of Picacho Butte, the upper member as measured is from 350 to 500 feet in thickness, and an additional but unknown amount has been removed by erosion.

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33. Noble, L. F., A section of the Paleozoic formations of the Grand Canyon at the Bass Trail, U.S. Geol. Surv., Prof. paper 131-B, pg. 59, 1922.

A gradational zone between the Supai and Coconino formations is exposed along the southern rim of the Kaibab National Forest, a few miles north of the Verde River (Fig. 1) and in the area west of Picacho Butte. Truncated wedges of cross-laminated Coconino sandstone are interbedded with flat-bedded Supai-type sediment, some of which shows typical Supai cross-lamination patterns (Fig. 4). A more complete discussion of this feature is on page 30.

Quantitative studies of the measured sections were made (Plates III, IV, V, VI) to give an estimate of the percentage of rock types present and of the predominate cements. The writer does not believe the percentages given to be precise measures but they are undoubtedly more accurate than estimates based on general impressions. With the exception of the deposits in one bed, all detrital material is less than 1/8 mm in size. Claystone underlies an unknown percentage of the concealed slopes, and though other sediments may also be represented in these weak beds, they were classed entirely as claystone in making computations.

These quantitative estimates indicate a preponderance of calcareous cement. Nearly all beds contain iron oxide but where acid loosens the individual grains, iron oxide was not considered as a cement. Longwell[34] indicates that

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34. Longwell, C. R., Geology of the Muddy Mountains Nevada, U.S. Geol. Surv., Bull. 798, pg. 35, 1928.

calcium carbonate is the principal cement in some of the sandstone units in Grand Wash Cliffs near the Arizona-Nevada boundary.

Distribution. Exposures of the Permian Supai formation in northern and northeastern Arizona indicate that it originally covered one third of the state, as indicated by Stoyanow[35]. Beds of this formation extend from near the Arizona-New Mexico boundary westward across the entire northern portion of Arizona and southern Utah and into southern Nevada. These beds, according to Darton[36], are of nearly uniform thickness (1100 - 1200 feet) over much of the area of their outcrop.

Type of Deposit. Red beds have been described[37] as being deposited both under marine and under fluvial conditions. Those of the Supai formation have been shown, through several types of evidence in the Black Mesa and contiguous areas, to be classified as deltaic deposits. The basal Supai, on the other hand, contains much limestone and is predominately of shallow marine origin.

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35. Stoyanow, Alexander, Paleozoic paleogeography of Arizona, Bull. Geol. Soc. Amer., Vol. 53, Pl. 5, 1942.

36. Darton, N. H., A resume' of Arizona geology, Univ. of Ariz. Coll. of Mines, Bull. No. 119, pg. 81, 1925.

37. Twenhofel, W. H., Principles of Sedimentation, McGraw-Hill Book Co., 1st Edit., pg. 315, 1939.

Evidence for a deltaic origin is: (1) distribution of well-sorted particles of the red bed material over wide areas (page 24), (2) a thickness of 1,000 feet or more of alternating layers of siltstone and very fine sandstone. Statistical studies of the four measured sections (Plates III, IV, V, VI) indicate that less than 1 percent of the detrital sediments contain particles greater in size than very fine sand. These particles are composed chiefly of quartz and clay minerals, with mica as a minor constituent. The cementing medium is predominately calcium carbonate. Observations made at Grand Canyon to the north and Oak Creek Canyon to the east indicate similar relationships. General lack of fossils in the red bed material favors a deltaic origin under oxidizing conditions. Fossils found in the Supai red beds[37]. of the Grand Canyon area include land plants and the tracks of vertebrate animals, but no marine fossils. Algal limestones are known in the middle and lower sections of the Supai formation in Grand Canyon[38]..

Cross-lamination studies made in the Black Mesa area are indicative of fluviatile deposition. Analysis of these cross-laminated units is discussed separately (pg. 34).

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38. White, David, Flora of the Hermit Shale, Grand Canyon, Ariz., Carnegie Inst. Wash., Publ. 405, pg. 10-11, 1929.

39. White, David, op. cit., pg. 11.

Limestone units are believed to represent deposits formed during marine invasions of the channels in the Supai delta, are at irregular intervals throughout the formation. Like the siltstones and sandstones, these limestone beds in most places are thin and of limited lateral extent, grading into detrital sediments within a few tens of feet.

Channeling, or scour and fill, (Plate VIII Fig. 1) is common in modern delta deposits. Ancient channels observed in the Supai formation are similar to those of the present day Colorado River delta[40].

Deep wells penetrating the entire formation disclose that nearly all beds are of various shades of red and brown. Thus on the unexposed portions, as well as the exposed surface, the rock colors are the same and therefore must be primary. Twenhofel[41] contends "that many parts of the 'Red Beds' were deposited in a subaerial environment with warm and relatively dry climate and that fluvial processes played a large part in the deposition and that other parts were deposited in standing bodies of shallow water of a salinity sufficiently high to prevent activity of sulphate-reducing bacteria".

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40. McKee, E. D., Some types of bedding in the Colorado River delta, Jour. of Geol., Vol. 47, pl. II, 1939.

41. Twenhofel, W. H., Principles of sedimentation, McGraw-Hill Book Co., pg. 318, 1939.

The conclusions reached in studies by Krynine[42] differ in part with Twenhofel. Krynine states that "At least 95 per cent of present day red soils are formed above 60° F. and 40" (of rainfall)".

Chert and such primary structures as ripple marks and mud cracks are to be found throughout the entire formation. These features are discussed in detail in chapter

The relationship with the overlying Coconino sandstone (pg. 30) indicates fluvial deposition for the Supai formation.

The few beds of structureless mudstones are of flood plain origin and it is quite possible that other environments are responsible for minor amounts of sediment.

Supai-Redwall Contact. Within Black Mesa only one locality is known in which the disconformity between the Redwall and Supai formations is exposed. In all other areas studied by the writer, talus from the slope-forming units of the Supai formation conceals the contact between the two formations. A pronounced stratigraphic break between these two formations has been noted in other localities[43.-44.].

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42. Krynine, Paul D., The origin of red beds, Trans. N.Y. Acad. Sci., Series II, Vol. 2, No. 3, pg. 61, 1949.

43. Darton, N. H., A resume' of Arizona Geology, Univ. of Ariz., Bull. No. 119, Coll. of Mines and Engin., pg. 80, 1925.

44. Gutschick, R. C., The Redwall limestone (Mississippian) of North Central Arizona, PhD thesis (unpublished), Univ. of Ill., pg. 4, 1942.

In the S.E. ¼ Sec. 4, R. 3 W., T. 20 N., a basal conglomerate, with a matrix of red siltstone and sandstone of the Supai formation, lies upon an uneven erosion surface of the Redwall limestone (Fig. 3). Angular to sub-rounded boulders of limestone and chert up to 20 inches in diameter were observed. The chert fragments are rare in comparison with the limestone, and sorting of the conglomeratic material is poor. Based upon lithology, the source of the limestone and chert appears to be the underlying Redwall formation.

Thin beds of red sandstone and siltstone are interbedded with the poorly sorted conglomerate. Some beds consist of coarse-grained, well-rounded, quartz particles having the size and shape of the constituents of the Cambrian Tapeats sandstone. The only formations older than the Supai which could have furnished the sand particles are the Tapeats sandstone, the pre-Cambrian quartzite, or the pre-Cambrian granite. The sandstone and granite are exposed a mile and a half west of the locality being described; and the pre-Cambrian quartzite is exposed along the south side of Chino Valley and in Grand Canyon.

The base of the conglomerate is not exposed but is known to be at least fourteen feet thick.

Approximately twelve miles south of the above locality Gutschick[45.] observed "several large blocks of coarse

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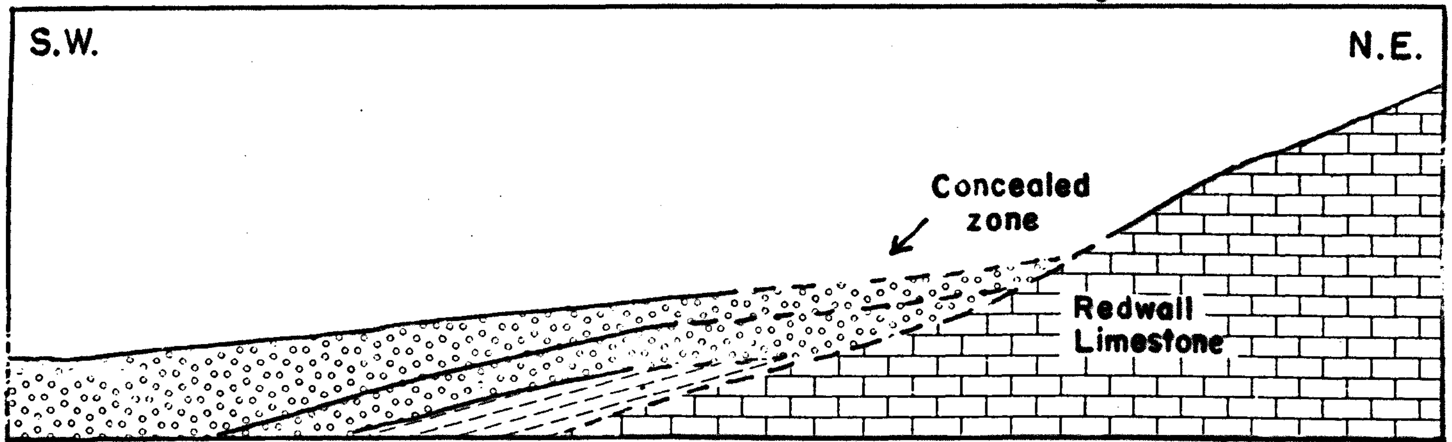
45. Gutschick, R. C., op. cit., pg. 18.

Figure 3.



Cross-sectional sketch (1" = approx. 15') of the unconformity between the Redwall limestone and the basal conglomerates and shaly sandstones of the Supai formation in Sec. 4, T. 20 N., R. 3W.

Beds of the Supai formation dip 8° to 16° to the southwest.

conglomerate (limestone and chert pebbles in a maroon, sandy matrix)" lying on the Redwall limestone. Gutschick believed these to have been remnants of a local basal conglomerate of the Supai formation.

The lower member of the Supai formation has been described as inter-bedded marine and continental deposits (pg. 22). A sequence of this type is indicative of a near shore environment and an oscillating sea over a pre-Supai surface of low relief.

Supai-Coconino Contact. Favorable exposures for the study of the contact between the Supai and Coconino formations are in a number of localities contiguous to the Black Mesa area. A nearly continuous outcrop of this contact is along the southern rim of the Kaibab National Forest from Sec. 36, R. 1 E., T. 19 N., in Bear Canyon, northwestward to Sec. 3, R. 1 E., T. 19 N., near Grindstone Wash (Fig. 1).

In a northwesterly direction, the next exposure of these two formations is in Sec. 1, R. 5 W., T. 21 N., two miles west of Picacho Butte and thirty miles from the exposure in Grindstone Wash. Beds of the Supai formation are exposed in this thirty-mile interval, but erosion has stripped away the Coconino sandstone (Fig. 1).

The contact between the Supai and Coconino formations in these localities is gradational with beds of Coconino sandstone intertonguing with those of the Supai formation.

This relationship is in marked contrast to the sharp, non-gradational contact of these same formations in the western and central Grand Canyon sections, 75 miles to the north. It is to be noted, however, that in Grand Canyon sections, the Coconino sandstone lies upon the Hermit shale, a formation which is either missing or indistinguishable in the area studied by the writer. This gradational contact was noted by McKee[46]. in the vicinity of Tanners Trail in the extreme eastern edge of Grand Canyon.

West of Picacho Butte, (Sec. 1, R. 5 W., T. 21 N.), 1072 feet of Supai siltstone is capped by 513 feet of Coconino sandstone. This is the thickest section of Supai measured. On top of it lies 49 feet of typical Coconino sandstone with truncated wedge-type of cross-lamination. This in turn is covered by 16.5 feet of flat-bedded Supai which thickens perceptibly to the east.

The topography at the locality west of Picacho Butte is favorable to the study of the Supai-Coconino contact relationship in three dimensions. Figure 4 shows clearly that, at least locally, deposition of some Coconino material was simultaneous with that of some Supai-type sediment. At the base of the gradational series, the Supai is composed of a shaly siltstone, covered by cross-bedded siltstone, and this

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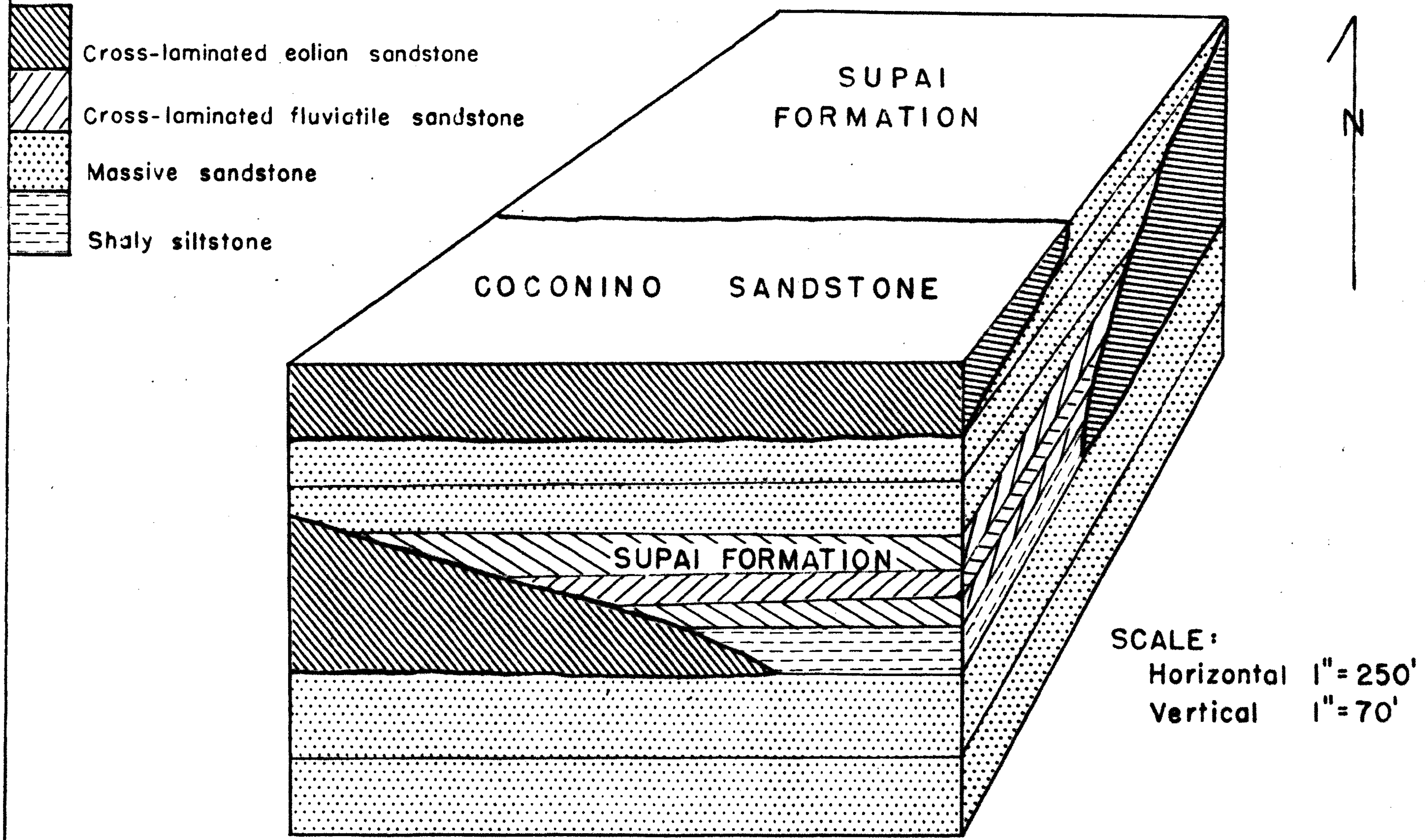
46. McKee, E. D., The Coconino Sandstone, Carnegie Inst. of Wash., Publ. No. 440, pg. 86, 1934.

in turn is followed by massive, thick-bedded layers of siltstone. These beds, together with their relationship to the Coconino, give evidence that the shaly siltstone layer was deposited in a distributary of the Supai that was nearly choked by sands. This was covered by cross-bedded silts of the normal Supai type, indicating a rejuvenation of Supai deposition toward the northwest (Fig. 4). Finally, the massive, thick-bedded siltstone was deposited, and it indicates relatively quick deposition and rapid sinking of the Supai basin.

