Northern Arizona University

Flagstaff

GEOLOGY OF WET BEAVER CREEK CANYON, YAVAPAI COUNTY, ARIZONA

By

John Robert Thompson, Jr.

A Thesis Submitted In Partial Fulfillment Of The
Requirements For The Degree Of
Master of Science in Geology

Approved by:

Chairman Richard M. Rush

Stanley S. Beus

De Forest Swanson

Date: June 5, 1968

Northern Arizona University

Flagstaff

GEOLOGY OF WET BEAVER CREEK CANYON, YAVAPAI COUNTY, ARIZONA

By

John Robert Thompson, Jr.

A Thesis Submitted In Partial Fulfillment Of The Requirements For The Degree Of Master of Science in Geology

TABLE OF CONTENTS

FIGURES

TABLES

PLATES

PURPOSE OF INVESTIGATION

This project was initiated to map, in more detail than had heretofore been attempted, the geology of Wet Beaver Creek Canyon. The project is intended to study stratigraphic sections never visited by geologists before and to map a cross-section of faults on the Mogollon Slope of the Colorado Plateau. Stratigraphic and structural information compiled from the study is expected to aid the geologic investigations of the Beaver Creek Experimental Watersheds, immediately to the north of the Canyon. It shows stratigraphic and structural trends of the region.

FIELDWORK AND METHODS

Fieldwork began in the summer of 1967 and the bulk of the geologic mapping was finished in August, 1967. Subsequent visits in the Fall of 1967 and the Spring of 1968 completed the fieldwork.

The project was done under the direction of Drs. Rush, Beus, and Smouse of Northern Arizona University.

A brunton compass was the primary instrument used in the field. It served to measure strike and dip, trends of faults, and as a hand level in measuring sections. A base map combining two maps, the Camp Verde 4NW and 4NE quadrangles, made by the United States Forest Service and United States Geological Survey was used in the field. These maps are presently available in fully edited form by the United States Geological Survey as Casner Butte and Apache Maid Mountain quadrangles. Data was plotted on air photographs and transferred to the base map by inspections.

PREVIOUS INVESTIGATIONS

Many studies have been made of the geology in and near the Verde Valley: the following articles are the most pertinent to this investigation.

In 1951 R.L. Jackson studied the Supai Formation along the Mogollon Rim and determined its depositional history (The Stratigraphy of the Supai Formation along the Mogollon Rim, Central Arizona: unpublished M.S. thesis, University of Arizona).

B.E. Sabels, in 1960, studied the volcanism of this region and tentatively correlated the Hickey Formation from the Mingus Mountain area to the San Francisco and Mormon Mountain volcanic fields (Late Cenozoic Volcanism in the San Francisco Volcanic Field and Adjacent Areas in North Central Arizona: unpublished PhD. thesis, University of Arizona).

In 1963 F.R. Twenter and D.G. Metzger made a study of the geology and ground water of the Verde Valley (U.S. Geological Survey Bulletin 1177). This study included some data from the Wet Beaver Creek area.

Dr. R.W. Rush investigated a small area immediately to the north of the lower end of Wet Beaver Creek Canyon in 1965. In his report he presented one of the first theories concerning the volcanic sequence of the area (Report of Geologic Investigation of Six Experimental Drainage Basins 1-6, Beaver Creek Watershed, Yavapai County, Arizona).

In 1966 Drs. Beus, Rush, and Smouse, all of Northern Arizona University, investigated a larger area to the north of Wet Beaver Creek Canyon. In this paper the authors presented structural trends of the area, in addition to mapping the surface geology (Geologic Investigation of Experimental Drainage Basins 7-14, Beaver Creek Watershed, Coconino County, Arizona).

ACKNOWLEDGEMENTS

The writer wishes to thank the Museum of Northern Arizona for the generous research grant which financed the field investigations. Miss Kathrine Bartlett, Librarian for the Museum of Northern Arizona assisted greatly in the search for material pertaining to the project. Mr. William Breed, Curator of Geology at the Museum of Northern Arizona gave counsel and provided office space which facilitated the writing of the thesis. Dr. R.W. Rush, Associate Professor of Geology at Northern Arizona University supervised the project and reviewed the manuscript. The U.S. Forest Service provided air photographs and base maps of the project area, and the Water Resources Division of the U.S. Geological Survey provided helpful comments and maps. Kenneth Veronda of the Southwestern Military Academy allowed access to the lower end of the Canyon. Summer assistants of the Museum of Northern Arizona who assisted in most of the field investigations include Donald Kron and George Billingsley. Also, friends of the author, Greye Dunning and Bruce Janis helped on several of the investigating trips. Drafting was done by Isobel Powell. Others deserving a note of gratitude are the staff and students of the Geology Department at Northern Arizona University. Finally, I wish to thank my wife, Kathi, who helped me through many difficult and trying hours during this project.

GEOGRAPHY AND LOCATION

Wet Beaver Creek Canyon, near the center of Arizona (Fig.1), is approximately one-half mile wide and fourteen miles long. It is bounded by 111°32'30" to 111°42'30" longitude and 34°38'30" to 34°42'30" latitude. The canyon drains 413 square miles and is bounded on the east by the town of Happy Jack and on the west by the Mogollon Rim(Fig. 2).

Two highways, U.S. 79 and State 87(Mormon Lake Road) provide the principle access routes to the area. Many unimproved Forest Service roads lead to widely separated points on the rim of the canyon. The major part of the canyon is accessibly on foot only. Maximum relief in the area is approximately 2500 feet.

Principle centers of population near the canyon are Camp Verde, McGuireville, and Lake Montezuma below the mouth of the canyon; the Southwestern Military Academy in the mouth of the canyon; and Happy Jack and Stoneman Lake near the head of the canyon.

Ecological and vegetation zones vary widely in the study area, primarily as functions of climate. Vegetation zones range from lower Upper Sonoran to Upper Transition, with an abundance of thorny plants covering