Several flat-bedded deposits, having a calcareous cement were noted stratigraphically higher in the Coconino at this same locality. One such unit was found 424 feet above the lowest unit assigned to the transition zone between the Supai and Coconino. It is assumed that these flat beds are also of water-lain origin. Their lateral extent is limited to a few tens of feet. It is possible that the calcareous cement is secondary and that the beds represent deposition in small pools of rain water in depressions of the wind-blown surface during Coconino deposition, rather than floodplain deposits. Evidence of rains is locally found in the form of rain or hail prints in exposures of Coconino sandstone.

Along the southern border of the Kaibab National Forest similar relationships demonstrating a gradational contact are found. In Sec. 3, R. 1 E., T. 19 N., 284 feet of



Three-dimensional sketch of the gradational contact between the Supai formation and the Coconino sandstone.

Figure 4

Supai is exposed in which the upper 106 feet displays intertonguing with Coconino sandstone. Worm borings are numerous in Coconino-like material which appears to have been partially reworked by Supai waters.

In many of the small canyons that empty into the Verde River, similar contact relationships are to be seen. Along the Drake-Perkinsville road in M.C. and Bear Canyons (Fig. 1), flat beds are exposed high up in the cliffs of Coconino sandstone. These beds are similar to the upper flat beds west of Picacho Butte in that they grade laterally into typical Coconino material. It is not known by the writer, however, if they have any relationship to Supai deposition.

The writer is in agreement with Huddle and Dobrovolny[47.] in arbitrarily drawing the contact "at the base of lowest massive sandstone with well-developed Coconino-type cross-bedding".

Interesting conclusions can be reached from the above field evidence. First, it is apparent that at least locally these two formations are conformable. Secondly, it seems probable that Supai deposition lasted longer in this area than elsewhere. Finally, though the basin must have continued to sink during the early stages of Coconino deposition,

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47. Huddle, J. W., and Dobrovolny, E., Late Paleozoic Stratigraphy of central and northeastern Arizona, U.S. Geol. Surv. Oil and Gas Invest. Prelim Chart 10, 1945.

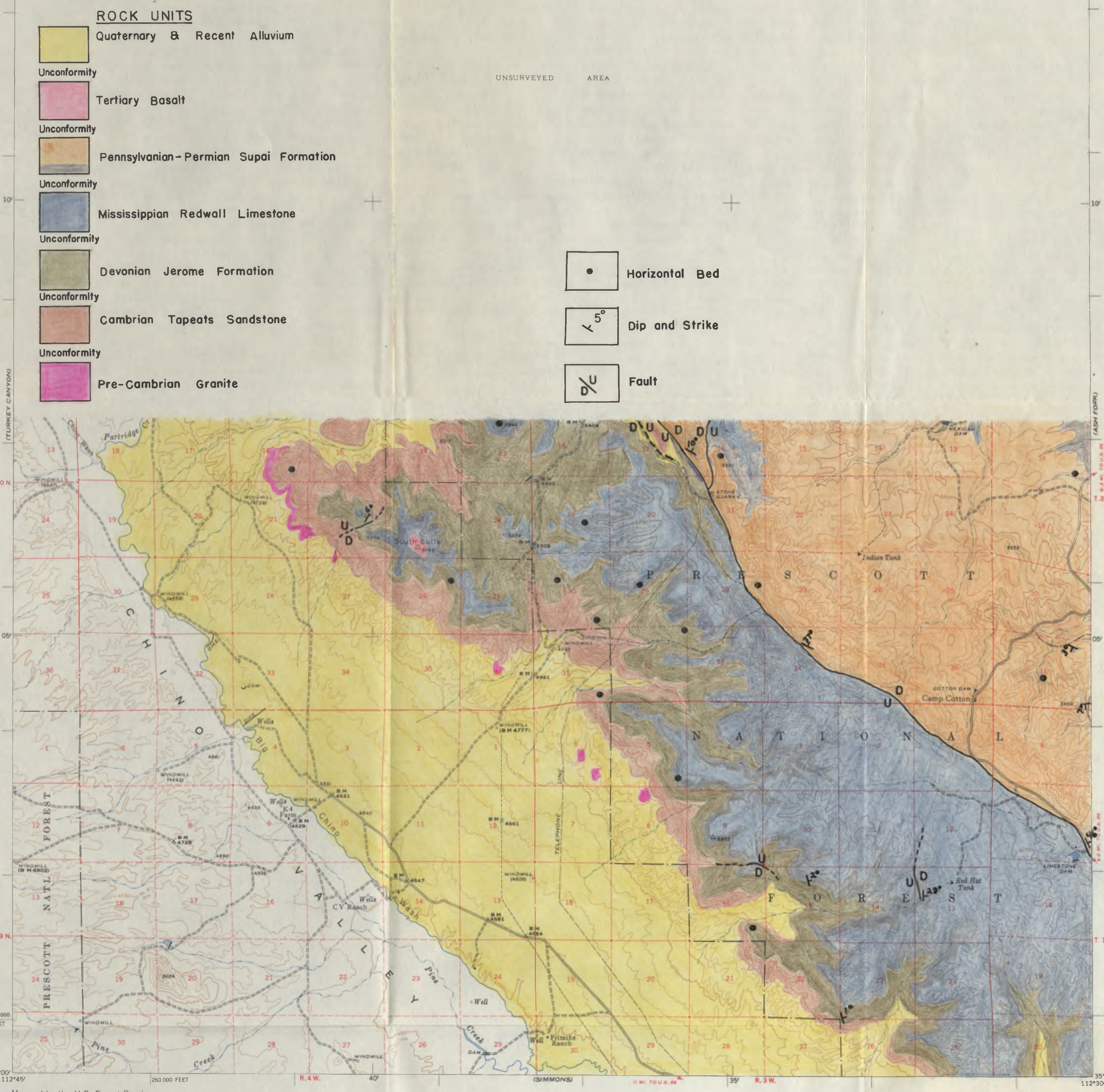
UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

UNITED STATES
DEPARTMENT OF AGRICULTURE
FOREST SERVICE

PICACHO BUTTE QUADRANGLE
ARIZONA-YAVAPAI CO.
15 MINUTE SERIES (TOPOGRAPHIC)

PLATE I.

GEOLOGIC MAP of the WESTERN PORTION of BLACK MESA YAVAPAI COUNTY, ARIZONA



Mapped by the U.S. Forest Service
Edited and published by the Geological Survey
Control by U.S. Forest Service, USGS and USC&GS

Topography from aerial photographs by KEK plotter
Aerial photographs taken 1946. Field check 1947

Polyconic projection. 1927 North American datum
10,000-foot grid based on Arizona coordinate system, central zone

No distinction is made between dwellings, barns, commercial, and industrial buildings

Dashed land lines indicate approximate location

APPROXIMATE MEAN DECLINATION, 1947

SCALE 1:62500

CONTOUR INTERVAL 50 FEET
DATUM IS MEAN SEA LEVEL

ROAD CLASSIFICATION
HARD-SURFACE ALL WEATHER ROADS / DRY WEATHER ROADS
Heavy-duty / Improved dirt
Medium-duty / Unimproved dirt
Loose-surface, graded, or narrow hard-surface
U. S. Route / State Route

PICACHO BUTTE, ARIZ.
N3500—W11230/15

EDITION OF 1950

THIS MAP COMPLIES WITH NATIONAL MAP ACCURACY STANDARDS
FOR SALE BY U. S. GEOLOGICAL SURVEY, DENVER, COLORADO OR WASHINGTON 25, D. C.

THE TOPOGRAPHIC MAPS OF THE UNITED STATES

The United States Geological Survey is making a series of standard topographic maps to cover the United States. This work has been in progress since 1882, and the published maps cover more than 47 percent of the country, exclusive of outlying possessions.

The maps are published on sheets that measure about $16\frac{1}{2}$ by 20 inches. Under the general plan adopted the country is divided into quadrangles bounded by parallels of latitude and meridians of longitude. These quadrangles are mapped on different scales, the scale selected for each map being that which is best adapted to general use in the development of the country, and consequently, though the standard maps are of nearly uniform size, the areas that they represent are of different sizes. On the lower margin of each map are printed graphic scales showing distances in feet, meters, miles, and kilometers. In addition, the scale of the map is shown by a fraction expressing a fixed ratio between linear measurements on the map and corresponding distances on the ground. For example, the scale $\frac{1}{62,500}$ means that 1 unit on the map (such as 1 inch, 1 foot, or 1 meter) represents 62,500 of the same units on the earth's surface.

Although some areas are surveyed and some maps are compiled and published on special scales for special purposes, the standard topographic surveys and the resulting maps have for many years been of three types, differentiated as follows:

1. Surveys of areas in which there are problems of great public importance—relating, for example, to mineral development, irrigation, or reclamation of swamp areas—are made with sufficient detail to be used in the publication of maps on a scale of $\frac{1}{31,680}$ (1 inch = one-half mile) or $\frac{1}{24,000}$ (1 inch = 2,000 feet), with a contour interval of 1 to 100 feet, according to the relief of the particular area mapped.

2. Surveys of areas in which there are problems of average public importance, such as most of the basin of the Mississippi and its tributaries, are made with sufficient detail to be used in the publication of maps on a scale of $\frac{1}{62,500}$ (1 inch = nearly 1 mile), with a contour interval of 10 to 100 feet.

3. Surveys of areas in which the problems are of minor public importance, such as much of the mountain or desert region of Arizona or New Mexico, and the high mountain area of the northwest, are made with sufficient detail to be used in the publication of maps on a scale of $\frac{1}{125,000}$ (1 inch = nearly 2 miles) or $\frac{1}{250,000}$ (1 inch = nearly 4 miles), with a contour interval of 20 to 250 feet.

The aerial camera is now being used in mapping. From the information recorded on the photographs, planimetric maps, which show only drainage and culture, have been made for some areas in the United States. By the use of stereoscopic plotting apparatus, aerial photographs are utilized also in the making of the regular topographic maps, which show relief as well as drainage and culture.

A topographic survey of Alaska has been in progress since 1898, and nearly 44 percent of its area has now been mapped. About 15 percent of the Territory has been covered by maps on a scale of $\frac{1}{500,000}$ (1 inch = nearly 8 miles). For most of the remainder of the area surveyed the maps published are on a scale of $\frac{1}{250,000}$ (1 inch = nearly 4 miles). For some areas of particular economic importance, covering about 4,300 square miles, the maps published are on a scale of $\frac{1}{62,500}$ (1 inch = nearly 1 mile) or larger. In addition to the area covered by topographic maps, about 11,300 square miles of southeastern Alaska has been covered by planimetric maps on scales of $\frac{1}{125,000}$ and $\frac{1}{250,000}$.

The Hawaiian Islands have been surveyed, and the resulting maps are published on a scale of $\frac{1}{62,500}$.

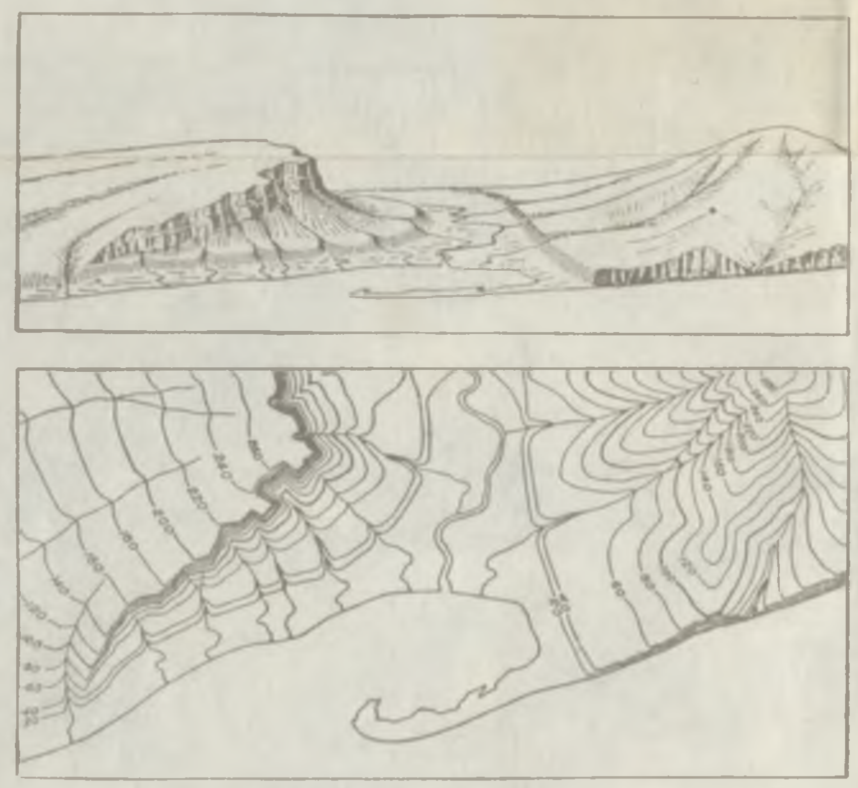
A survey of Puerto Rico is now in progress. The scale of the published maps is $\frac{1}{30,000}$.

The features shown on topographic maps may be arranged in three groups—(1) water, including seas, lakes, rivers, canals, swamps, and other bodies of water; (2) relief, including mountains, hills, valleys, and other features of the land surface; (3) culture (works of man), such as towns, cities, roads, railroads, and boundaries. The symbols used to represent these features are shown and explained below. Variations appear on some earlier maps, and additional features are represented on some special maps.

All the water features are represented in blue, the smaller streams and canals by single blue lines and the larger streams by double lines. The larger streams, lakes, and the sea are accentuated by blue water lining or blue tint. Intermittent streams—those whose beds are dry for a large part of the year—are shown by lines of blue dots and dashes.

Relief is shown by contour lines in brown, which on a few maps are supplemented by shading showing the effect of light thrown from the northwest across the area represented, for the purpose of giving the appearance of relief and thus aiding in the interpretation of the contour lines. A contour line represents an imaginary line on the ground (a contour) every part of which is at the same altitude above sea level. Such a line could be drawn at any altitude, but in practice only the contours at certain regular intervals of altitude are shown. The datum or zero of altitude of the Geological Survey maps is mean sea level. The 20-foot contour would be the shore line if the sea should rise 20 feet above mean sea level. Contour lines show the shape of the hills, mountains, and valleys, as well as their altitude. Successive contour lines that are far apart on the map indicate a gentle slope, lines that are close together indicate a steep slope, and lines that run together indicate a cliff.

The manner in which contour lines express altitude, form, and grade is shown in the figure below.



The sketch represents a river valley that lies between two hills. In the foreground is the sea, with a bay that is partly enclosed by a hooked sand bar. On each side of the valley is a terrace into which small streams have cut narrow gullies. The hill on the right has a rounded summit and gently sloping spurs separated by ravines. The spurs are truncated at their lower ends by a sea cliff. The hill at the left terminates abruptly at the valley in a steep scarp, from which it slopes gradually away and forms an inclined tableland that is traversed by a few shallow gullies. On the map each of these features is represented, directly beneath its position in the sketch, by contour lines.

The contour interval, or the vertical distance in feet between one contour and the next, is stated at the bottom of each map. This interval differs according to the topography of the area mapped: in a flat country it may be as small as 1 foot; in a mountainous region it may be as great as 250 feet. In order that the contours may be read more easily certain contour lines, every fourth or fifth, are made heavier than the others and are accompanied by figures showing altitude. The heights of many points—such as road intersections, summits, surfaces of lakes, and benchmarks—are also given on the map in figures, which show altitudes to the nearest foot only. More precise figures for the altitudes of benchmarks are given in the Geological Survey's bulletins on spirit leveling. The geodetic coordinates of triangulation and transit-traverse stations are also published in bulletins.

Lettering and the works of man are shown in black. Boundaries, such as those of a State, county, city, land grant, township, or reservation, are shown by continuous or broken lines of different kinds and weights. Public roads suitable for motor travel the greater part of the year are shown by solid double lines; poor public roads and private roads by dashed double lines; trails by dashed single lines. Additional public road classification if available is shown by red overprint.

Each quadrangle is designated by the name of a city, town, or prominent natural feature within it, and on the margins of the map are printed the names of adjoining quadrangles of which maps have been published. More than 4,100 quadrangles in the United States have been surveyed, and maps of them similar to the one on the other side of this sheet have been published.

Geologic maps of some of the areas shown on the topographic maps have been published in the form of folios. Each folio includes maps showing the topography, geology, underground structure, and mineral deposits of the area mapped, and several pages of descriptive text. The text explains the maps and describes the topographic and geologic features of the country and its mineral products. Two hundred twenty-five folios have been published.

Index maps of each State and of Alaska and Hawaii showing the areas covered by topographic maps and geologic folios published by the United States Geological Survey may be obtained free. Copies of the standard topographic maps may be obtained for 10 cents each; some special maps are sold at different prices. A discount of 40 percent is allowed on an order amounting to $5 or more at the retail price. The discount is allowed on an order for maps alone, either of one kind or in any assortment, or for maps together with geologic folios. The geologic folios are sold for 25 cents or more each, the price depending on the size of the folio. A circular describing the folios will be sent on request.

Applications for maps or folios should be accompanied by cash, draft, or money order (not postage stamps) and should be addressed to

THE DIRECTOR,
United States Geological Survey,
November 1937. *Washington, D. C.*

STANDARD SYMBOLS

NOTE:—Effective on and after October 1, 1946, the price of standard topographic quadrangle maps will be 20 cents each, with a discount of 20 percent on orders amounting to $10 or more at the retail rate.

CULTURE
(printed in black)

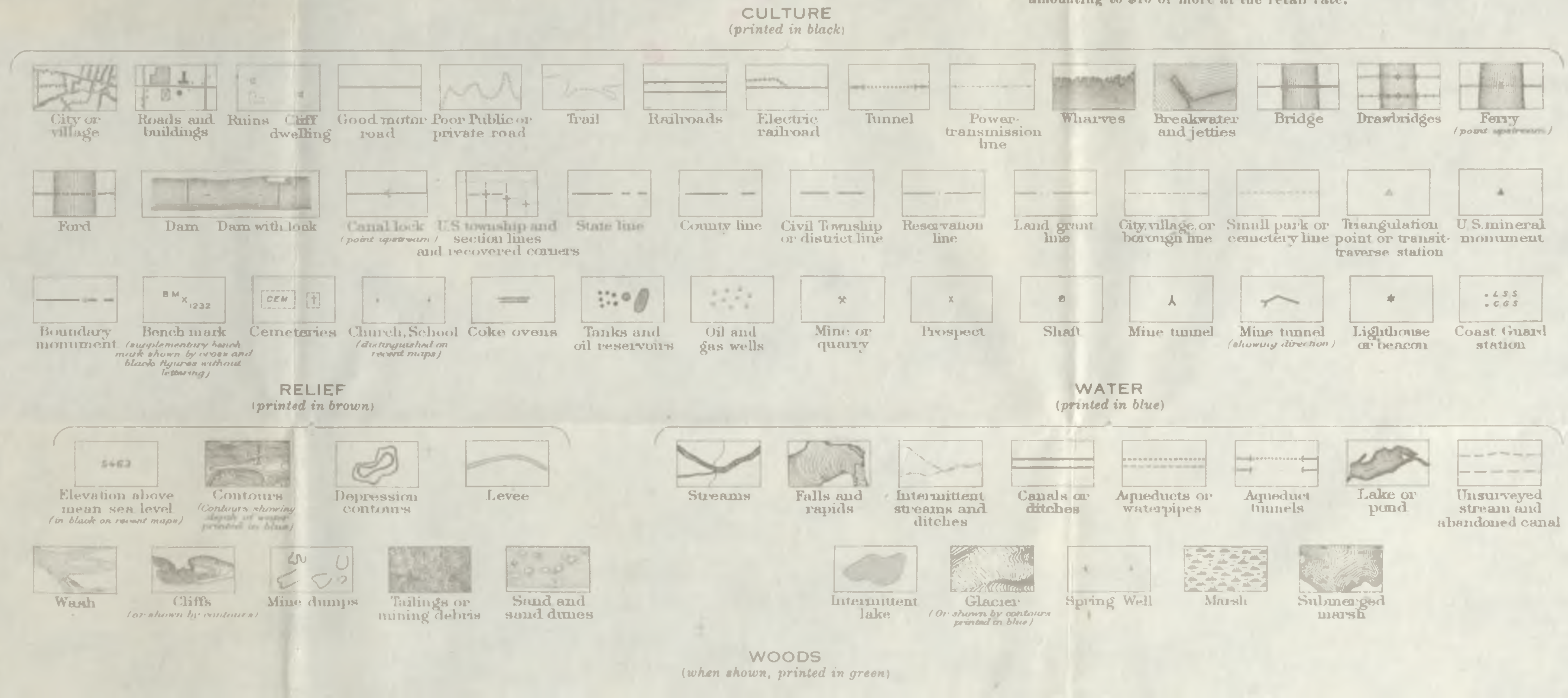
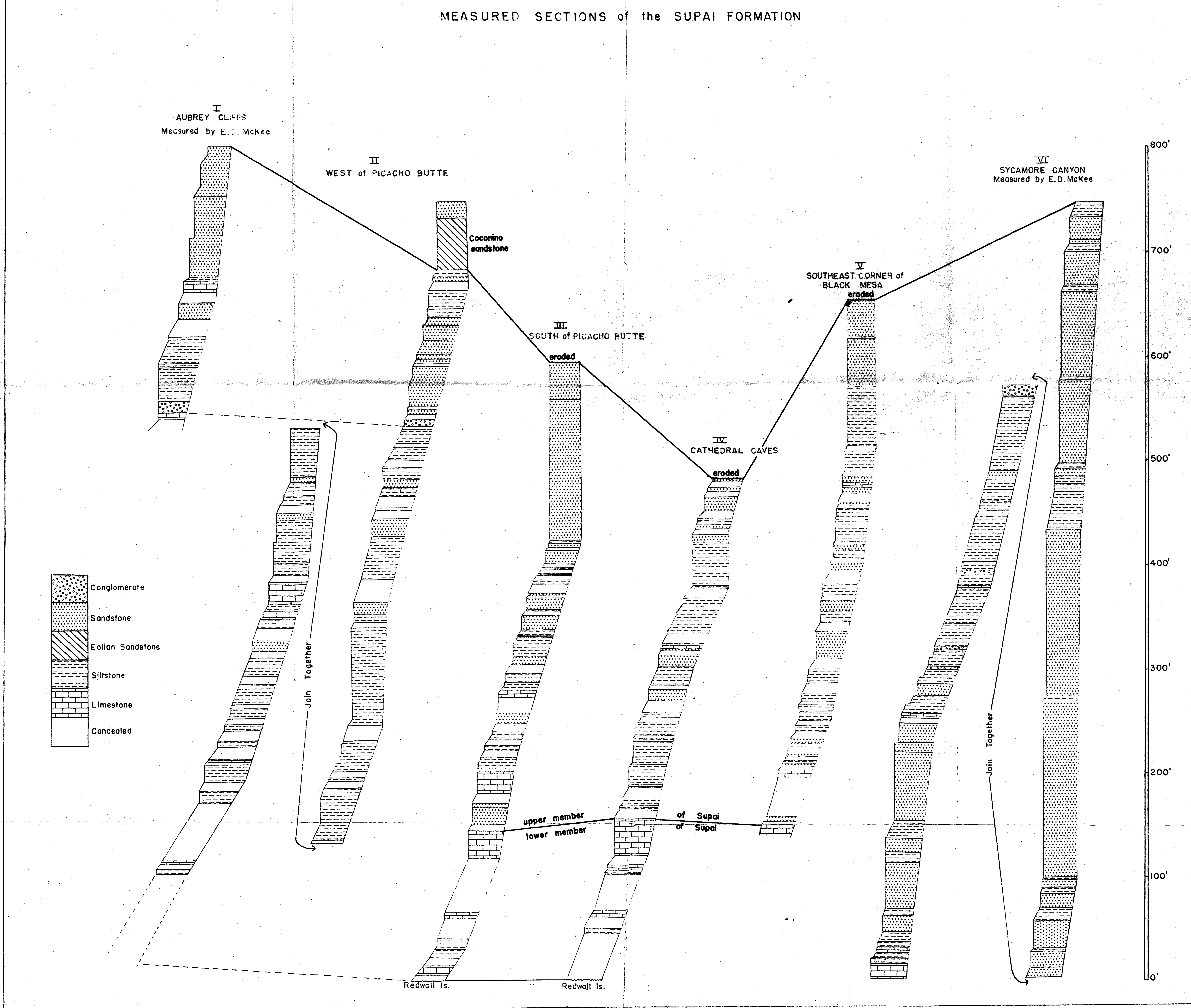


PLATE II



MEASURED SECTIONS of the SUPAI FORMATION
I
AUBREY CLIFFS
Measured by E.D. McKee
II
WEST of PICACHO BUTTE
Coconino sandstone
III
SOUTH of PICACHO BUTTE
eroded
IV
CATHEDRAL CAVES
eroded
V
SOUTHEAST CORNER of BLACK MESA
eroded
VI
SYCAMORE CANYON
Measured by E.D. McKee
Join Together
Join Together
upper member of Supai
lower member of Supai
Redwall ls.
Redwall ls.
Conglomerate
Sandstone
Eolian Sandstone
Siltstone
Limestone
Concealed
800'
700'
600'
500'
400'
300'
200'
100'
0'

Plate 2

there is no evidence that a sea encroached upon this area.

According to Reiche[48.], the transporting agent of the Coconino sandstone had a southerly direction over most of this area and it is quite possible that the eolian Coconino sands forced the deltaic Supai deposition southward.

The Supai formation has been shown to have many characteristics of a deltaic deposit (pg. 25), and will be referred to as such. An eolian origin has been assigned to the Coconino sandstone by McKee[49.], and with this the writer is in agreement.

Cross-lamination Studies. A study of the cross-laminated units in the upper member was two-fold in purpose. First, as a primary structure, it gives evidence as to the agent and the environment of deposition. Secondly, a study of the direction of dip, when applied on a regional basis, gives evidence of the source direction, providing the material studied was transported and deposited by the same agent.

The studies are limited to the upper member because in the few localities in which the lower member is exposed no cross-lamination patterns were observed.

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48. Reiche, Parry, An analysis of cross-lamination: The Coconino sandstone, fig. 4, Jour. of Geol., Vol. 46, No. 7, 1938.

49. McKee, E. D., The Coconino sandstone, Carnegie Inst. of Wash., Publ. No. 440, 1934.

The writer has previously shown[50.] that the cross-lamination patterns within the Supai formation are divisible into three basic types. The first type is comparable to the coalescence of the lobes of small deltas as described by McKee[51.] (Plate IX fig. 2). The second occurs when the Supai material has been beveled or channeled before consolidation, and later sediments were deposited upon the sloping, beveled surfaces (Plate IX fig. 1). The third type of cross-lamination is typical[52.] of foreset bedding, the type which is found on the advancing front of modern deltas (Plate X fig.-1). In many localities this foreset type of cross-lamination is continuous for several hundred feet without change in the dip of the beds. It is of interest to note that where the foreset type of cross-lamination has been recognized, the rock is of a distinctly lighter color than the surrounding red siltstones and sandstones of the topset type of bedding. This feature is interpreted as a subaquous reduction of the red iron oxide.

Individual beds of cross-laminated sandstone and silt-

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50. Hughes, P. W., History of the Supai formation in the Black Mesa Yavapai County, Arizona, Plateau, Museum of Northern Ariz., Vol. 22, No. 2, pg. 35, 1949.

51. McKee, E. D., "Three types of cross-lamination in Paleozoic rocks of Northern Arizona", Amer. Jour. Sci., Vol. 238, pg. 821, 1940.

52. Lahee, F. H., Field Geology., Fourth Edition, McGraw-Hill, pg. 81, 1941.

stone are in many places separated by thin units of structureless mudstone. Rarely the mudstone contains fossil mudcracks and ripplemarks. The sequence of sediments described indicates a seasonal type of deposition in which the coarser materials were transported during periods of heavy runoff and the fine particles were transported during periods of minimum runoff.

Thirty random readings were taken in each of a number of localities in order to determine the average amount and direction of dip of the cross-laminated beds. The arrows on Fig. 1 indicate the average direction of dip for the upper member of the Supai in that locality. From the tabulation which follows, it is apparent that the maximum dip is high but consistent for the five localities visited. Further, the last three localities show nearly the same average direction of dip.

Cross-lamination in the upper Supai

Location	Average direction of dip	Average dip	Maximum dip
1. Sec. 2, T. 21., R. 5 W.	N. 75° W.	17°	29°
2. Sec. 19, T. 21 N., R. 4 W.	S. 58.5° W.	16.5°	33°
3. S.E. ¼ Sec. 31, T. 20 N., R. 2 W.	S. 1.5° W.	19°	33°
4. N.E. ¼ Sec. 27, T. 19 N., R. 2 W.	S. 5.5° W.	15.5°	23°
5. N.W. ¼ Sec. 24, T. 19 N., R. 2 W.	S. 7.5° W.	19°	31°

The dip and its direction were plotted on polar coordinate paper in the field. For the most part, the directions of dip are nearly in the same direction with an occasional reading deviating as much as 145° from the average direction.

At the first locality (preceding table), the dip readings were taken at the Supai-Coconino contact. As the contact has been shown to be gradational (pg. 30), the two formations are locally contemporaneous, and the eolian Coconino sandstone probably forced the last stages of Supai deposition northward in this locality. The readings in the other localities are believed to have been taken between 400 feet and 500 feet above the top of the lower member.

The average direction of dip in the localities studied by the writer differ from those by McKee[53] in the Grand Canyon region. All of the average directions of dip in the upper Supai obtained by McKee are to the southeast.

Chert Studies. Various forms of chert occupy an appreciable part of the Supai formation. Much of this chert is believed to be primary and is therefore of significance to the depositional history of the red beds. Chert of probable secondary origin is also present.

Present day streams carry large amounts of silica to

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53. McKee, E. D., op. cit. fig. 5.

the sea annually. Tarr[54] points out that silica "ranks second to calcium, which heads the list of materials carried in solution".

The chert in the Supai formation occurs in the limestones and calcareous siltstones. Those cherts within the siltstones which are believed to be primary are of a different type than those found within the limestone beds.

Occurrence of chert in limestone: In the massive limestone at the base of the Supai formation and in the thin beds of limestone throughout the upper member, the chert is some shade of red or white and is opaline in appearance. It occurs as irregular beds and stringers, parallel to the bedding plane of the limestone (Plate XI fig. 1). An individual bed may be continuous for several hundred feet or be less than a foot in length, and range in thickness from a fraction of an inch to a foot or more. The contact between the limestone and chert is sharp.