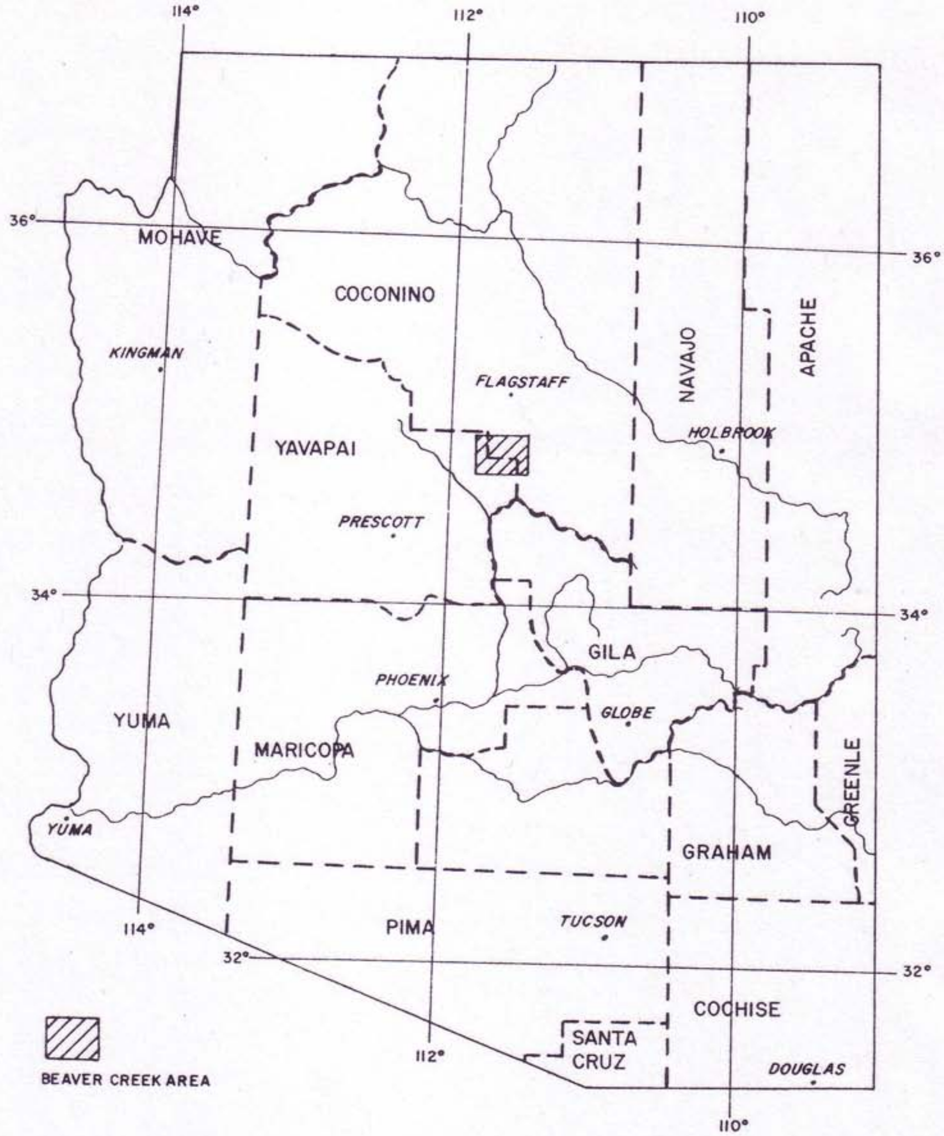


FIGURE I - MAP OF ARIZONA SHOWING LOCATION OF STUDY AREA

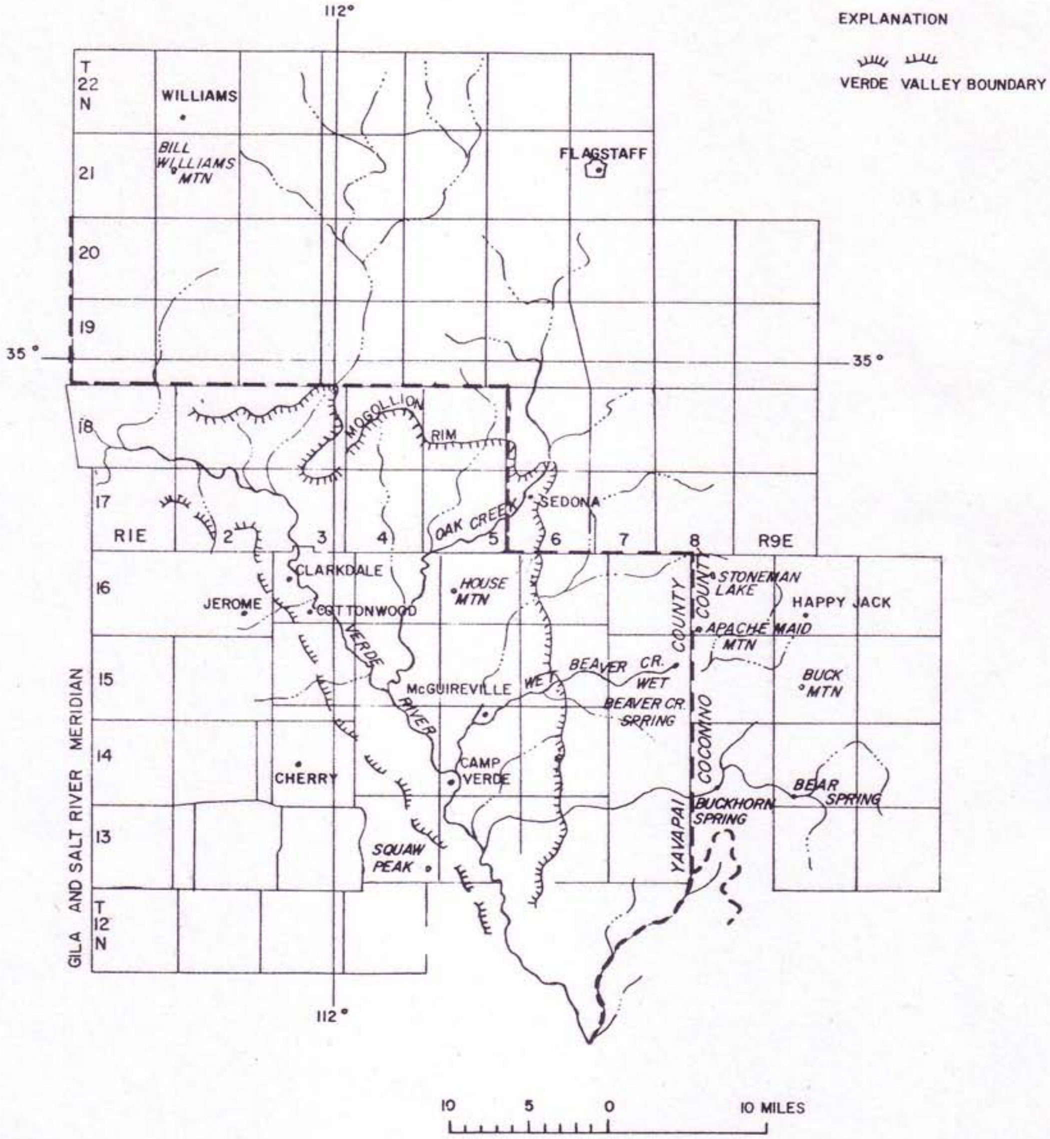


FIGURE 2: INDEX MAP OF VERDE VALLEY, YAVAPAI AND COCONINO COUNTIES, ARIZONA

the canyon slopes. Cactus is common in the lower end of the Canyon, and Ponderosa is predominant in the upper reaches.

Along Wet Beaver Creek Canyon the climate varies greatly in a relatively short distance, with temperatures and precipitation being functions, primarily, of the elevation.

Two separate and distinct climatic patterns are characteristic of the area. In the summer, southeast winds carry moisture in from the Gulf of Mexico. In the winter most of the precipitation is caused by low pressure areas off the coast of southern California which send the moisture to Arizona by southwest winds.

The moisture laden air rises and cools as it passes over the Mogollon Rim. Precipitation results from this uplift if the moisture content and temperature change fall within certain critical limits.

In July and August, showers occur frequently. The temperatures range from 65 to 90 degrees for the low and high temperatures near Happy Jack to 75 to 110 degrees at Montezuma Castle. Precipitation ranges for the two stations are, respectively, 16 inches and 5 inches.

The winter wet season occurs from December to February. Snow falls range from a record of 94 inches at Happy Jack in 1949 to an average of 2 inches at Montezuma Well.

The summer climate of the Wet Beaver Creek Canyon area is one of the factors making the region a desirable vacation site.