A few rounded nodules of chert which weathered out from the lower limestone beds have been observed. The largest found is 1.5 inches in diameter. The nodules are banded with colors of dark gray to white.

Veinlets of red and white chert are numerous. Veinlets penetrate through bedding planes and penetrate beds of other

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54. Tarr, W. A., The origin of chert and flint, Univ. of Missouri Studies, Vol. 1, No. 2, pg. 2, 1926.

types of chert so are definitely younger than either.

With one exception, all fossils found in the limestone beds or on bedding planes are silicified. A Composita sp. is the most prevalent fossil of the basal Supai. These fossils are completely embedded either in chert or in limestone, and in many specimens the interiors are filled with quartz crystals.

Southwest of Picacho Butte, between measured sections II and III, and also 18 mileswest of Seligman at Pica, Arizona, fragments of chert breccia are found near the base of the Supai. These are composed of small angular fragments of chert recemented by a second generation of chert.

In an interpretation of the cherty limestone, evidence seems sufficient that both primary and secondary chert are present. The author favors Tarr's[55.] theory that the bedded chert is primary. The veinlets of chert which cut through bedding planes and older chert is undoubtedly secondary. The origin of the small nodules of banded chert which weather from the limestone is unknown.

The silicified fossils are found not only imbedded in chert but also in limestone. It is difficult for some to believe that silica would selectively replace the fossil shell material after consolidation of the limestone, leaving the surrounding limestone unaltered. This type of

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55. Tarr, W. A., op. cit., pg. 28.

relationship to surrounding rock has been observed by the writer among fossils in the Kaibab and Redwall formations in many localities. The limestone beds contain an appreciable amount of silt and sand and are indicative of shallow water, near-shore deposition. Silicification of fossils can take place before or after consolidation of the surrounding rock. According to Clark[56.], coral has been silicified artificially.

Occurrence of chert in siltstone and sandstone: Chert is associated in various forms with calcareous detrital sediments. Nodular chert is the most abundant in these sediments (Plate X fig. 2). The chert is a dull medium gray with tinges of red from included silt particles. Some flattened nodules are eight feet in length (parallel to the bedding) and one foot thick; other more nearly spherical nodules are as large as three and one half by two feet. Centers of some are composed of limestone. The contact between chert and surrounding rock is sharp. Nearly all nodules are concentrically banded. Alternate bands are composed of red silt and weather as thin depressions. The shape of the nodules is strikingly similar to cross-sections of petrified wood; the silt bands giving the effect of annular rings (Plate XI fig. 2). The thin, red bands between the white

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56. Clark, F. W., Data of geochemistry, U.S. Geol. Surv. Bull. 770, pg. 549, 1924.

chert bands probably represent layers of Supai silt, deposited between intervals of silica accumulation. The nodules occur both in structureless and in cross-laminated red beds. In the latter they are flattened and lie parallel to the layers of cross-lamination. These nodular cherts are believed by the writer to be primary.

Chert veinlets have two modes of occurrence in the detrital sediments. In some, small veinlets radiate from chert nodules, not unlike spokes in a wheel. In others, thin sheets of chert have developed on cliff faces. These are parallel to the joint pattern of the massive siltstones and represent secondary silica fillings in a joint. Where softer detrital material has weathered away, a thin, resistant chert veneer is left on the cliff face.

A few of the shaly siltstones contain dark reddish brown nodules which have the appearance of chert. Close examination, however, indicates a sugary texture typical of orthoquartzite. It is believed these nodules represent silicification before the surrounding rock was consolidated, as the nodules are flattened and conform to the shaly bedding.

Age of the Supai Formation. It has long been known that Paleozoic deposits of the Colorado Plateau are relatively thin when compared with those of corresponding age in the geosyncline to the west in Nevada and Utah. The

Supai formation represents a considerable part of total upper Paleozoic deposits of the Plateau. Within the area studied, the formation is composed of an interfingering of marine limestones, which thicken to the west, and deltaic sediments whose source was to the east and northeast. Marine deposition which was predominate during early stages of Supai accumulation became slight or non-existent during later stages of the deltaic deposition.

In the western Grand Canyon region the basal Supai is Pennsylvanian[57.] in age. On the basis of stratigraphic position and similar lithology, with added faunal evidence, the lower member of the Supai formation of the Black Mesa area has been assigned to the Pennsylvanian period.

A detailed study of the contact between the two recognized members is in agreement with results of work by Huddle and Dobrovolny[58.]. They state "no evidence of an unconformity between the Pennsylvanian and Permian beds was observed". The contact between the two members appears to be gradational, and limestone beds found in the upper member indicate that a delicate balance existed between marine and continental deposition for nearly all of the time,

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57. Noble, L. F., A section of the Paleozoic formations of the Grand Canyon at the Bass Trail., U.S. Geol. Surv. Prof. Paper 131, pg. 59, 1922.

58. Huddle, J. W., and Dobrovolny, E., Late Paleozoic stratigraphy of Central and Northeastern Arizona, U.S. Geol. Surv. Oil and Gas Invest., Prelim. Chart 10, 1945.

during which the Supai was forming.

Faunal evidence indicates that the lower member is Early Pennsylvanian in age (Fig. 5a). If further studies bear out this evidence of age, then the indication of a gradational contact between the two members suggests the possibility that an unknown thickness of the upper member is also Pennsylvanian. If the basal Supai is of Late Pennsylvanian age (Fig. 5b), then the possibility of all the upper member being Permian is more likely.

Sharp changes in bedding are indicative of a hiatus between each individual bed. These periods of non-deposition (diastems) within the Supai formation are numerous according to the criteria suggested by Eaton[59].

It has further been shown[60] that in many places more material is supplied to a basin than is finally deposited in the basin. From the above observations it is apparent that long periods of non-deposition are possible in a formation such as the thinly-bedded Supai and that material once deposited could later be moved basin-ward. Thus, the Supai formation, having a Pennsylvanian fauna at its base and a Permian fauna near its upper boundary, needs not be divided by an unconformity nor have large thicknesses of

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59. Eaton, J. E., The by-passing discontinuous deposition of sedimentary materials, Bull. A.A.P.G., Vol. 13 No. 7, pg. 728, 1929.

60. Eaton, J. E., op. cit., pg. 713.

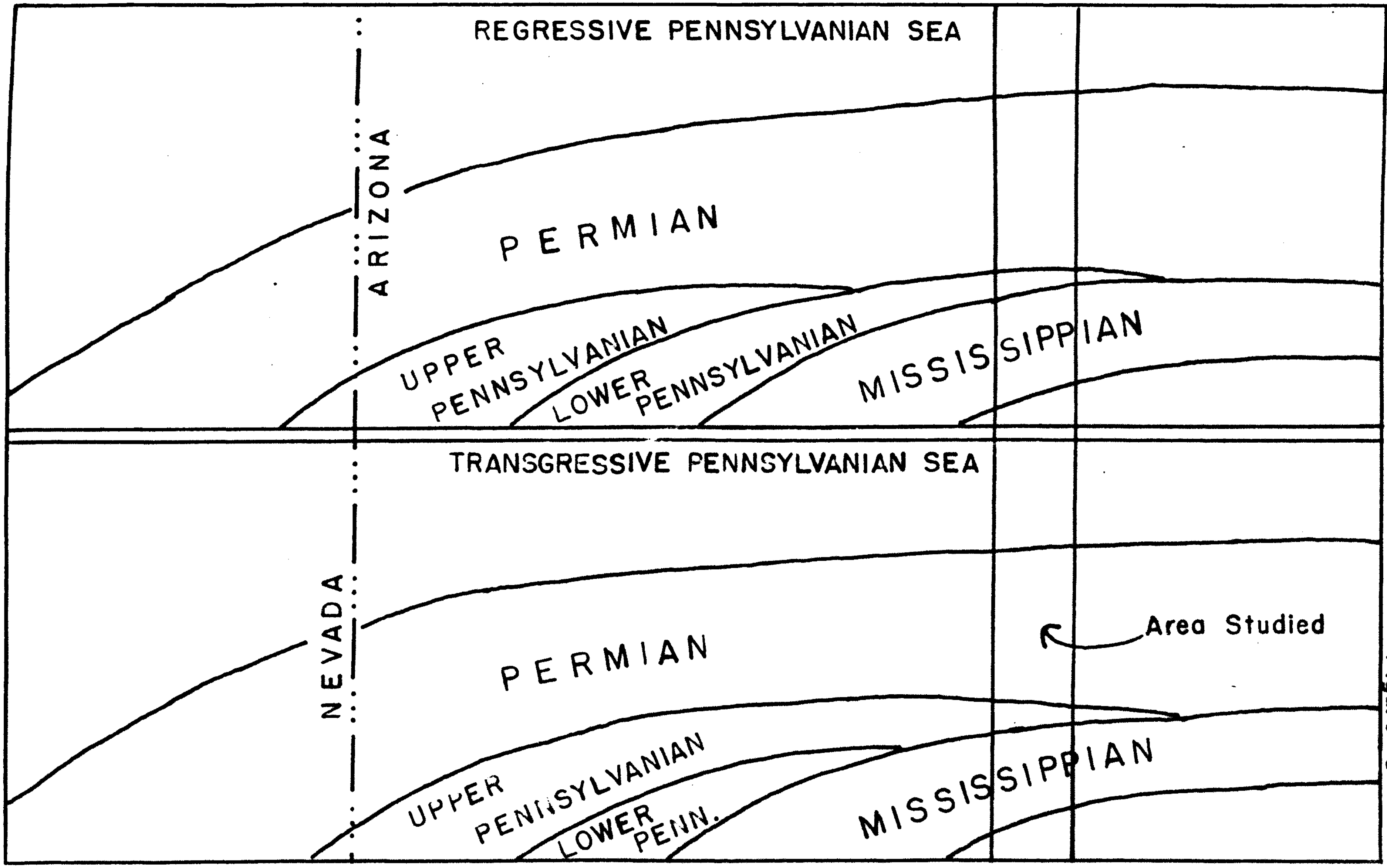
REGRESSIVE PENNSYLVANIAN SEA
ARIZONA
PERMIAN
UPPER PENNSYLVANIAN
LOWER PENNSYLVANIAN
MISSISSIPPIAN
TRANSGRESSIVE PENNSYLVANIAN SEA
NEVADA
PERMIAN
Area Studied
UPPER PENNSYLVANIAN
LOWER PENN.
MISSISSIPPIAN

Figure 5.

sediments to account for long periods of time.

The dating of the Supai formation in the eastern Grand Canyon region has been aided by the presence of a distinctive flora in the overlying Hermit shale. In the Black Mesa region however, where the contact of the Supai and the overlying Coconino formation is gradational (pg. 30), it appears that the Hermit shale was not deposited. David White[61.] in his studies of the Grand Canyon region stated that "the few fossil remains in the upper Supai indicate a lower Permian age, or at least an age not lower than the highest Pennsylvanian". In a later paper White[62.] added confusion to the problem by indicating a Permian age for the basal Supai. (This paper was published long after Noble had redefined the Supai to include the Pennsylvanian limestones at the base.). The evidence was based on poorly preserved plant remains.

Studies by McKee[63.] in the Grand Canyon "suggest that the basal part of the Supai is of progressively greater age as followed from east to west or toward the Nevada geosyncline". Longwell and Dunbar[64.] believe "it is possible

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61. Shimer, H. W., Permo-Triassic of northwestern Arizona, Bull. G.S.A., Vol. 30, pg. 492, 1919.

62. White, D., Carnegie Year Book 27, pg. 389, 1927-28.

63. McKee, E. D., Studies on the history of Grand Canyon Paleozoic formations, Carnegie Inst. Wash., Year Book No. 39, pg. 297, 1939.

64. Longwell, C. R., and Dunbar, C. O., Problems of Pennsylvanian-Permian boundary in southern Nevada, Bull. A.A.P.G., Vol. 20, No. 9, pg. 1206, 1936.

that a large part of the Bird Spring formation is the time equivalent of beds in the lower part of the Supai formation in the Grand Canyon district". Furthermore, the lower limestone and clastic beds of the Bird Spring formation increase in thickness toward the west, being at least 2,000 feet thick in the Muddy Mountains and 5,000 feet thick in the Las Vegas Quadrangle.

In Sycamore and Oak Creek Canyons to the east of the area studied, limestone units of the basal Supai are missing. Evidence at hand indicates that the limestone thickens toward the Nevadan geosyncline to the west. The area studied therefore appears to mark the most eastward transgression of the Pennsylvanian seas.

The relationship of the basal Supai to the Naco limestone to the southeast is not known, but Wanless[65] reports Fusulinella of Early Pennsylvanian age in the Naco formation between the Supai and Redwall formations at Fossil Springs, northwest of Pine, Arizona.

Collections of fossil material were made by the writer at three localities in the Black Mesa area. Unfortunately most of the fossils are fragmental and thick-shelled as would be expected in a near shore deposit.

Locality 1. The first locality examined lies within Black Mesa in the north central part of Sec. 15, T. 20 N.,

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65. Wanless, H., Personal communication, 1949.

R. 3 W. and the fossils occur 120 feet above the Redwall-Supai contact. Specimens of Composita and Spirifer were collected in a cherty limestone zone seven feet thick. Nearly all of the fossil material is silicified. The specimens of Composita are, for the most part, found on the surface of bedding planes in the limestone, and are so numerous in the locality examined as to suggest they had no enemies and became prolific. The Composita valves are complete with shell interiors filled with secondary chert or quartz crystals.

Locality 2. The second locality visited is approximately three and one-half miles northwest of locality 1. in the S.E. ¼ of Sec. 4, T. 20 N., R. 3 W. A bed of red silty limestone ten feet thick yielded many hundreds of minute specimens of Spirorbus (?). The fossiliferous stratum is fourteen feet above the Supai-Redwall contact and occurs between a basal conglomerate and a thin-bedded sandy limestone. All the rock types exposed at this locality are indicative of near shore deposition.

Locality 3. The last locality examined is eighteen miles southwest of Pica, Arizona. The lithology of the fossiliferous beds is the same as at locality.1. The faunas collected at the two places are similar, at approximately the same horizon, but that near Pica has a greater vertical distribution. The contact of the Redwall and Supai formations is concealed by talus, and erosion has removed all the upper member of the Supai in this area. Specimens collected include Composita, Spirifer and Derbyia (?), one poorly preserved pelecypod and two trilobite pygidia.

Significance of fauna. Much of the fauna collected is of little value in determining the age of the Supai formation. Either the fossils are too fragmental for positive identification or the geologic range of species is too great to be of value. The specimens of Derbya (?) and Composita were examined by Wanless[66] who was of the opinion they were not diagnostic. The single pelecypod collected and the trilobite pygidiums were also of no value because of poor preservation.

The many specimens of Spirorbis (?) collected at locality 2 were at first thought to be gastropods and were sent to Dr. J. Brooks Knight of the Smithonian Institution for identification. Knight[67] states "it is my opinion that these fossils are not gastropods but tubicolous worms such as Spirorbis." As these aminals range in age from Ordovician to Recent and inhabited both fresh and salt water, they are considered of no value in the determination of the age of the Supai.

The geologic range of the genus Spirifer Sowerby

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66. Wanless, H., op. cit., 1949.

67. Knight, J. Brooks, Personal communication, 1949.

1814-18 as given by Zittel[68], is from Devonian to Permian. The original genus has been subdivided into a large number of genera by Fredericks[69]. According to Shimer and Shrock[70] the genus Spirifer Sowerby 1814, as now recognized, is limited to the Mississippian to Lower Pennsylvanian periods.

Several specimens of Spirifer were collected by the writer in the basal member of the Supai formation. Nearly all specimens collected are silicified so it is impossible to study the internal structure. Comparisons were made with known specimens and with descriptions and plates by Dunbar and Condra[71].

The writer tentatively referred the specimens to Spirifer rockymontanus Marcou. Later these same fossils were sent to Dr. James Steele Williams of the U. S. Geological Survey. Williams[72] was of the opinion that "As preserved,

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68. Zittel, Karl A., Textbook of Paleontology, Vol. 1, Second Edition Revised and Enlarged, pg. 410, 1927.

69. Fredericks, George, Table pour de'finition des genres de la Fam. Spiriferidae King, Bull. de l'Ac. Sci. URSS, pp. 393-423, nos. 4-5, 1926.

70. Shimer, and Shrock, Index fossils of North America, Wiley, 1947.

71. Dunbar, Carl O., and Condra, G. E., Brachipods of the Pennsylvanian System in Nebraska, Nebraska Geol. Surv., Bull. 5, Second Series, pp. 318-319 and Pl. 41, 1932.

72. Williams, James Steele, Personal communication, 1949.

the specimens resemble in many respects, forms that I have in the past designated as belonging to the *Spirifer opimus* Hall - S. *increbescens* Hall type --".

From the preceding discussion, it is apparent that a definite age cannot yet be assigned to the basal Supai. On the basis of stratigraphic position, lithology, relationship to the Nevadan geosyncline and incomplete faunal evidence, the writer believes the basal Supai to be of Early Pennsylvanian age (Fig. 5).

DESCRIPTION OF MEASURED SECTIONS

Section of Supai Formation
Aubrey Cliffs
3 miles west of Seligman
Measured by E. E. McKee

Hermit shale.
Unconformity (assumed).

Supai formation:

	Feet
1. Sandstone: pale reddish brown, calcareous, thick-bedded, cros-laminated; forms cliff; alternates with: Sandstone: pale reddish brown, friable, structureless; forms slope; total forms series of slopes and cliffs........	53.5
2. Sandstone: pale reddish brown, very fine-grained, calcareous; partly sandy, crystalline limestone; beds near base very thick, near top, thinner; middle portion structureless, weakly cemented; weathers weak reddish brown; forms massive cliff with bench at weak middle portion..........................	77.0
3. Siltstone; dark reddish gray, calcareous, weakly cemented; forms slope with rounded knobs..................................	4.5
4. Limestone: reddish gray, fine-grained, cross-laminated; weathers pale brown, sandy, with laminae etched out; forms cliff with straight face and sharp edges.........................	9.5
5. Concealed; probably pale reddish brown, thin-bedded siltstone............................	11.0
6. Sandstone: pale reddish brown, uniformly very fine-grained, calcareous, cross-laminated (prominently at base); beds 2-4 ft. thick; weathers weak reddish brown; forms massive cliff rounded at top........................	12.0
7. Limestone: reddish gray, fine-grained, cross-laminated, cliff-forming; like no. 4 but less sandy..................................	3.0

	Feet
8. Concealed: probably pale reddish brown, thin-bedded siltstone..........................	17.0
9. Siltstone: reddish gray, calcareous, structureless; weathers same; forms rounded cliff....................................	3.0
10. Siltstone: weak reddish brown, argillaceous, thin-bedded (less than ½ inch); weathers same; forms slope........................	23.0
11. Siltstone: reddish gray to light brown, calcareous, cliff-forming; like no. 9; weathers same to pale brown..................	3.0
12. Siltstone: weak reddish brown, thick-bedded, structureless; forms weak cliffs with rounded surfaces...............................	33.0
13. Conglomerate.............................. matrix: reddish gray silt; gravel size: commonly 2-4 inches in diameter, up to 8 inches; gravel shape: mostly well rounded; gravel composition: weak brown, reddish gray, and light brownish gray limestone and siltstone.	11.0
14. Limestone: dark reddish gray, crystalline; weathers pale brown, sandy; forms cliff.....	6.0
15. Concealed: probably continuation of no. 14 in upper part	
Total:	266. 5

Section of Supai Formation
3 Miles West of Picacho Butte
Sec. 2, R. 5 W., T. 21 N.

	Feet
Coconino sandstone:....................................	513.5
Contact, gradational.	
Supai formation:	
1. Sandstone: pale reddish brown, very fine-grained, flat-bedded, calcareous, friable; weathers to rough cliff......................	16.5
2. Quartzite: moderate reddish orange; Coconino-type crossbedding, firm; weathers to rough cliff.......................................	49.0
3. Siltstone: pale reddish brown, flat-bedded, calcareous and hematitic, firm; weathers to feddish brown, pitted slope..................	7.0
4. Siltstone: pale reddish brown, thick, massive, calcareous, firm; weathers to rounded and pitted, reddish brown cliff..............	5.0
5. Quartzite: moderate reddish brown, thick, massive; weathers to reddish brown slope.....	2.0
6. Concealed slope:...............................	6.0
7. Siltstone: moderate reddish orange, sandy, thick, cross-bedded, calcareous and hematitic, firm; concretions of rounded, white calcite rare; weathers to rounded, pitted cliff......	15.5
8. Siltstone: grayish red purple, thin-bedded, wavy-bedded, dolomitic, firm; weathers to purplish brown recess.......................	2.5
9. Siltstone: moderate reddish orange, thick, cross-bedded, calcareous; inclusions of white ovoids of calcite common and stringers of purplish siltstone; weathers to pitted, reddish brown cliff..........................	9.0
10. Quartzite: pale red purple; very thick to thin bedding, firm; inclusions of white calcite nodules common; weathers to rounded slope; contains worm borings.......................	8.0

		Feet
11.	Quartzite: pale reddish brown, thick, flat-bedded, massive, firm; inclusions of vugs of white calcite common in upper half and banded ovoids of red chert common in lower half; weathers to rough, pitted cliff..........	14.0
12.	Siltstone: pale reddish brown, thin, flat-bedded, dolomitic, firm; weathers to light gray and reddish brown slope; wavy bedding plane..	14.0
13.	Sandstone: moderate orange pink, very fine-grained, thick, massive, calcareous, firm; weathers to rough pitted cliff.................	4.5
14.	Quartzite: moderate reddish brown, thick, gnarly to massive, firm; white ovoid vugs of calcite rare; weathers to rough slope..........	4.5
15.	Concealed slope:...............................	4.5
16.	Sandstone: moderate reddish brown, very fine-grained, thin to thick, flat-bedded, calcareous and hematitic, firm; inclusions of light gray, sandy, irregular, areas; weathers to rough slope and cliff........................	20.0
17.	Sandstone: pale reddish brown, very fine-grained, very thick, massive, calcareous and hematitic, firm; weathers to pitted, rough, reddish brown cliff.............................	18.0
18.	Siltstone: dark reddish brown, thin, massive, hematitic, firm; weathers to rough, dark reddish brown slope.........................	1.0
19.	Concealed slope:...............................	3.5
20.	Sandstone: pale reddish brown, very fine-grained, thin-bedded, massive, calcareous and hematitic, firm; weathers to rough medium reddish brown cliff...........................	1.0
21.	Sandstone: pale red, very fine-grained, thick, massive, calcareous, firm; weather to rough, light gray and reddish brown cliff............	4.5
22.	Concealed slope................................	3.5

		Feet
23.	Conglomerate: with thin lenses of reddish brown, very fine-grained sandstone; matrix: very fine-grained reddish brown sandstone; pebble size: up to 1.5 inches in diameter, average approx. 0.5 inch; pubble shape: sub-rounded to rounded; pebble composition: red sandstone and gray limestone; forms slope.	7.0
24.	Concealed slope:	3.0
25.	Siltstone: moderate reddish orange, thin-bedded, gnarly, calcareous, firm; inclusions of light gray and purplish stringers of siltstone; weathers to rough reddish brown slope	14.5
26.	Concealed slope:	4.0
27.	Siltstone: moderate reddish brown, thick, massive, calcareous and hematitic, firm; weathers to rough, dark reddish brown cliff	2.0
28.	Siltstone: pale red, thin-bedded, gnarly, calcareous, firm; nodules of gray calcite rare; weathers to light reddish brown, rough slope	10.0
29.	Concealed slope:	8.0
30.	Siltstone: pale reddish brown, thick, massive, calcareous and hematitic, firm; inclusions of vugs of irregular, white calcite; weathers to rounded, reddish brown cliff; contains mud cracks	13.5
31.	Sandstone: grayish orange pink, very fine-grained, thick, massive, calcareous, firm; inclusions of irregular, gray nodules of limestone common; weathers to light gray pitted slope	6.0
32.	Siltstone: pale reddish brown, thick, gnarly, calcareous, firm; nodules of spherical, light red, quartzitic sandstone common; weathers to rough, reddish brown slope	9.5

	Feet
33. Concealed slope:..................................	10.0
34. Siltstone: moderate reddish orange, thick, massive, calcareous, firm; weathers to rounded light reddish brown cliff.................	3.5
35. Concealed slope:..................................	8.0
36. Sandstone: moderate reddish orange, very fine-grained, very thick; massive in upper part; cross-bedded in lower part, calcareous, firm; concretions of irregular white calcite rare; weathers to pitted, reddish brown cliff.......	17.0
37. Siltstone: moderate reddish orange, thin to thick-bedded, flat-bedded, calcareous, firm; nodules of quartzitic, spherical, pale red sandstone in upper portion; weathers to gnarly and shaly, reddish brown slope; grades laterally into cliff forming unit similar to number 36....................................	42.5
38. Concealed slope:..................................	21.5
39. Quartzite: pale reddish brown, thick, cross-bedded, firm; weathers to smooth, dark reddish brown cliff; wedges out laterally very rapidly..................................	12.0
40. Siltstone: moderate reddish orange, thick, massive, calcareous, friable; inclusions of irregular, white masses of sandstone common; weathers to smooth, pale reddish brown cliff; worm burrows rare............................	8.5
41. Concealed slope:..................................	4.0
42. Siltstone: moderate reddish orange, very thick, cross-bedded, calcareous, firm; inclusions of irregular patches of gray limestone abundant; weathers to rounded, pale red cliff..................................	67.0
43. Siltstone: pale reddish brown, shaly to thick, flat-bedded, calcareous, firm; weathers to rounded, shaly, reddish brown slope and cliff..............................	27.0
44. Concealed slope:..................................	15.5

		Feet
45.	Siltstone: moderate reddish orange, thick flat-bedded, calcareous, firm; weathers to rounded, pale reddish brown cliff and slope....	11.0
46.	Siltstone: moderate reddish orange, thick, cross-bedded, calcareous, firm; weathers to smooth, pale red slope........................	18.5
47.	Concealed slope:................................	7.5
48.	Siltstone: grayish orange pink, thin, flat-bedded, calcareous, friable; weathers to rough, pale red slope.........................	3.0
49.	Concealed slope:................................	2.5
50.	Limestone: light brownish gray, aphanitic, thick, flat-bedded, firm; weathers to rough, gray slope...................................	3.5
51.	Siltstone: moderate orange pink, thick to shaly, cross-bedded, calcareous, firm; weathers to rough, light gray alternating slope and cliff..............................	49.5
52.	Concealed slope:................................	4.5
53.	Siltstone: light brown and pale red purple, thin, flat-bedded, calcareous, firm; weathers to rough, light gray slope; contains mudcracks....................................	4.0
54.	Siltstone: grayish pink, thick, cross-bedded, calcareous, firm; weathers to "honeycombed", light gray cliff; channeling common............	27.5
55.	Siltstone: moderate reddish orange, very thick, cross-bedded, calcareous, friable; irregular inclusions of white sand abundant; weathers to smooth, rounded, reddish brown cliff...................................	19.5
56.	Quartzite: pale red, thick, massive, firm; vugs of white calcite rare; weathers to rounded, light gray cliff....................	5.0
57.	Siltstone: pale red, shaly to thick, flat-bedded, calcareous, firm; weathers to rounded and shaly, pale reddish slope..........	8.0

	Feet
58. Concealed slope:................................	5.5
59. Siltstone: pale red, thin, flat-bedded, calcareous, firm; weathers to rounded, light gray slope...............................	9.0
60. Concealed slope:................................	8.5
61. Quartzite: moderate reddish orange, thick, massive, firm; weathers to rounded, smooth, reddish brown cliff............................	6.0
62. Siltstone: grayish orange pink, very thick, cross-bedded, calcareous, firm; contains red chert bands in upper part; weathers to rounded, light gray cliff with ledge in middle...	42.0
63. Quartzite: pale reddish brown, very thick, massive, firm; vugs of yellowish calcite common; weathers to smooth, reddish brown cliff..	12.5
64. Concealed slope: probably pale red siltstone..	6.5
65. Limestone: medium light gray, aphanitic, sandy, thick, cross-bedded, firm; red chert bands abundant; weathers to rough, medium gray cliff.....................................	4.0
66. Limestone: light gray, aphanitic, silty, thick, cross-bedded, firm; irregular patches of white, limey sandstone abundant; weathers to rounded, light gray and red cliff..........	14.0
67. Siltstone: dark reddish brown, thick, massive, hematitic, firm; weathers to brick red, rounded cliff...........................	2.5
68. Siltstone: pale reddish brown, thick, flat-bedded, calcareous, firm; weathers to rounded, reddish brown slope................	5.5
69. Limestone: pinkish gray, aphanitic, sandy, thick, flat-bedded, firm; weathers to rounded, gray cliff and slope..................	10.5

		Feet
70.	Siltstone: pale red, thick, massive, calcareous, firm; weathers to smooth, brick red slope	8.5
71.	Concealed slope: probably moderate reddish brown siltstone	12.0
72.	Quartzite: moderate reddish orange, thick, cross-bedded, firm; inclusions of irregular, gray limestone nodules common; weathers to rough, pitted, pale reddish brown cliff	11.5
73.	Concealed slope:	5.0
74.	Siltstone: moderate reddish orange, thick, massive, calcareous, firm; vugs of white calcite common; weathers to rough, pitted, pale reddish brown cliff	5.5
75.	Siltstone: pale reddish brown, shaly to thick, flat-bedded, calcareous, firm; weathers to shaly, brick red slope	11.0
76.	Concealed slope:	9.5
77.	Limestone: medium dark gray, aphanitic, thick, flat-bedded, firm; red chert bands abundant; weathers to rough, pitted, gray cliff	2.5
78.	Siltstone: pale reddish brown, shaly, flat-bedded, câlcareous and hematitic, firm; weathers to moderate reddish brown slope	16.5
79.	Concealed slope:	4.0
80.	Siltstone: moderate orange pink, thick, massive, calcareous, friable; weathers to gnarly, pale red cliff	5.5
81.	Siltstone: moderate orange pink, thin, flat-bedded, calcareous, firm; concretions of gray limestone common; weathers to light gray slope	4.0
82.	Concealed slope:	5.5

		Feet
83.	Siltstone: grayish orange pink, thick, cross-bedded, calcareous, form; concretions of spherical gray sandstone common; weathers to pale reddish brown cliff....................	9.0
84.	Limestone: medium light gray, aphanitic, thick, flat-bedded, firm; red, irregular chert bands common; weathers to rough, gray cliff..	1.0
85.	Concealed slope:..............................	10.5
86.	Siltstone: pale reddish brown, thick, flat-bedded, calcareous, firm; weathers to rough, pale red ledge...................................	2.0
87.	Limestone: medium light gray, aphanitic, thin, flat-bedded, firm; red and white chert bands common; weathers to rough, light gray slope..	2.0
88.	Concealed slope: probably shaly, reddish brown claystone..............................	15.0
89.	Limestone: grayish red purple, same as number 87.................................	3.0
90.	Concealed slope:..............................	2.5
91.	Quartzite: pale red purple, thick, massive, firm; weathers to smooth, pale reddish brown cliff.................................	1.5
92.	Siltstone: moderate reddish brown, very thick, massive, calcareous and hematitic, firm; irregular concretions of gray sand common; weathers to rounded, reddish brown cliff.................................	16.5
93.	Concealed slope:..............................	7.5
94.	Siltstone: pale reddish brown, shaly, flat-bedded, calcareous, firm; weathers to smooth, reddish brown cliff.........................	11.0
95.	Siltstone: grayish red purple, thick, massive, hematitic, firm; concretions of white sand common; weathers to reddish brown recess.......................................	2.5

		Feet
96.	Concealed slope:................................	55.0
97.	Limestone: medium dark gray, aphanitic, thin, flat-bedded, firm; red and white chert bands abundant; weathers to rough, gray slope........	3.0
98.	Concealed slope:................................	5.5
99.	Quartzite: moderate reddish orange, thin, gnarly, firm; weathers to weak, rough, reddish orange ledge............................	3.5
100.	Siltstone: grayish red, very thin, flat-bedded, calcareous, firm; weathers to rough, reddish brown ledge............................	2.0

Faulting and talus conceal the base of the Supai formation. The thick cherty limestones characteristic of the basal Supai are exposed approximately one mile south of this locality.