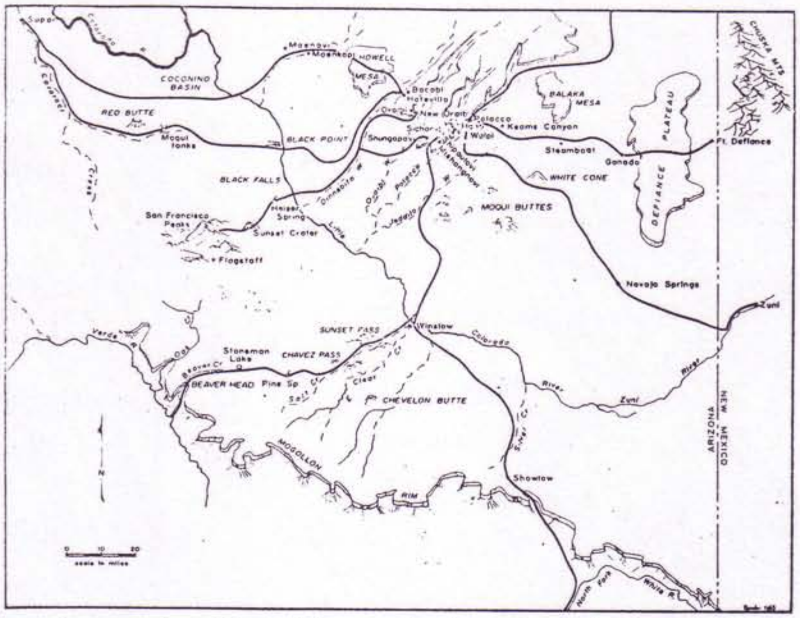
EARLY HISTORY

Earliest writings concerning Wet Beaver Creek Canyon date back to 1599. Colton(1963) condensed the history of an Indian and Spanish trail passing through the lower part of the canyon(see Fig.3). The trail led to salt deposits in the Verde Valley.

The name has been changed several times in its history. Early settlers is the area found many beavers in the stream and called it Beaver Creek. In 1880 the name was changed to Main Beaver Creek(Official Map of the Territory of Arizona, author unknown) apparently to distinguish it from another branch of the Beaver Creek called Dry Beaver, which often went dry. Later, in 1935, Barnes(Arizona Place Names) denoted the stream as Wet Beaver Creek.

Because of the availability of good-quality water and abundant game, Wet Beaver Creek Canyon was inhabited by Indians for many years, and numerous ruins in the canyon attest to its history. Ruins and remains, such as dwelling sites(Fig. 4), pottery, jewelry, hunting materials, and stone tools, are abundant in the canyon. A brochure containing a brief history of the Verde Valley, including the Wet Beaver Creek Canyon area,"Montezuma Castle National Monument, Arizona" is distributed by NPS.

the National Park Service.



A map of northern Arizona showing principal Hopi trails

Fig. 3 (after Colton)

Fig. 4 Indian dwelling site cut into welded tuff

STRATIGRAPHY

Summary

The rocks that outcrop in Wet Beaver Creek Canyon are sedimentary and igneous. The sediments are chiefly Paleozoic, including Supai, Coconino, and Kaibab formations. According to Sabels' correlation work(1960), the igneous rocks are exclusively Tertiary. A generalized stratigraphic column of the rocks exposed is given in Fig. 5 and the areal extent of the exposed rocks is shown in Plate 1. Table 1 shows a generalized stratigraphic section of all rocks in the area, including those believed to be in the subsurface.

Previous areal and regional studies have shown that the Redwall Formation(Mississippian), Martin Formation (Devonian), and possibly a thin section of the Tapeats Formation(Cambrian) lie beneath the section observed at the surface, but much thinner as compared to surrounding sections.

In 1960 Sabels tentatively correlated the Hickey Formation of the Black Hills with the strata in the Wet Beaver Creek area.

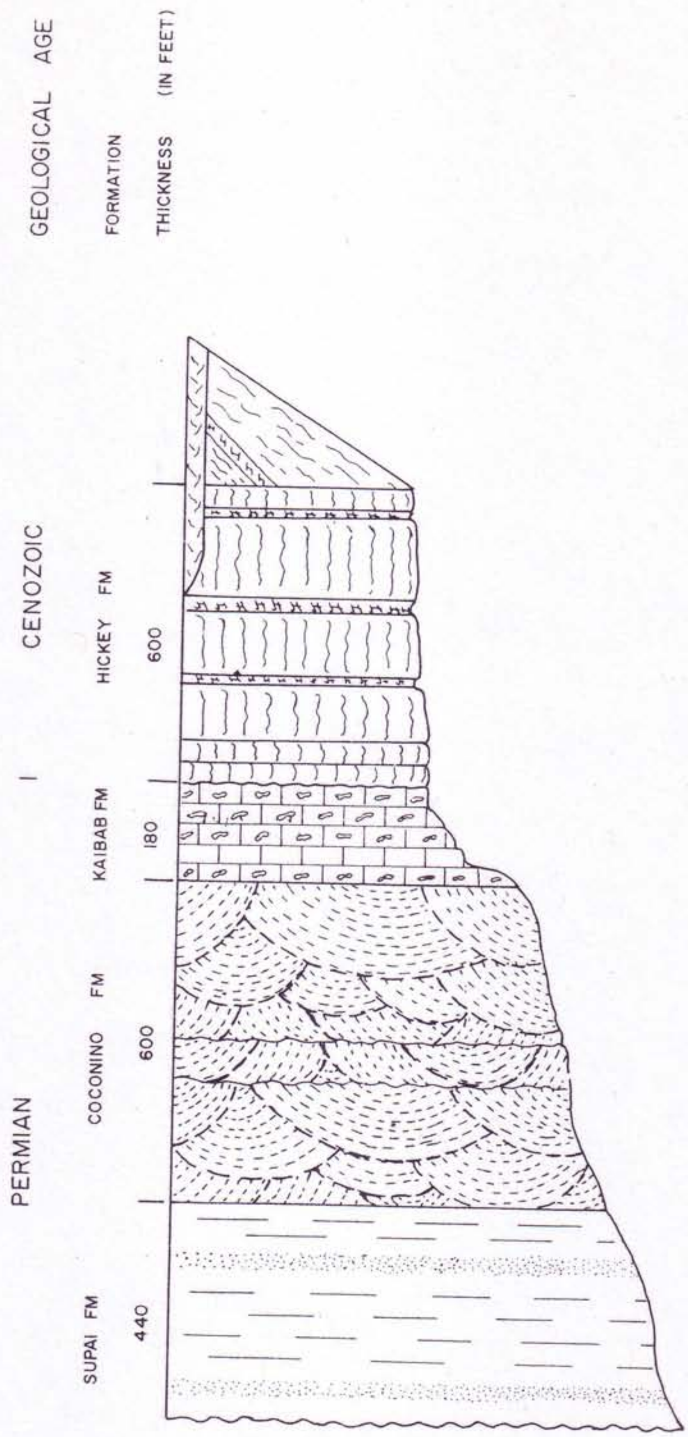


FIGURE 5
GENERALIZED
COMPOSITE COLUMNAR SECTION
WET BEAVER CREEK CANYON

Table 1. Generalized section of rocks in Wet Beaver Creek Canyon, Arizona (after Twenter and Metzger, 1963)

Era	System	Series	Formation	Thickness (Feet)	Lithologic Characteristics
Cenozoic	Quaternary	Recent	Stream wash	0-30	Terrace and stream deposits
	Tertiary	Miocene	Hickey Fm.	0-1000	Olivine basalt lava, tuffs, dikes, cinder cones, sediments, consisting of detrital residue Coconino and Kaibab rocks Unconformity
			Kaibab Fm.	0-180	Limestone or dolomitic limestone containing nodules and thin beds of chert. Some calcareous sandstone.
Paleozoic		Permian	Coconino Fm.	400-650	Sandstone composed of fine to medium grained sub-rounded quartz. Conspicuous cross-bedding
		Penn	Supaim Fm.	1500-1600	Mudstone, limestone, dolomite, sandstone, siltstone. Unconformity
		Miss	Redwall Ls.	250	Coarsly crystalline cherty limestone. Some beds contain crinoids and other fossils Unconformity

System	Series	Formation	Thickness feet	Lithologic Characteristics
Paleozoic	Devonian	Martin	200	Dolomite and dolomitic limestone. Contains thin beds of mudstone, shale and sandstone. Unconformity
Pre-cambrian				Metaconglomerate and Granite

Pennsylvanian - Permian

Supai Formation - The Supai Formation was named by N.H. Darton from the type locality located near the village of Supai in Havasu Canyon, Arizona.