Total Supai exposed : 1072.5

Section II
Approx. 3 miles South of Picacho Butte
Sec. 19, T. 21 N., R. 4 W.

Tertiary basalt.
Unconformity.

Supai formation:	Feet
1. Sandstone: moderate reddish orange, very fine-grained, thin, flat-bedded, calcareous, firm; forms smooth, rounded cliff.............	2.0
2. Sandstone: grayish pink, very fine-grained, thick to very thin bedding, hematitic, cross-bedded, firm; forms smooth, rounded cliff..	34.0
3. Sandstone: moderate reddish orange, very fine-grained, very thick, massive calcareous, firm; inclusions of white, irregular "stringers" of very fine sand common; forms smooth cliff, light grey to reddish brown in color...	12.0
4. Sandstone: same as no. 3, medium scale cross-bedding, inclusions of red and white chert layers common, also irregular patches of gray limestonecommon......................	125.0
5. Siltstone: moderate reddish orange, sandy, very thin, flat-bedded, micaceous, calcareous, firm; weathers to rough, brick red recess..	3.0
6. Sandstone: grayish orange pink, very fine-grained, thick, flat-bedded, calcareous, firm; irregular nodules of gray limestone common; weathers to smooth, light gray cliff..	1.0
7. Sandstone: moderate reddish orange, very fine-grained, thick, massive, calcareous, firm; weathers to reddish orange cliff........	2.0
8. Concealed slope:................................	3.5

	Feet
9. Sandstone: moderate orange pink, very fine-grained, very thick; medium scale cross-bedding, calcareous, firm; red and white chert "stringers" common; forms smooth purplish red cliff..................................	12.0
10. Concealed slope:................................	3.5
11. Siltstone: pale red, clayey, thick, flat-bedded, calcareous, firm; weathers to rough, brick red cliff..............................	1.5
12. Concealed slope:................................	5.0
13. Limestone: grayish red, aphanitic, silty, thick, flat-bedded, firm; forms rounded slope....................................	1.5
14. Concealed slope:................................	4.0
15. Siltstone: moderate reddish orange, sandy, thick, massive, calcareous, firm; forms rounded, reddish brown cliff..................	4.0
16. Concealed slope:................................	10.0
17. Sandstone: moderate reddish brown, very fine-grained, thick, massive, calcareous and hematitic, firm; weathers to reddish orange rounded cliff............................	2.0
18. Concealed slope:................................	1.5
19. Sandstone: moderate brown, very fine-grained, very thick, massive, calcareous and hematitic, firm; inclusions of white chert bands and nodules of gray limestone common; weathers to reddish brown, rounded cliff..................	11.0
20. Siltstone: pale reddish brown, sandy, very thin, flat-bedded, hematitic, weak; weathers to rough reddish brown recess................	1.5
21. Concealed slope:................................	4.0
22. Sandstone: moderate reddish brown, very fine-grained, thick, flat-bedded, hematitic, firm; weathers to rough, brick red slope...........	1.0

		Feet
23.	Sandstone: moderate reddish orange, very fine-grained, very thick; small scale cross-bedding, calcareous; weathers to rough, pale reddish orange cliff..............................	5.5
24.	Siltstone: pale reddish brown, sandy, very thin to thick, massive, calcareous and hematitic; weathers to pitted, reddish orange cliff..	6.5
25.	Limestone: light olive gray, aphanitic, thick, massive, firm; red chert bands common; weathers to rough gray cliff............................	1.5
26.	Concealed slope:................................	6.5
27.	Limestone: medium gray, aphanitic, thick, massive, firm; red chert bands common; weathers to rough, gray cliff...........................	1.0
28.	Concealed slope:.................................	4.5
29.	Siltstone: pale reddish brown, sandy, very thin to thick, massive, calcareous and hematitic; has inclusions of bluish gray, irregular patches of siltstone; weathers to pitted, reddish orange cliff..........................	13.5
30.	Sandstone: moderate orange pink, very fine-grained, thickm massive, calcareous and hematitic, friable; irregular concretions of white calcite common; weathers to pale reddish orange rounded cliff.....................	5.5
31.	Limestone: light olive gray, aphanitic, sandy, thick, flat-bedded, firm; weathers to rounded, gray slope....................................	2.0
32.	Concealed slope:................................	9.0
33.	Siltstone: pale red, sandy, very thick, massive, calcareous and hematitic, firm; weathers to rough, pitted, pale red and gray cliff......	9.0
34.	Sandstone: grayish red purple, very fine-grained, thick, flat-bedded, hematitic, firm; weathers to rough, purplish recess.............	1.0

Feet

35. Limestone: pale brown, aphanitic, thick, gnarly, firm; irregular bands of red chert common; weathers to rounded, rough, gray cliff.................................... 1.5

36. Siltstone: pale reddish brown, thick, flat-bedded, calcareous and hematitic; irregular concretions of light-colored limestone; forms rounded slope................................ 5.5

37. Siltstone: moderate reddish brown, sandy, thick, flat-bedded, hematitic, firm; weathers to purplish red, rounded slope................. 1.5

38. Limestone: pale red purple; same as no. 35..... 5.5

39. Siltstone: pale red, shaly to thick, flat-bedded, calcareous and hematitic, firm; weathers to slope and cliff which is rough; contains abundant worm borings(?)............... 14.0

40. Sandstone: moderate reddish orange, very fine-grained, thick, massive, firm, calcareous; small nodules of light gray siltstone abundant; weathers to rounded, reddish orange cliff.. 4.0

41. Sandstone: pale reddish brown, very fine-grained, shaly, flat-bedded calcareous; weathers to rough, reddish brown cliff.......... 6.5

42. Concealed slope:................................ 8.0

43. Quartzite: pale reddish brown, aphanitic, thick, flat-bedded, siliceous; weathers to smooth reddish brown cliff...................... 1.5

44. Siltstone: moderate reddish brown, sandy, thick, flat-bedded, calcareous and hematitic; weathers to rough, brick red slope.............. 4.0

45. Sandstone: pale reddish brown, very fine-grained, thick, flat-bedded, calcareous; weathers to a smooth slope.......................1.5

46. Concealed slope:................................ 5.5

47. Siltstone: pale reddish brown, sandy, thick, flat-bedded, hematitic, firm; weathers to rounded cliff................................. 4.0

	Feet
48. Sandstone: pale reddish brown, very fine-grained, thick, flat-bedded, hematitic; weathers to rough cliff........................	1.0
49. Concealed slope:................................	7.0
50. Sandstone: moderate reddish brown; same as no. 36; forms rough, purplish red cliff.......	2.0
51. Siltstone: pale red, shaly, flat-bedded, calcareous, firm; weathers to rough cliff and slope.................................	11.5
52. Limestone: medium gray, flat-bedded; same as no. 35................................	13.0
53. Sandstone: pale reddish brown, very fine-grained, thick, gnarly, calcareous and hematitic, firm; irregular, gray concretions of limestone common; weathers to rough, pitted, reddish brown cliff.........................	1.5
54. Limestone: grayish red purple; same as 35.....	5.5
55. Concealed slope:................................	6.5
56. Sandstone: pale reddish brown, very fine-grained, thick, flat-bedded, calcareous and hematitic, firm; weathers to rough, brick red slope.................................	4.5
57. Quartzite: pale reddish brown, aphanitic, thick, flat-bedded, siliceous, firm; inclusions of irregular quartzite concretions; weathers to rough, reddish brown cliff; contains abundant worm borings(?)...............	3.5
58. Sandstone: grayish pink, very fine-grained, shaly, flat-bedded, calcareous, firm; weathers to rough, reddish gray, shaly cliff...........	16.5
59. Concealed slope:................................	6.5
60. Limestone: light olive gray, aphanitic, very thick, massive, firm; layers of red and white chert abundant; weathers to rough, pitted cliff.....................................	27.0
61. Concealed slope:................................	52.5

	Feet
62. Limestone: yellowish gray, aphanitic, thick, massive, firm; weathers same as no. 60........	5.5
63. Concealed slope:.............................	19.5
64. Siltstone: dark reddish brown, sandy, thick, flat-bedded, gnarly, hematitic; pebbles up to 4 mm. in diameter of chert and hematite abundant; weathers to rough, dark red cliff.......	10.5
65. Concealed slope:.............................	1.0
66. Siltstone: dark reddish brown, thick, gnarly, calcareous and hematitic, firm; weathers to rough, dark red slope.........................	7.5
67. Concealed slope:.............................	8.0
68. Limestone: white to moderate reddish brown, aphanitic, thick, massive, friable; angular fragments of gray chert common; weathers to a rough, pitted, light gray slope.............	10.0
69. Concealed slope..............................	5.5
Total:	599.5

Redwall limestone:

Aphanitic limestone.

Section of Supai Formation
Cathedral Caves
N.W. $\frac{1}{4}$, Sec. 15, T. 20 N., R. 3 W.

	Feet
Supai formation:	
1. Sandstone: grayish orange pink, very fine-grained, thick, massive, siliceous; weathers to rough, reddish brown cliff..................	4.0
2. Concealed slope:.................................	5.5
3. Sandstone: moderate reddish orange, very fine-grained, thin-bedded, gnarly, calcareous, firm; weathers to smooth, reddish brown cliff..	4.0
4. Concealed slope:.................................	7.0
5. Sandstone: grayish orange pink, very fine-grained, very thick, cross-bedded, calcareous, firm; weathers to rough cliff...........	13.0
6. Concealed slope:.................................	7.5
7. Siltstone: pale reddish brown, sandy, shaly, flat-bedded, calcareous, firm; weathers to rough, reddish brown cliff....................	3.0
8. Concealed slope:.................................	3.0
9. Sandstone: pale red, very fine-grained, very thick, cross-bedded, calcareous, firm; weathers to rough, reddish orange cliff.................	4.0
10. Concealed slope:.................................	5.0
11. Sandstone: same as no. 9; weathers to rough, purplish red cliff.............................	8.0
12. Siltstone: pale reddish brown, sandy, thick, massive, calcareous and hematitic, firm; weathers to rough, reddish brown cliff.........	24.0
13. Siltstone: moderate reddish orange, sandy, very thick, massive, calcareous, firm; irregular masses of gray ls. common; weathers to reddish orange, pitted cliff..................	7.5

	Feet
14. Limestone: medium gray, aphanitic, thick, gnarly, firm; weathers to rough, gray cliff...	3.0
15. Siltstone: pale red, sandy, very thick, massive, calcareous, firm; inclusions of pale, reddish brown quartzite pebbles common; weathers to smooth, pale reddish brown cliff..	7.5
16. Siltstone: moderate reddish brown, sandy, thick, flat-bedded, hematitic, firm; weathers to rough, brick red slope....................	2.0
17. Concealed slope:..............................	9.0
18. Siltstone: pale reddish brown, sandy, very thick, massive, calcareous; inclusions of irregular masses of gray ls. and white chert bands common; weathers to smooth, reddish orange cliff................................	6.5
19. Siltstone: pale reddish brown, snady, shaly, flat-bedded, calcareous and hematitic; weathers to rough, reddish orange slope..........	7.5
20. Siltstone: pale reddish brown, sandy, thick, massive, calcareous and hematitic, firm; weathers to smooth, reddish orange cliff......	2.0
21. Siltstone: moderate reddish brown, sandy, thick, massive, calcareous, firm; weathers to smooth, brick red slope....................	16.0
22. Limestone: pale red, aphanitic, sandy, thick, gnarly, firm; weathers to rough, light gray cliff....................................	2.0
23. Concealed slope:..............................	8.5
24. Limestone: very light gray, very fine-grained, massive, thick, firm; inclusions of irregular, red and white chert bands rare; weathers to smooth, gray cliff..........................	3.0
25. Concealed slope:..............................	3.0
26. Sandstone: moderate reddish orange, very fine-grained, thick, massive, calcareous, firm; inclusions of irregular, gray nodules of limestone common; weathers to smooth, reddish orange cliff................................	1.5

		Feet
27.	Concealed slope:	4.0
28.	Sandstone: moderate reddish orange, very fine-grained, thick, massive, calcareous and hematitic, firm; weathers to rough, reddish orange cliff	11.0
29.	Quartzite: pinkish gray, thick, massive, firm; weathers to rough, pinkish gray cliff	2.0
30.	Siltstone: grayish orange pink to moderate reddish orange, sandy, shaly, flat-bdded, calcareous, firm; weathers to a smooth, light reddish brown slope	14.0
31.	Quartzite: moderate reddish brown, thick, massive, firm; weathers to smooth, reddish orange cliff	2.0
32.	Concealed slope:	3.5
33.	Sandstone: moderate reddish orange, very fine-grained, very thick, massive, calcareous, firm; inclusions of red and white chert bands common; weathers to a smooth, pale reddish brown cliff	6.0
34.	Sandstone: moderate reddish brown, very fine-grained, thick, massive, calcareous, firm; inclusions of irregular, gray, nodular limestone common; weathers to reddish brown, smooth cliff	5.5
35.	Concealed slope:	12.0
36.	Siltstone: moderate red, sandy, very thin to gnarly, calcareous and hematitic, firm; weathers to rough, purplish red cliff; fossil worm borings abundant	4.0
37.	Concealed slope:	5.5
38.	Claystone: pale reddish brown, thick, crumbly, calcareous; very weakly cemented; weathers to smooth, brick red slope	5.0
39.	Siltstone: pale reddish brown, sandy, shaly to thick, flat-bedded, hematitic, firm; weathers to rough, purplish red cliff	7.5

	Feet
40. Concealed slope: probably mudstone.............	3.0
41. Siltstone: pale reddish brown, sandy, thick, massive, siliceous and hematitic, firm; weathers to rough, purplish red cliff............	3.0
42. Siltstone: pale red purple, sandy, shaly, gnarly, quartzitic, firm; inclusions of silty, gray ovoid nodules of limestone and red and white chert bands common; weathers to rough cliff....................................	16.5
43. Claystone: pale reddish brown, very thin, flat-bedded, calcareous, friable; weathers to light red and gray recess.........................	4.0
44. Claystone: pale purple to pale red purple, sandy, thick, gnarly, calcareous and hematitic, firm; weathers to rough, purplish red cliff....	1.5
45. Claystone: pale red; same as no. 43...........	1.5
46. Concealed slope:.............................	2.5
47. Siltstone: pale red; same as no. 42...........	16.5
48. Limestone: medium light gray, aphanitic, massive, thick, firm; inclusions of irregular, red and white chert bands rare; weathers to smooth, gray cliff..............................	3.0
49. Concealed slope:.............................	10.0
50. Siltstone: pinkish gray, sandy, thick, massive, calcareous; inclusions of small, reddish nodules of very fine-grained sandstone common; weathers to rough cliff.....................	5.5
51. Claystone: grayish red purple, thick, calcareous and hematitic, friable; weathers to a crumbly recess............................	2.0
52. Concealed slope:...............................	1.5
53. Siltstone: moderate reddish brown, sandy, very thin, gnarly, hematitic, inclusions of white chert bands common; weathers to rough, reddish brown cliff............................	3.0

	Feet
54. Concealed slope:..............................	8.0
55. Limestone: yellowish gray, medium-grained, very thick, gnarly, firm; inclusions of irregular, white chert bands abundant, also some red siltstone; composita and spirifers(?) replacements of poor preservation, very abundant.............	36.0
56. Concealed slope:..............................	8.0
57. Limestone: yloowish gray, fine-grained, very thick, gnarly, firm; irregular stringers of white chert abundant; weather to rough cliff...	6.5
58. Concealed slope:..............................	2.0
59. Limestone: pale reddish purple, aphanitic, sandy, thick, massive, firm; weathers to smooth, purplish red cliff............................	2.0
60. Concealed slope:..............................	34.5
61. Limestone: pale reddish purple, aphanitic, thick, gnarly, firm; weathers to rough, gray slope..	6.5
62. Concealed slope:..............................	11.0
63. Claystone: pale reddish brown to medium gray, very thick, massive, calcareous, friable; angular fragments of reddish siltstone abundant; weathers to rough, purplish gray cliff.........	5.5
64. Concealed slope:..............................	45.5
Total:	488.0

Redwall limestone:

Section of Supai Formation
S.E. Edge of Black Mesa
N.E. $\frac{1}{4}$, Sec. 26, T. 19 N., R. 2 W.