It is the conclusion of Jackson(1953) that "the Supai Formation of Pennsylvanian-Permian age(Fig. 7) of central Arizona is an advancing deltaic deposit from the north which has caused a regression of the Pennsylvanian sea toward the south and southeast due to sedimentation exceeding subsidence in the area."

The thickness of the Supai Formation in neighboring Oak Creek Canyon is approximately 1,500 feet(Mears,1948). The Supai Formation outcrops in the lower end of Wet Beaver Creek Canyon. An exact thickness cannot be given because the lower part of the formation is not exposed. Between the upper Supai and the overlying Coconino Formation is a zone of interbedded red and white sandstones. The United States Geological Survey recognizes the uppermost red unit of the zone as the top of the Supai. The transitional zone(Fig. 8) in the Supai thickness ranges from 80 to 120 feet. Jackson used the lowermost unit having lithologic characteristics similar to those of the Coconino Formation as the contact between

Fig. 6 Air view of lower end of canyon

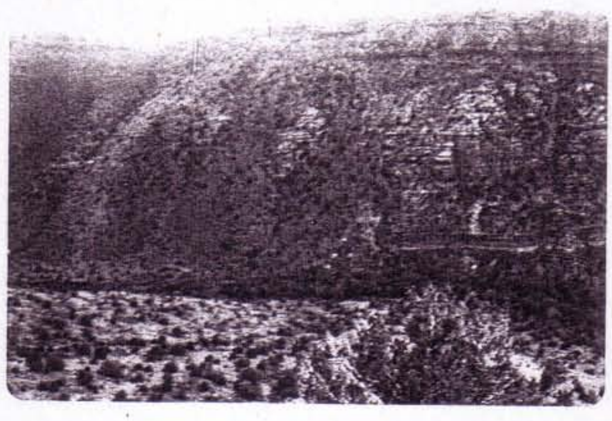


Fig. 7 Supai outcrop near mouth of canyon

the two units and Twenter used the top of the uppermost bed having lithologic characteristics similar to those of the upper member of the Supai Formation as the contact. This author follows the United States Geological Survey interpretation in using the top of the uppermost red-bed as the boundary.

The lower member of the Supai Formation is not exposed in Wet Beaver Creek Canyon, but Twenter(1963, p. 29) reports alternating beds of sandstone, shaly mudstone, limestone, and dolomite in Oak Creek Canyon.

The middle member of the Supai Formation is alternating beds of light colored and fine-grained siltstones and sandstones. Approximately 143 feet of the unit were measured by Jackson and later by this author. No conglomerate, which is characteristic in the middle Supai in Oak Creek Canyon(McKee, 1938) occurs in the Wet Beaver Creek section.

In contrast to the lower units, the upper member of the Supai Formation is predominantly a cliff-former lacking abundant vegetation. The thickness of 300 feet for the upper member was measured by Jackson and later by this author at the Southwestern Military Academy (Beaver Creek Ranch on map). The lithology reported is reddish brown to pale brown quartz sandstones and the sand grains in the unit range in texture from fine to medium following the Wentworth Scale The Fort Apache Limestone Member is absent in the section studied in this report.

A summary of the regional aspects of the Supai Formation is presently being compiled by E.D. McKee (Personal Communication, 1967) of the United States Geological Survey.

Permian

Coconino Formation - The Coconino Formation was first mentioned by N.H. Darton in 1910(Willmarth, 1963). The type section is in the Aubrey Cliffs, Coconino County, Arizona.

The Coconino Formation in the Wet Beaver Creek Canyon is well exposed in some cliffs in the canyon. The measured thickness of this unit is approximately 628 feet. "In the Verde Valley south of U.S. Highway 79 the characteristics that distinguish the Coconino Sandstone from the Toroweap Formation disappear, and rocks equivalent to the two formations appear as a massive sandstone unit containing similar cross-bedding types. . .here the overlying Toroweap Formation is not recognizable."(Twenter, 1966, p 33) As the characteristics of the sandstone unit in Wet Beaver Creek Canyon are similar to those of the Verde Valley, the combined thickness of the sandstone unit is considered as Coconino Formation in this paper.

The Coconino Formation is a cream to orange-buff sandstone of rounded to sub-rounded, fine to medium-grained quartz grains. Coherence ranges from weak to strong, resulting in a predominance of cliffs(Fig. 9) with a few gentle slope forming units. In the upper

Fig. 8 Transition zone between Coconino and Supai Formations

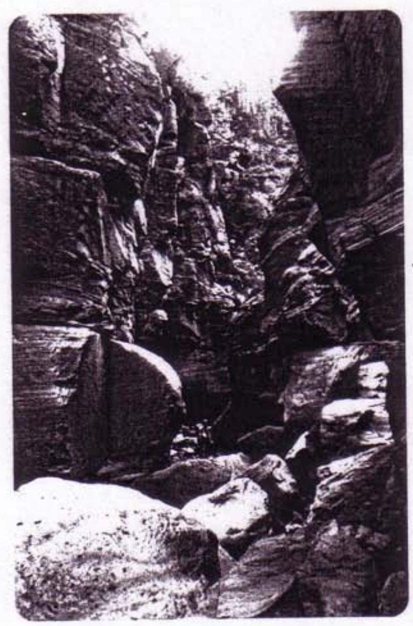


Fig. 9 Coconino Formation cliffs in upper end of canyon

part of the canyon, the formation coherence may be the result of silica cement. This formation is both porous and permeable and forms a good aquifer. It is this unit which is the source of the Wet Beaver Creek Springs.

Large scale cross-beds occur throughout the formation(Fig. 10), with interbedded smaller cross-beds(Fig.11) some of which have level tops and bottoms(Fig. 12). The cross-bedded units dip as much as 27 degrees to the southwest. "The nature and size of the cross-beds suggests a wind blown sand deposit typical of the Coconino Sandstone"(Beus, et al, p. 10).

The Coconino Formation crops out throughout almost the entire region.

Kaibab Formation - The type section is in Kaibab Gulch in the Kaibab Plateau, six miles north of the Arizona border and eight miles south of Paria, Utah.

The distinct contact between the Coconino and Kaibab formations is two differing rock types. A limestone bed is overlain by a buff sandstone(Fig. 13). Approximately 180 feet of the formation were measured in two of the sections. In both sections only the Beta Member of McKee(1938) is present.