		Feet
Supai formation:		
1.	Sandstone: grayish pink, very fine-grained, thin to very thick, cross-bedded, calcareous, firm; occasional irregular lenses of gray limestone; weathers to rough, reddish brown cliff	37.5
2.	Limestone: pale red purple, aphanitic, sandy, thick, gnarly, firm; weathers to smooth, light gray cliff	3.0
3.	Sandstone: moderate reddish orange, very fine-grained, thin to very thick, massive, calcareous, firm; weathers to rough, reddish brown cliff	45.0
4.	Siltstone: moderate orange pink, sandy, thick, cross-bedded, calcareous, firm; possibly reworked Coconino sandstone; contains grayish orange pink tongues of siltstone	57.5
5.	Concealed slope:	5.5
6.	Siltstone: moderate reddish orange, sandy, thin to very thick, massive, calcareous and hematitic, firm; weathers to rough, reddish brown cliff	17.0
7.	Concealed slope:	5.5
8.	Sandstone: moderate reddish orange, very fine-grained, thick, massive, calcareous, firm; weathers to rounded, reddish brown cliff	5.5
9.	Limestone: pale red purple, aphanitic, thick, flat, firm; weathers to rough, gray cliff	5.0
10.	Quartzite: moderate orange pink, thick, massive, firm; weathers to smooth, pale reddish brown cliff	6.5

	Feet
11. Concealed slope:................................	7.5
12. Quartzite: moderate orange pink, same as no. 10......................................	3.0
13. Concealed slope:................................	4.0
14. Siltstone: moderate orange pink, sandy, very thick, massive, calcareous, firm; weathers to rounded, reddish brown cliff....................	7.5
15. Concealed slope:................................	3.0
16. Siltstone: moderate reddish orange; same as no. 14..	21.0
17. Concealed slope:................................	2.0
18. Sandstone: moderate orange pink, very fine-grained, thin, flat-bedded, calcareous, firm; weathers to rough, reddish brown cliff.........	7.0
19. Siltstone: pale reddish brown, sandy, very thin to thick, flat-bedded, calcareous and hematitic, firm; weathers to rounded, pale reddish brown cliff............................	7.5
20. Concealed slope:................................	3.0
21. Sandstone: moderate reddish orange, very fine-grained, very thick, massive, calcareous, firm; weathers to rounded, reddish brown cliff.	9.5
22. Concealed slope:................................	11.0
23. Siltstone: moderate reddish orange, sandy, very thick, massive, calcareous, firm; inclusions of irregular "stringers" of gray limestone common; weathers to rounded, pale reddish brown cliff............................	13.0
24. Concealed slope:................................	3.0
25. Sandstone: moderate reddish orange, very fine-grained, very thick, cross-bedded, calcareous, firm; weathers to rounded, reddish brown cliff..	12.0

		Feet
26.	Limestone: pale red purple, aphanitic, sandy, thin, gnarly, firm; weathers to shaly, gray cliff..	3.0
27.	Siltstone: moderate orange pink, sandy, thin, cross-bedded, calcareous, firm; weathers to smooth, pale reddish brown cliff..............	6.0
28.	Siltstone: pale reddish brown, sandy, thick, flat-bedded, hematitic, firm; weathers to rounded, reddish orange cliff.................	1.0
29.	Concealed slope:..............................	8.0
30.	Sandstone: moderate orange pink, very fine-grained, very thick, massive, calcareous, firm; weathers to rounded, reddish brown cliff..	27.5
31.	Concealed slope:..............................	10.0
32.	Siltstone: moderate reddish orange, sandy, thin, flat-bedded, calcareous, firm; in upper 2 feet, gray limestone fragments common; weathers to rough, reddish brown cliff...........	4.0
33.	Concealed slope:..............................	2.0
34.	Siltstone: moderate orange pink, sandy, thick, massive, calcareous, firm; weathers to rough, pale reddish brown cliff.......................	6.5
35.	Concealed slope:..............................	10.0
36.	Limestone: pale red, aphanitic, silty, thick, flat-bedded, firm; weathers to rough, gray cliff..	1.0
37.	Siltstone: pale red, sandy, thick, gnarly, calcareous, firm; weathers to rough, reddish gray cliff: boundary with bed above is gradational..	2.5
38.	Siltstone: pale reddish brown, sandy, very thin, flat-bedded, calcareous, firm; weathers to rough, reddish brown cliff: contact gradational with bed above........................	4.5
39.	Concealed slope:..............................	3.0

		Feet
40.	Siltstone: purplish red, sandy, thick, massive, calcareous and hematitic, firm; weathers to rough reddish brown cliff........................	1.0
41.	Siltstone: moderate orange pink, sandy, thick, cross-bedded, calcareous, firm; weathers to smooth, pale reddish brown cliff................	5.0
42.	Siltstone: moderate reddish brown, sandy, thin, flat-bedded, hematitic, firm; weathers to smooth, brick red recess.........................	1.0
43.	Claystone: very pale orange, very thin, flat-bedded, calcareous, friable; weathers to smooth recess..................................	0.5
44.	Concealed slope:................................	5.5
45.	Siltstone: pale yellowish orange and pale reddish brown, sandy, thick, massive, calcareous, firm; weathers to smooth, pale red cliff........	6.5
46.	Concealed slope:................................	6.0
47.	Quartzite: pale yellowish orange, thick, massive, firm; weathers to smooth, pale red cliff...	6.5
48.	Siltstone: pale reddish brown, sandy, very thin, flat-bedded, calcareous, friable; weathers to reddish brown, shaly slope.............	3.5
49.	Concealed slope:................................	5.0
50.	Quartzite: moderate reddish orange, thick, massive, firm; inclusions of irregular veinlets of gray limestone common; weathers to pitted, reddish brown cliff; grades laterally into limestone..................................	3.0
51.	Concealed slope:................................	6.0
52.	Siltstone: pale reddish brown, sandy, thick, massive, calcareous, firm; weathers to brick red cliff......................................	2.0
53.	Concealed slope:................................	2.0
54.	Sandstone: moderate reddish brown, very fine-grained, thick, massive, calcareous and hematitic, firm; weathers to pitted, reddish orange cliff...	1.0

		Feet
55.	Concealed slope:................................	3.5
56.	Limestone: pale reddish brown to light brownish gray, aphanitic, thin, flat-bedded, firm; inclusions of red and white, irregular chert bands common; weathers to smooth, gray cliff.........	0.5
57.	Concealed slope:................................	38.5
58.	Sandstone: moderate reddish orange, very fine-grained, thick, massive, hematitic, firm; weathers to pitted, reddish orange slope..........	4.5
59.	Concealed slope:................................	3.5
	Total:	507.0

Pennsylvanian (?) limestone:
Generally included as the lower portion of the Supai formation. Concealed at this locality.

Section of Supai Formation
Sycamore Canyon
(Member A Measured at Base of Mooney Trail,
East Side: Rest of Section Measured
at S.W. Corner of Island Mesa)
Measured by E. D. McKee

Coconino Sandstone: Feet

Sandstone: very pale brown, very fine-grained, friable; shows compound cross-bedding on huge scale to base; contains no flat bedding; composed of clear even-grained quartz; shows wind ripples; weathers same to light yellowish brown; forms massive cliff.

Supai-Coconino contact: (placed at top of uppermost flat-bedded red siltstone) Surface level where observed.

Supai formation:

Member A. units forming massive, rounded cliffs (an alternating series of thick, massive, light red, cross-laminated sandstone units and thin, weak red, wavy-bedded siltstone units, well delineated by very light brown bands at top of each unit.)

1. Siltstone: weak reddish brown with some very light brown beds; beds flat to irregular, wavy- forms recess (cliff-dwelling level); grades upward into very light brown siltstone..14.5

2. Sandstone: very light brown, very fine-grained, silty, calcareous; cross-laminated on large scale with individual laminae sloping from top to base; forms massive rounded cliff.......22.0

3. Siltstone: weak reddish brown, wavy-bedded; like no. 1; wedges out........................... 1.0

4. Sandstone: very light brown, cross-laminated, cliff-forming; like no. 2....................... 2.5

5. Siltstone: weak reddish brown, wavy-bedded; like no. 1.................................... 8.5

		Feet
6.	Sandstone: very light brown, cross-laminated, cliff-forming; like no. 2	32.0
7.	Siltstone: weak reddish brown, wavy-bedded; like no. 1; forms recess	6.5
8.	Sandstone: light brown, fine-grained, very friable; cross-laminated on large scale; at 44 feet from base, laminae show prominent irregular folding due to penecontemporaneous deformation (folded zone 2 feet thick, very widespread; folds overturned to south); weathers same color to weak brown; forms massive, rounded cliff	82.5
9.	Siltstone: weak reddish brown, wavy-bedded; like no. 1	2.5
10.	Sandstone: light brown, cross-laminated; like no. 8; weathers white over wide area	80.0
11.	Siltstone: weak reddish brown, wavy-bedded; like no. 1; sandy	5.0
12.	Sandstone: light brown, cross-laminated; like no. 8	8.0
13.	Siltstone: weak reddish brown, wavy-bedded; like no. 1	1.5
14.	Siltstone: pale reddish brown; cross-laminated on small scale throughout; weathers to light brown; appears as conspicuous band	3.5
15.	Siltstone: weak reddish brown, wavy-bedded; like no. 1	1.5
16.	Siltstone: pale reddish brown, cross-laminated; like no. 14; laminae in basal 6 inches show close, overturned folds due to penecontemporaneous deformation	8.0
17.	Siltstone: weak reddish brown, wavy-bedded; like no. 1; forms prominent bench in canyon wall	32.0
18.	Sandstone: light brown, cross-laminated; like no. 8	159.5

	Feet
19. Siltstone: weak reddish brown, wavy-bedded; like no. 1; occurs as lens which thins and disappears within $\frac{1}{4}$ mile........................	4.5
20. Sandstone: light brown, very fine- to fine-grained; cross-laminated throughout on large scale with much local small-scale structure; contains a few lenses of flat-bedded siltstone; grades from fine-grained, poorly-laminated sandstone downward into fine- to very fine-grained sandstone which is less yellowish in color and which shows well-developed cross-lamination; forms major cliff................................	171.5
21. Siltstone: weak reddish brown, wavy-bedded; like no. 1....................................	2.0
22. Sandstone: light brown, cross-laminated; like no. 8....................................	7.0
23. Siltstone; Weak reddish brown, wavy-bedded; like no. 1....................................	6.0
24. Sandstone: light brown, fine-grained; cross-laminated; like no. 8; grades down into very fine-grained, pale reddish brown sandstone.....	13.5
25. Siltstone: weak reddish brown, wavy-bedded, recess-forming; like no. 1; shows erosion channels at top (max. depth 1 foot)............	12.5
26. Sandstone: light brown, cross-laminated; like no. 8; contains small lenses of flat-bedded siltstone like no. 3; very light brown near top; forms massive rounded cliff...............	27.5
27. Siltstone: weak reddish brown, wavy-bedded; like no. 1....................................	2.5
28. Sandstone: light brown, cross-laminated; like no. 8....................................	29.5
29. Sandstone: weak to pale reddish brown, friable; shows comples cross-laminations on large scale throughout unit; forms weak cliff or recess....	10.5
A. total	758.0

	Feet
Member B: units forming shaly slopes and thin ledges.	
1. Conglomerate.. matrix: weak reddish brown, argillaceous siltstone; gravel: mostly one inch or less; very light brown argillaceous siltstone, no limestone noted.	11.0
2. Siltstone: moderate reddish brown; beds thin and shaly; weathers weak reddish brown; forms partly-concealed slope; alternates with: siltstone: moderate reddish brown, thick-bedded (1-2 ft.); many beds near base contain white rods and discs; weathers rounded; forms lidges; total..............................	71.5
3. Sandstone: pale reddish brown, calcareous, weakly bedded; weathers same; forms resistant ledge (marker bed).............................	7.0
4. Siltstone: moderate reddish brown; beds thin, shaly; forms slope.............................	11.0
5. Siltstone: weak reddish brown, argillaceous, resistant; beds flat, 1-12 inches thick; forms ledge..................................	6.0
6. Slope: concealed................................	5.5
7. Siltstone: pale reddish brown, argillaceous, structureless, resistant; beds $\frac{1}{2}$-3 feet thick; weathers rounded; forms series of ledges.......	10.0
8. Siltstone: pale reddish brown; similar to no. 7 but in thin shaly layers; forms slope........	5.0
9. Siltstone: pale reddish brown, ledge-forming; like no. 7.....................................	43.0
10. Siltstone: moderate reddish brown, slope-forming; like no. 4; contains worm boring; includes: Conglomerate: lenses near base; matrix: pale to weak red siltstone; gravel: up to several inches, rounded; pale siltstone and medium gray limestone; total..	25.0

Feet

11. Limestone: very pale reddish brown, structureless; weathers very pale brown, silty; forms prominent ledge........................ 3.0

12. Siltstone: weak reddish brown, calcareous, hard; beds flat, 2-5 ft. thick; weathers rounded; forms resistant ledges; alternates with:
Siltstone: weak reddish brown; beds thin and flat; forms slopes;
total..33.0

13. Siltstone: weak reddish brown, calcareous, structureless; contains nodular structures; weathers same, rounded; forms slopes and weak ledges; grades laterally into gray limestone....22.5

14. Conglomerate: massive......................... 3.0
matrix: weak reddish brown siltstone;
gravel: up to five inches, rounded and subangular; many laminated siltstones, light brownish gray limstone, medium gray algal limestone.

15. Siltstone: weak reddish brown, structureless; beds 1-2 ft. thick; surface shows small white rods and siscs (limestone nodules) scattered in abundance; forms ledges with rounded surfaces; alternates with:
Claystone: weak reddish brown; beds thin (1-3 inches), flat;
total forms series of ledges and slopes..........16.5

16. Conglomerate.................................. 3.0
matrix: pale to weak red siltstone;
gravel: up to 3 inches, mostly ½ inch or less; rounded; weak reddish brown and pale brown siltstone.

17. Siltstone and claystone: weak reddish brown, ledge- and slope-forming; like no. 15...........13.5

18. Sandstone: mottled light brown, pale reddish brown, and weak reddish brown; fine- to very fine-grained, calcareous cross-laminated on large scale; contains large patches of limestone showing structure lines...................11.5

	Feet
19. Siltstone: weak reddish brown, calcareous, resistant, thick-bedded ($\frac{1}{2}$-1 ft.), weathers same color to light brown; alternates with; Siltstone: shaly, calcareous, weak; contains thin, irregularly-bedded limey nodules; and Limestone: dark reddish gray, aphanitic, silty, massive; weathers pale reddish gray, pitted; total forms slope with ledges..................	16.0
20. Limestone: dark reddish gray, aphanitic, silty to sandy, prominantly cross-laminated; contains irregular patches of reddish clay and obscure algal ? markings; weathers pale reddish gray, pitted, massive; forms ledge..................	6.0
Slope: concealed..................................	5.5
B. total	328.5

Member C: units forming main cliffs of inner gorge.