The Kaibab Formation is buff to light gray dolomitic and sandy limestone, containing nodules and stringers

Fig. 10 Large scale cross-beds in Coconino Formation

Fig. 11 Small cross-beds in Coconino Formation

Fig. 12 Cross-beds with planar tops and bottoms in Coconino Formation

Fig. 13 Contact between Coconino and Kaibab Formations

of gray to orange chert which is irregularly fractured (Fig. 14). The formation is resistant and forms a step-like series of cliffs and ledges. Thin bedding planes ranging from six inches to several feet are abundant.

In localized areas solution channels and caverns are exposed(Fig. 15). Silicified fossils are present but poorly preserved.

Fig. 14. Cherty Kaibab Formation

Fig. 15 Solution channels in Kaibab Formation

CENOZOIC

Hickey Formation - Anderson and Creasey(1958) named the Hickey Formation in the Black Hills near Jerome. The formation is gravel, tuff, and basalt. Sabels(1960) tentatively correlated the Hickey Formation with the volcanics of the San Francisco and Mormon Mountain volcanic fields. In the Wet Beaver Creek Canyon area the formation is stream gravels, a basal tuff unit, alternating tuffs and basalt with a basalt capping. Using thermoluminescence curves from a large number of tuff sections Sabels correlated the Hickey exposures and concluded that the age ranged from the late Miocene to Pliocene. The absolute date given for the oldest section was 14 million y ears.

In Wet Beaver Creek Canyon the Hickey Formation is the thickest formation exposed, ranging from 200 to over 1,000 feet in thickness(Fig. 16). The lower gravels are exposed in only one small area at the base of the thick tuff sequence a few hundred yards west of the largest fault in the canyon(Fig. 17). The gravel contains Kaibab and Coconino fragments and it is loosely cemented by calcite. A similar gravel outcrops immediately beneath the basalts covering Red Tank Draw Red Tank Draw is the canyon immediately west of Wet Beaver Creek Canyon(Fig. 18).

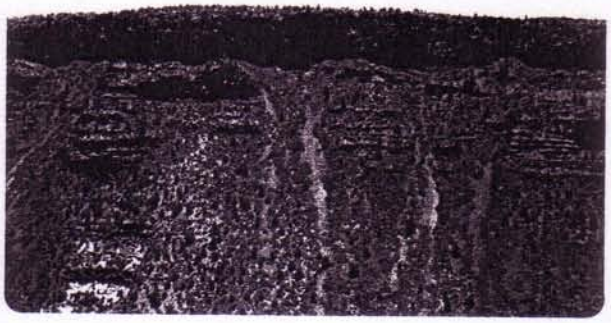


Fig. 16 Large exposure of Hickey Formation

Fig. 17 Exposures(white area) of Hickey gravels near bottom of canyon

Fig. 18 Gravel outcrop in Red Tank Draw

Fig. 19 Lower tuff zone of Hickey Formation

The lower tuff zone outcrops throughout most of the canyon exposures which are not covered by vegetation or talus(Fig. 19). The tuff section has a thickness of up to 200 feet in some sections. The tuff is light colored volcanic glass, feldspar, and quartz fragments of coarse sand-sized grains. The best classification would be gray lapilli tuff. Much of it is attributed by Sabels to have come from Thirteen Mile Caldera

The overlying basalts and tuffs range greatly in thickness and extent(Fig. 20). Most of these are local in origin and extend less than a mile. In this zone localized tuff and pyroclastic ejecta(Fig. 21) and volcanic agglomerate(Fig. 22) occur. The basalts exhibit columnar jointing in most areas

The basalt flows capping the Wet Beaver Creek Canyon area are much thicker and cover a larger area than the interbedded flows and tuffs below The individual capping flows range from 50 to 200 feet in thickness and appear to have been moved in a west-southwest direction. The composition of the capping basalts is similar to those lower in the section. The capping basalts contain numerous lava tunnels. Tuffs between the upper flows are absent. Numerous pieces of xenolithic material derived from the Coconino and Kaibab rocks occur on the surface of the upper basalts.

Fig. 20 Basalt and tuff zone of Hickey Formation

Fig. 21 Tuff and pyroclastic ejecta

Intrusive Bodies - Several intrusive plugs crop out in Wet Beaver Creek Canyon(see Plate 1). The plug nearest the mouth of the canyon is called Casner Butte(Fig. 23) and it is located in sections 13, 14, 23, 24, in T15NR6E. Peculiar to this plug are olivine phenocrysts ranging up to 3/4 of an inch. Excellent examples of spheroidal weathering are located on Casner Butte (Fig. 24). Columnar jointing is exhibited on the upper portion of the plug, with large amounts of lapilli covering the lower slopes.

The smallest of the plugs exposed is at the junction of Long Canyon and Wet Beaver Creek Canyon(Fig. 25). The contact with the sedimentary rocks is easily recognized. Some upwarping of the sediments is apparent in the contact zone, with little metamorphism visible.

The largest igneous plug exposed in the canyon (Fig. 26) is called Maverick Butte which is the name accepted by the local district of the United States Forest Service, a name not accepted by the United States Geological Survey. Outcropping in Sections 10, 11, 14, 15, T15NR7E, this butte has several radiating dikes. Maverick Butte rises approximately 250 feet above the surrounding surface.

Fig. 22 Volcanic agglomerate

Fig. 23 Casner Butte

Fig. 24 Spheroidal weathering exhibited by basalt on Casner Butte

Fig. 25 Small plug at junction of Long and Wet Beaver Creek canyons.

Extrusives - A buried cinder cone consisting of pyroclastics which have been disected by the stream(Fig. 27) is exposed about 1/3 mile east (Sw¼S16R7ET15N) of the smallest plug. A close examination shows that the cinders rest on the Coconino Formation at the base and the cinders are overlain by a thin basalt flow and a layer of basalt overlies all of these units. The conduit is not visible and probably the canyon has not yet exposed it.

A plug built of welded fine-grained pyroclastic material or melaphyre tuff and with almost vertical walls is exposed in the Sw¼ of S16T15NR7E(Fig. 28). Because of its unique vertical walls and the ease with which the material can be carved, the structure was used as a communal dwelling and fortress by the early Indians. Two vertical dikes striking northwest, outcrop on the southwest and northeast of the plug but do not cut the plug. The evidence is insufficient to show a genetic relation.

Surprisingly few dikes cut across the Wet Beaver Creek Canyon(Fig. 29). These are shown in Plate 1. The dikes form local barriers to the movement of surface water and ground water and may also provide a conduit down the fracture they occupy through which water may descend to buried aquifers(Beus, et al, 1966, p. 17).

Fig. 26 Maverick Butte

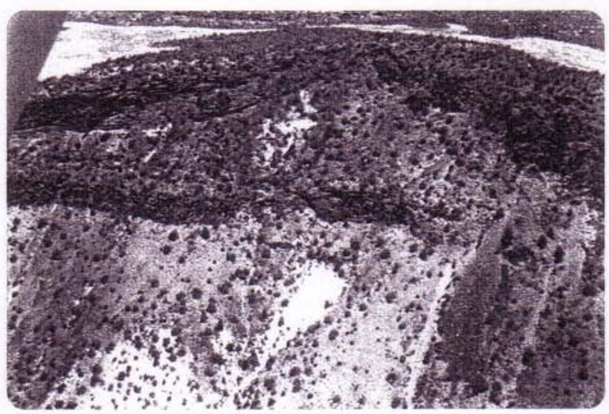


Fig. 27 Buried and dissected cinder cone

Fig. 28 Melaphyre tuff plug

Fig. 29 Dike cutting Canyon near Maverick Butte

STRUCTURAL GEOLOGY

Exposures in Wet Beaver Creek Canyon yield evidence which shows the regional structural pattern. The regional pattern exhibits two general directions of fractures. A northwest-southeast fracture set with an approximate preferred strike of north 35° west was designated by Beus, et al, (1966)as the Lake Mountain trend. The northwest trend is well exposed in the canyon. The second set of fractures is not clearly exposed. The direction of trend of Wet Beaver Creek Canyon leads to the inference that a second northeast trend controls, in part, the pattern of the Canyon.

Tracing the regional fracture systems into the surrounding lava covered area is difficult. The northwest trend is visible in some areas. The entire Paleozoic sequence in Wet Beaver Creek Canyon is cut by the regional system. Large fractures(Fig. 30) are exposed throughout most of the canyon walls. The exposed faults have displacements which range from 3 to over 600 feet. Between Hog Hill and Maverick Butte a series of horsts and grabens parallel the northwest trend. In one area a horst is associated with an intrusive plug (Fig. 31).

Fig. 30 Large fracture in Coconino Formation

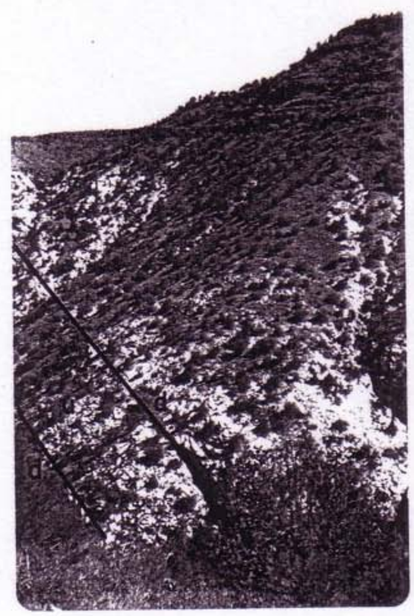


Fig. 31 Horst radiating from intrusive plug

Local sets of structural features are exhibited by the radiating fracture systems extending from intrusive bodies. But the fractures radiating from igneous plugs are obscured by the lava cover in the surrounding area.

Stratigraphic evidence indicates that there were three periods of faulting in the Wet Beaver Creek Canyon area. Much of the movement took place prior to extrusion of the lava cover as evidenced by faults terminated by the volcanics.

Some of the movement occurred during the volcanic activity as evidenced by faults and fractures radiating from intrusive structures. Several small faults are along vertical dikes, also.

A smaller amount of movement occurred after the volcanism(Fig. 32). Also, at least one fault, the easternmost, shows recurrent movement, which occurred before and during the volcanic extrusion(Fig. 33).

The largest fault block exposed in Wet Beaver Creek Canyon is the most conspicuous, with over 600 feet of apparent displacement(Fig. 34). The fault block is beneath Hog Hill which is one of the high points in the area. The fault block has bedding planes that dip to the east approximately 4 degrees.

Immediately to the east of the large fault block is

Fig. 32 Waterfall on recent fault

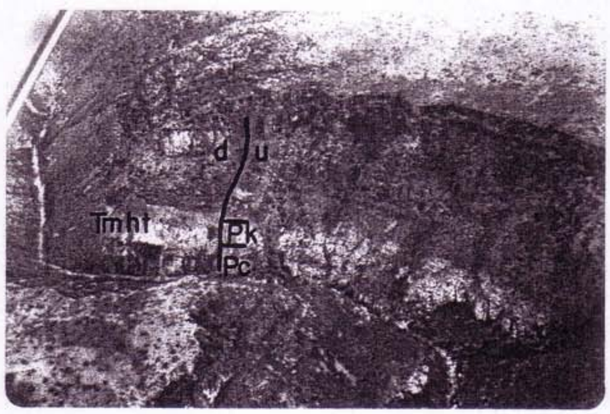


Fig. 33 Fault exhibiting recurrent movement

a similar one in which the bedding planes dip to the west approximately 2 degrees(Fig. 35). This fault block contains the springs.

Both Wet Beaver Creek Canyon and Clear Creek Canyon to the south have similar map patterns in their upper reaches(Fig. 36). The similarity apparently shows a structural control of the major stream systems in the area. Definitely northwest-southeast and northeast-southwest structural patterns appear to control the geographic pattern of both Clear and Wet Beaver canyons. A similar set of fracture trends has been mapped in areas to the north of the Wet Beaver Creek area (Beus, Rush, Smouse, 1968).

The Coconino Formation is brittle and commonly is highly shattered. The formation is the most extensively exposed unit in Wet Beaver Creek Canyon and its highly fractured character, presumably obscures any exposures of faults trending parallel to the canyon.

The Mogollon Rim, which forms the western boundary of Wet Beaver Creek Canyon does not appear to be a distinct fault escarpment. Rather, there appears to be an erosional feature. Instead of an often hypothesized single fault, there is a system of step faults extending down to the Verde Valley, with possibly some faults

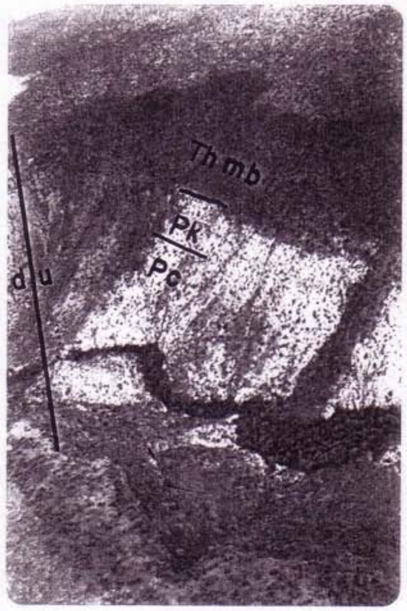


Fig. 34 Largest fault observed

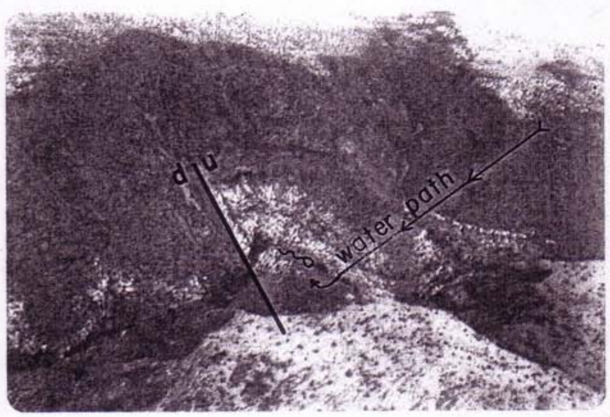


Fig. 35 Fault block containing springs

lying beneath the Verde lake beds. In the area near the mouth of Wet Beaver Creek Canyon no faults are adjacent to the rim.

In an earlier paper, Akers(1962) reported a regional dip to the southwest. Wengard(1962) reported a northeast regional dip. Rush(1965) stated his results indicating a southwest regional dip substantiating Akers work. No regional dip was detected in this study.

The volcanic sequence began with the gray lapilli tuffs from Thirteen Mile Caldera, followed by quiet fissures flows, with more explosive volcanism and less fluid basalt extrusion occurring last. All workers agree that the faulting and volcanism are genetically related. Sabels(1960) dating of a tuff at the base of the Hickey Formation at 14 million years allowed him to postulate that the faulting and volcanism began in the Miocene.