1. Sandstone: pale red, very fine-grained, dolomitic, cross-laminated; weathers very pale reddish brown, sandy, pitted; forms cliff......	19.5
2. Sandstone: pale red, very fine-grained; like an iron oxide cement; consists of small (1-2 mm.) sand concretions; weathers light yellowish brown to light brown; forms bench..........	8.5
3. Sandstone: pale red, very fine-grained; like no. 1; grades down into: Sandstone: very pale reddish brown, very fine-grained, very calcareous; weathers with calcite patches; total forms major cliff........................	66.0
4. Siltstone: weak red, thin-bedded ($\frac{1}{2}$-2 inches); weathers pale red.............................	16.5
5. Sandstone: pale reddish brown, very fine-grained, calcareous, prominently cross-laminated on large scale; weathers light brown; forms cliff....................................	14.0
6. Siltstone: pale red, argillaceous, calcareous, laminated; forms ridge..................	10.0

		Feet
7.	Sandstone: pale red, very fine-grained; like no. 1; weathers light brown to light reddish gray; forms major cliff........................	44.0
8.	Siltstone: pale reddish brown, calcareous, beds irregular; forms slope....................	7.0
9.	Sandstone: very pale orange, very fine-grained, massive, friable; large-scale cross-lamination weakly developed; weathers very pale brown; forms prominent rounded cliff..................	16.0
10.	Siltstone: pale reddish brown, argillaceous; beds thin and shaly; weathers same color; forms slope..................................	8.5
11.	Siltstone: very pale reddish brown, structureless; contains light brownish gray limestone nodules oriented vertically; weathers same color to weak brown; forms rounded ledges.............	5.5
12.	Limestone: weak reddish brown, finely crystalline, silty; cross-laminated on large scale; weathers pale reddish brown; forms vertical ledge......................................	6.0
13.	Siltstone: weak reddish brown, shaly; like no. 10.....................................	5.0
14.	Siltstone: weak red, massive; beds flat and irregular; weathers same color; forms ledge....	5.5
15.	Limestone: reddish gray, aphanitic, silty; beds at base thin, those in center thick (10-15 ft.); cross-laminated on large scale; weathers very pale red, silty, pitted; forms massive cliff.................................	14.0
	C. total	246.5

Bottom of C member? (Boundary arbitrarily placed at base of massive, cliff-forming units, conforming with usage of Huddle and Dobrovolney.)

Naco limestone: units forming alternating cliffs and slopes.

Bibliography

Barnes, W.C., Arizona Place Names, Univ. of Ariz. Gen. Bull. No. 2, 1935.

Clark, F.W., Data of geochemistry, U.S. Geol. Survey Bull. 770, 1924.

Darton, N.H., A Reconnaissance of parts of Southwestern New Mexico and Northern Arizona, U.S. Geol. Survey Bull. 435, 1910.

_____ A resume' of Arizona geology, Univ. of Ariz., Coll. of Mines Bull. No. 119, 1925.

Dunbar, Carl O., and Condra, G.E., Brachiopoda of the Pennsylvanian System in Nebraska, Nebraska Geological Survey, Bull. 5, Second Series, 1932.

Eaton, J.E., The by-passing discontinuous deposition of sedimentary materials, Bull. A.A.P.G., Vol. 13, No. 7, 1929.

Fenneman, N.M., Physiographic Provinces of Western United States, McGraw-Hill Book Co., 1931.

Fredericks, George, Table pour de'finition des genres de la Fam. Spiriferidae King, Bull. de l'ac. Sci. URSS, 1926.

Gilbert, G.K., U.S. Geog. and Geol. Surveys W. 100th Mer. Rept., Vol. 3, pp. 161, 162, 177, 178, 185, fig. 82, 1875.

Glock, Waldo, Geology of the east-central part of the Spring Mountain Range, Nevada, Amer. Jour. of Sci., Vol. 17, 1929.

Gutschick, R.C., Personal communication, 1949.

_____ The Redwall limestone (Mississippian) of North Central Arizona, PhD thesis (unpublished), Univ. of Ill., 1942.

Huddle, J.W., and Dobrovolny, E., Late Paleozoic stratigraphy and oil and gas possiblilities of central and northeastern Arizona, U.S. Geol. Survey Oil and Gas Invest. Prelim. Chart 10, 1945.

Hughes, P.W., History of the Supai formation in the Black Mesa Yavapai County, Arizona, Plateau, Museum of Northern Arizona., Vol. 22, No. 2, 1949.

Ives, J.C., Report upon the Colorado River of the West, Ex. Doc., 1st Session of the 36th Congress, U.S. Senate, 1861.

Knight, J. Brooks, Personal communication, 1949.

Krynine, Paul D., The origin of red beds, Trans. N.Y. Acad. Sci., Series II, Vol. 2, No. 3, pg. 61, 1949.

Lahee, F.H., Field Geology., Fourth Edition, McGraw-Hill Book Co., 1941.

Longwell, C.R., Geology of the Muddy Mountains Nevada, U.S. Geol. Survey Bull. 798, 1928.

Longwell, C.R., and Dunbar, C.O., Problems of Pennsylvanian-Permian boundary in southern Nevada, Bull. A.A.P.G., Vol. 20, No. 9, 1936.

Marcou, Jules, Geology of North America, Zürcher and Furrer, Zurich, Switzerland, 1858.

McKee, E.D., The Inverted Mountains, Vanguard Press, 1948.

_____Cambrian History of the Grand Canyon Region, Carnegie Inst. Wash., Publ. 563, 1945.

_____The Coconino Sandstone, Carnegie Inst. Wash., Publ. No. 440, 1934.

_____Three types of cross-lamination in Paleozoic rocks of Northern Arizona, Amer. Jour. of Sci., Vol. 238, 1940.

_____Some types of bedding in the Colorado River delta, Jour. of Geol., Vol. 47, 1939.

_____Studies on the history of Grand Canyon Paleozoic formations, Carnegie Inst. Wash., Year Book No. 39, 1939.

_____Personal communication, 1950.

Newberry, J.S., in Ives, J.C., op. cit.

Noble, L.F., The Shinumo Quadrangle, Grand Canyon District, Arizona, U.S. Geol. Survey Bull. 549, 1914.

_____A section of the Paleozoic formations of the Grand Canyon at the Bass Trail, U.S. Geol. Survey Prof. Paper 131-B, 1922.

Reiche, P., An Analysis of Cross-lamination: The Coconino Sandstone, Jour. of Geology, Vol. 46, No. 7, 1938.

Shimer, H.W., Permo-Triassic of northwestern Arizona, Bull. G.S.A., Vol. 30, 1919.

Shimer and Shrock, Index fossils of North America, Wiley, 1947.

Stoyanow, A.A., Correlation of Arizona Paleozoic formations, Bull. Geol. Soc. Amer., Vol. 47, p. 495, 1936.

_____Paleozoic paleogeography of Arizona, Bull. Geol. Soc. Amer., Vol. 53, 1942.

Tarr, W.A., The origin of chert and flint, Univ. of Missouri Studies, Vol. 1, No. 2, 1926.

Twenhofel, W.H., Principles of Sedimentation, McGraw-Hill Book Co., 1st Edit., 1939.

Wanless, H., Personal communication, 1949.

White, David, Flora of the Hermit shale, Grand Canyon, Arizona, Carnegie Inst. Wash., Publ. 405, 1929.

_____Carnegie Year Book 27, 1927-28.

Williams, James Steele, Personal communication, 1949.

Zittel, Karl A., Textbook of Paleontology, Vol. 1, Second Edition Revised and Enlarged, 1927.

QUANTITATIVE ESTIMATE of MEASURED SECTION of SUPAI FORMATION Sec. 2, T. 21 N, R. 5 W.

ROCK TYPE	Number of beds	Thickness	% of total thickness	CEMENT: CALCAREOUS — Number of beds	Thickness	% of total thickness	HEMATITIC — Number of beds	Thickness	% of total thickness	CALCAREOUS & HEMATITIC — Number of beds	Thickness	% of total thickness	SILICEOUS — Number of beds	Thickness	% of total thickness	DOLOMITIC — Number of beds	Thickness	% of total thickness
Concealed slope believed to be mostly CLAYSTONE	29	259	24.0															
SILTSTONE	41	546	50.7	30	452.5	42.0	3	6	0.6	6	71	6.6	0	0	0	2	16.5	1.5
VERY FINE SANDSTONE	20	217	20.1	5	48.5	4.5	0	0	0	3	39	3.6	12	129.5	12	0	0	0
CONGLOMERATE	1	7	0.6	1	7.0	0.6	0	0	0	0	0	0	0	0	0	0	0	0
LIMESTONE	9	43.5	4.0	9	43.5	4.0	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL	100	1072.5	99.4	45	551.5	50.1	3	6	0.6	9	110	10.2	12	129.5	12.0	2	16.5	1.5

PLATE III

QUANTITATIVE ESTIMATE of MEASURED SECTION of SUPAI FORMATION Sec. 19, T. 21N, R. 4W.

ROCK TYPE	Number of beds	Thickness	% of total thickness	CEMENT: CALCAREOUS Number of beds	Thickness	% of total thickness	HEMATITIC Number of beds	Thickness	% of total thickness	CALCAREOUS & HEMATITIC Number of beds	Thickness	% of total thickness	SILICEOUS Number of beds	Thickness	% of total thickness	DOLOMITIC Number of beds	Thickness	% of total thickness
Concealed slope believed to be mostly CLAYSTONE	20	171.5	28.4															
SILTSTONE	15	97.5	16.6	4	20.0	3.5	4	17.5	3.1	7	60.0	9.9						
VERY FINE SANDSTONE	23	256.5	42.0	11	188.0	31.5	4	37.0	5.8	6	26.5	4.1	2	5.0	0.4			
CONGLOMERATE	0																	
LIMESTONE	11	74.0	12.8	11	74.0	12.8												
TOTAL	69	599.5	99.8	26	282.0	47.8	8	54.5	8.9	13	86.5	14.0	2	5.0	0.4			

PLATE IV

QUANTITATIVE ESTIMATE of MEASURED SECTION of SUPAI FORMATION Sec. 15, T. 20N., R. 3 W.

ROCK TYPE	Number of beds	Thickness	% of total thickness	CEMENT: CALCAREOUS Number of beds	Thickness	% of total thickness	HEMATITIC Number of beds	Thickness	% of total thickness	CALCAREOUS & HEMATITIC Number of beds	Thickness	% of total thickness	SILICEOUS Number of beds	Thickness	% of total thickness	DOLOMITIC Number of beds	Thickness	% of total thickness
Concealed slope believed to be mostly CLAYSTONE	28	219	44.9															
SILTSTONE	17	146	29.9	7	60.0	12.3	4	15.5	3.6	4	37.5	7.5	2	33.0	6.6			
VERY FINE SANDSTONE	11	61	12.5	7	42.0	8.6				1	11.0	2.2	3	8.0	1.6			
CONGLOMERATE	0																	
LIMESTONE	8	62	12.7	8	62.0	12.7												
TOTAL	64	488	100.0	22	164.0	33.6	4	15.5	3.6	5	48.5	9.7	5	41.0	8.2			

PLATE V

QUANTITATIVE ESTIMATE of MEASURED SECTION of SUPAI FORMATION Sec. 26, T. 19N, R. 2 W.

ROCK TYPE	Number of beds	Thickness	% of total thickness	CEMENT: CALCAREOUS Number of beds	CALCAREOUS Thickness	CALCAREOUS % of total thickness	HEMATITIC Number of beds	HEMATITIC Thickness	HEMATITIC % of total thickness	CALCAREOUS & HEMATITIC Number of beds	CALCAREOUS & HEMATITIC Thickness	CALCAREOUS & HEMATITIC % of total thickness	SILICEOUS Number of beds	SILICEOUS Thickness	SILICEOUS % of total thickness	DOLOMITIC Number of beds	DOLOMITIC Thickness	DOLOMITIC % of total thickness
Concealed slope believed to be mostly CLAYSTONE	23	153.5	30.2															
SILTSTONE	18	167.0	32.8	13	139.5	27.7	2	2.0	0.2	3	25.5	4.9						
VERY FINE SANDSTONE	13	168.5	34.0	7	144.0	28.8	1	4.5	0.9	1	1.0	0.2	4	19.0	3.8			
CONGLOMERATE	0																	
LIMESTONE	5	18.0	3.5	5	18.0	3.5												
TOTAL	59	507.0	100.5	25	301.5	60.0	3	6.5	1.1	4	26.5	5.1	4	19.0	3.8			

PLATE VI

PLATE VII

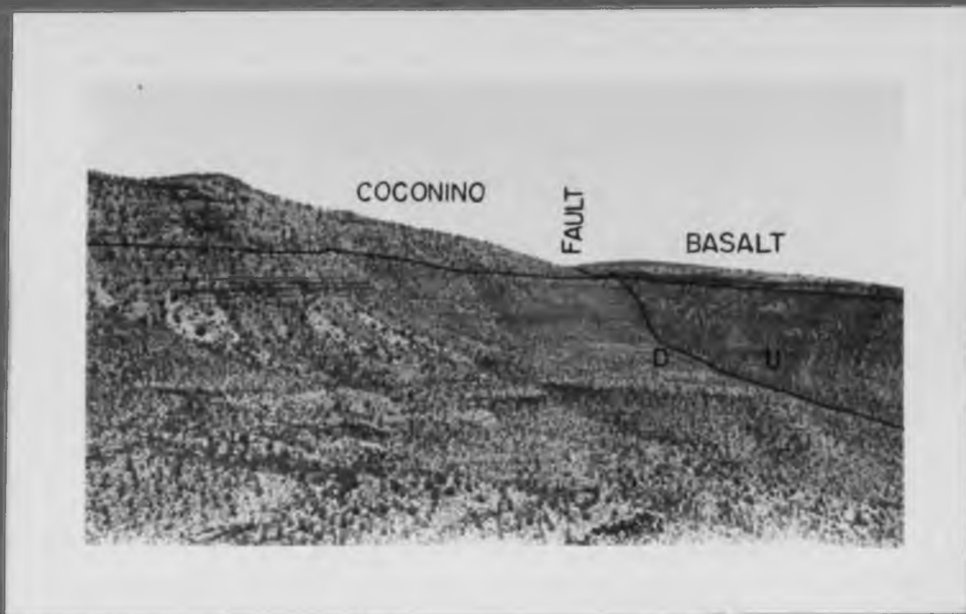

PLATE VIII

Fig. 1

Scour and fill in Supai formation in Black Mesa.

Fig. 2

Basal conglomerate and shaly sandstone of the Supai formation.

PLATE VIII

PLATE VII

Fig. 1

General view, to the southeast, of Supai formation three miles west of Picacho Butte. The Permian Coconino sandstone and Tertiary basalt are in contact with the Supai formation.

Fig. 2

Basalt feeder dike and flows along west side of Chino Valley.

PLATE IX

PLATE IX

Fig. 1

Beveling and deposition type of cross-lamination in the Supai formation.

Fig. 2

Cross-lamination due to coalescence of small lobes built on the advancing front of the deltaic Supai formation.

PLATE X

PLATE X

Fig. 1

Foreset type of cross-lamination in the Supai formation.

Fig. 2

Nodular chert in sandstone of Upper Supai formation.

PLATE XI

PLATE XI

Fig. .1

Beds and stringers of chert in massive limestone of the basal Supai.

Fig. 2

Nodular chert in sandstone of Upper Supai. Annular-like rings are composed of red silt.

Гл Роскат
2 мая