A future effort to combine all of the localized areas of study in this area should, when tied together with absolute radiometric dating of the volcanics, show the overall regional tectonic history of the area. Sabels (1962) has completed part of the work in his paper "Mogollon Rim Volcanism and Geochronology." Future work should be based on his authoritative beginning in the effort to unravel the geologic history of this part of the Colorado Plateau.

Wet Beaver Creek Canyon is a slope and structure controlled masted drainage system which drains 413 square miles of the southwestern arm of the Mormon Mountain Anticline. The stream follows the slope towards the Verde Valley in a southwesterly direction. In many cases, however, the orientation of the canyon appears to show a preferential direction following the regional tectonic structural patterns as was shown in Fig. 36 in the discussion on structure. Few faults strike parallel to the stream and most cut the canyon perpendicularly. In several cases faults striking parallel to the canyon are suspected, but the lack of key stratigraphic units and the highly fractured condition of the Coconino Formation obscure any traces. Only in a very few cases can structural control be positively seen, and it must be inferred from the regional patterns.

The canyon is parallel to the southern edge of a lava cascade which flowed into the Verde lake bottom. Evidently, the filling of the channel to the north deflected drainage southward, in the case of Wet Beaver Creek. The evidence given here is that the inception of the Wet Beaver Creek came much later than the development of the lava-filled channel to the north and later than the volcanism of the Wet Beaver Creek area because no lavas poured into the canyon. Therefore, the cutting of the canyon is post-volcanic and post-tectonic yet it is remarkable that it cut to the recorded depth in such a relatively short period of time. Most likely, the rate of canyon cutting increased after the exposure of the springs emerging from the Coconino Formation--and the additional flow of water facilitated the streams' apparent mastery of the drainage.

If it is assumed that concomittant volcanism and tectonic activity migrated northward and eastward with time(Beus, Rush, Smouse, 1966), then Wet Beaver Creek may have begun its canyon cutting after the initial phase of volcanic activity at the extreme southern and western adge of the San Francisco volcanic field. It can be hoped that additional new absolute dating methods may be used to date the beginning of canyon cutting and the rate of canyon cutting. The methods of lichenometry, radiometry and dendrochronology show promise in this respect but the techniques and training required are beyond the scope of this report. In addition, techniques available in anthropology may be useful in this intriguing quest.

SPRINGS

Springs which produce continuous flow in Wet Beaver Creek appear in the Coconino Formation at approximately 5,025 feet. Above the main springs many seeps emit from bedding surfaces(Fig. 37 and 38). It is estimated that about 5 percent of the flow comes from the seeps.

The larger springs appear to emerge from fractures in the Coconino Formation. Several springs flow from fractures several hundred feet upstream from one of the larger faults cutting the canyon(Fig. 39 and 40). The larger springs show a noticable flow of about 2½ cfs. The combined flow of all of the springs is estimated at 3 cfs. It should be pointed out here that stream flow at the mouth of the canyon is estimated at 7 cfs. The differing figures indicate that between the known springs and the gaging station in the mouth of the canyon other springs are adding to stream flow. Thorough searches along the creek failed to show the locations of any additional springs. It is presumed that additional flow is added by underwater springs in deep pools. Many such deep pools are common throughout the length of the creek. An example may be seen in Fig. 41.

Twenter and Metzger(1963) compiled a detailed study

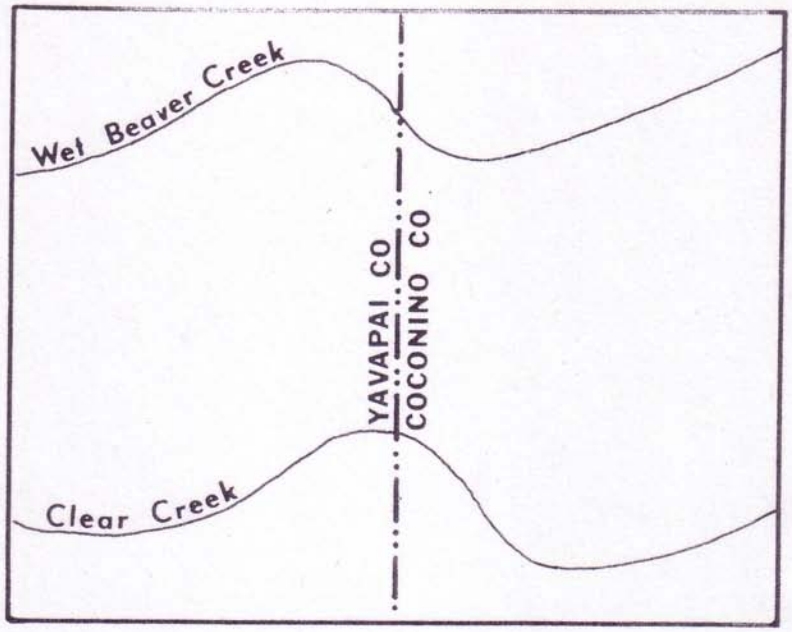


Figure 36

Similar map patterns of Clear and Wet Beaver creeks

Fig. 37 Seeps in weak bedding planes of Coconino Formation

Fig. 38 Seeps in weak bedding planes of Coconino Formation

Fig. 39 Small spring flowing from fracture in Coconino Formation

Fig. 40 Large spring flowing from fracture in Coconino Formation

Fig. 41 An example of many deep pools which may cover hidden springs

of the water in Wet Beaver Creek. Their results are shown in Table 2. A rather low content of dissolved solids is observed in the water. This indicates that most of the transportation of the groundwater has taken place in fractures in the clean, well-sorted, porous and permeable sandstone of the Coconino Formation.

An interesting point concerning the springs is their location in relation to the topography of the area. The springs are at the base of a point between two canyons(Fig. 35). Close examination of the area shows that the water must flow in a southeast direction to the springs or it must run under the canyon northeast of the springs and rise up to the spring outlets. In either case, following a water table with an even gradient seems unlikely. Moreover, it appears that the springs are controlled primarily by minor structures, rather than by an even water table gradient. If this assumption is true, the probability is greatest that structural control of groundwater is predominant throughout the surrounding area, including the experimental watersheds to the north of Wet Beaver Creek Canyon.

Table 2: (Twenter and Metzger)

Name	Approximate land surface altitude (feet)	Date of collection	Source
Wet Beaver Creek Spring	5,025	10-19-59	Coconino Sandstone

Discharge(gpm)	Temp. (°F.)	Silica (SiO_2)	Calcium (Ca)	Magnesium (Mg)
1,200-1,500E	60	23	29	10

Sodium and Potassium (Na + K)	Bicarbonate ($CaCO_2$)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)
4.8	147	.2	2.5	.2

Nitrate (NO_3)	Dissolved solids (sum)	Hardness as ($CaCO_2$)	Sodium (percent)	Specific conductance (micro-mhos at 25° C)
1.1	143	115	8	236

pH	Remarks
7.4	Initial flow is several hundred feet upstream from fault

SUMMARY AND CONCLUSIONS

Exposures in Wet Beaver Creek Canyon clearly indicate the regional stratigraphy and structural trends. The Supai, Coconino, Kaibab, and Hickey formations underly the area surrounding Wet Beaver Creek. The regional structural trends, one striking northwest-southeast and the other an inferred northeast-southwest, are recorded. A gently sloping erosional surface carved on the sedimentary rocks beneath the volcanics descends southwest to the Mogollon Rim.

This study indicates that the Mogollon Rim is an eorsional escarpment rather than a single fault scarp.

The springs are controlled by the joint systems and planes of weakness in the sedimentary rock units, rather than by the major fault systems.

REFERENCES

Akers, J.P., 1962, Relation of Faulting to the Occurrence of Ground Water in the Flagstaff Area, Arizona: U.S.G.S. Prof. Paper 450-B.

Barnes, William C., Arizona Place Names, U of A Bull., General Bulletin #2, University of Arizona, Tucson, 1935, Vol. VI, No. 1.

Beus, S.S., Rush, R.W., Smouse D., Geologic Investigation of Experimental Drainage Basins 7-14, Beaver Creek Watershed, Coconino County, Arizona, 1966.

Colton, Harold S., "Principle Hopi Trails," Plateau, Vol. 36, pp. 91-94, 1963.

Darton, N.H., A Reconniassance of Parts of Northwestern New Mexico and Northern Arizona, U.S.G.S. Bulletin, #35, 1910.

Editor, Suggestions to Authors of the Reports of the United States Geological Survey, 5th Edition, 1958.

Feth, J.H., "Springs of the Mogollon Rim Region, Arizona" U.S.G.S. Open File Report 1554, Tucson, Arizona.

Granger, Byrd C., Arizona Place Names, University of Arizona Press, Tucson, 1960.

Jackson, R.L., "Supai Formation Along the Mogollon Rim," unpublished M.S. thesis, University of Arizona, 1951.

McKee, E.D., 1934, The Coconino Sandstone, Its History and Origin, Carnegie Inst., Wash. Pub. 440.

McKee, E.D., 1938, The Environment and History of the Toroweap and Kaibab Formations of Northern Arizona and Southern Utah; Carnegie Inst., Wash. Pub. 92.

Mears, B., Cenozoic Faults, Gravels and Volcanics of Oak Creek Canyon, Arizona, unpublished PhD. thesis, Columbia University, 1948.

Price, W.E., "Rim Rocks of Sycamore Canyon, Arizona," unpublished M.S. thesis, University of Arizona, 1948.

Robinson, H.H., "The San Francisco Volcanic Field, Arizona," U.S.G.S. Prof. Paper #76, 1913.

Rush, R.W., Report of Geologic Investigations of Six Experimental Drainage Basins, Beaver Creek Watershed, Yavapai County, Arizona #1-6, 1965.

Sabels, B.E., "Late Cenozoic Volcanism in the San Francisco Volcanic Field and Adjacent Areas in Northcentral Arizona," unpublished PhD. thesis, University of Arizona, 1960.

Twenter, F.R. and Metzger, D.G., Geology and Ground Water in Verde Valley, the Mogollon Rim Region, Arizona, U.S.G.S. Bull. 1177, 1963.

Wengard, S.A., Regional Structure in Stratigraphic Cross-section, East central Arizona to West Central New Mexico, 1962.

UPPER SECTION

NW¼SE¼S13T15NR7E

Measured by Beus and Thompson

Hickey Formation:

Massive basalt flow; dense; dark olivine basalt; columnar jointing; forms sheer cliff.	54.0
Breccia zone; reddish broken fragments.	3.5
Massive basalt flow; dense, dark olivine basalt; columnar jointing; large lava tube near base; forms sheer cliff. .	115.0
Tuff and lapilli; red to grey; eroded back; mostly small(¼ -½ cm); some larger(2 - 80 cm) fragments.	15.0
Massive basalt flow; dense, dark olivine basalt; columnar jointing; forms sheer cliff; poor jointing in lower part .	100.0
Tuff; gray to reddish brown; no bedding visible; highly weathered; mostly small (¼ -½ cm) fragments; forms slope. . .	10.5
Massive basalt flow; dense, dark olivine basalt; poor columnar jointing; cliff former	85.0
Thin basalt flow; dense, dark olivine basalt; columnar jointing; forms small cliff	25.0
Thin basalt flow; dense, dark olivine basalt; columnar jointing; forms small cliff	20.0
Massive tuff and lapilli; gray to reddish brown; some thin beds of agglomerate; forms gentle slope	201.0
Total Hickey Formation	628.0

Kaibab Formation:

Limestone, medium light gray; very fine grained; cherty, 1 foot layers of cherty limestone; cherty nodules and stringers throughout; 1 to 2 foot parting planes	68.0

Limestone; massive; medium light gray; small amount of chert	5.8
Limestone; cherty; up to 90% chert; forms resistant units 1 to 2 feet thick	12.5
Limestone; medium light gray; abundant irregular chert nodules (up to 20%); up to 3inches in diameter; fine grained; cliff former.	12.0
Limestone; medium light gray; fine grained; cherty; sliff former	5.8
Sandy limestone; abundant chert nodules oriented vertically to bedding; crinoid stems; massive encrusting bryozoans, Productid brachiopod remains; 6 inch layers of fractured chert	28.0
Sandy limestone; light gray brown; 1 to 2 foot units; traces of fossils; weathers to steep slope; massive upper layer . .	32.0
Cherty limestone; large irregular chert nodules	1.0
Limestone; light gray brown; finely crystalline; few small concretions; massive; resistant.	4.0
Limestone; reddish brown; silty; thin beds at base.	2.0
Total Kaibab	170.8

Coconino Formation:

Sandstone; grayish-brown to light brown; medium to fine grained quartz grains; sub-angular; well sorted; massive . . .	135.4
Sandstone; cream to grayish-orange; poorly sorted; fine to large quartz sand grains cracks with calcite fillings.	28.4
Bottom	
Total Coconino	163.8

MIDDLE SECTION
NE¼SW¼ S15T15NR7E
Measured by J.R. Thompson, Jr.

Hickey Formation:

Massive basalt flows; dense, dark olivine basalt; cliff former.	516.0
Massive lapilli tuff; light gray; slope former; fine sand grains to small pebble grains	32.0
Detritus;basalt and tuff	15.0
Total Hickey Formation	563.0

Kaibab Formation

Limestone, medium light gray; very fine grained; cherty; 1 foot layers of cherty limestone; cherty nodules and stringers throughout; 1 to 2 foot parting planes .	68.0
Limestone; massive; medium light gray; small smount of chert	5.8
Limestone; cherty; up to 90% chert; forms resistant units 1 to 2 feet thick	12.5
Limestone; medium light gray; abundant irregular chert nodules(up to 20%); up to 3 inches in diameter; fine grained; cliff former	12.0
Limestone; medium light gray; fine grained; cherty; cliff former	5.8
Sandy Limestone; abundant chert nodules oriented vertically to bedding; crinoid stems; massive encrusting bryozoans, Productid brachiopod remains; 6 inch layers of fractured chert	28.0
Sandy limestone; massive upper layer; light gray grown; 1 to 2 foot units; traces of fossils; weathers to steep slope;	32.0
Cherty limestone; large irregular chert nodules	1.0
Limestone; light gray brown; finely crystalline; few small concretions; massive; resistant	4.0

Limestone; reddish brown; silty; thin beds at base.	2.0
Total Kaibab	170.8

Coconino Formation:

Sandstone; grayish brown; medium to fine grained quartz grains; sub-angular; well sorted; massive	125.0
Sandstone; creamy orange; poorly sorted; fine to large quartz sand grains; calcite stringers	29.1
Sandstone; clean; well sorted; cream; medium sized quartz grains; fissile . .	54.2
Sandstone; light orange; well sorted; sub-rounded; medium size quartz grains.	15.4
Sandstone; large grains; well sorted; frosted; moderate orange-pink	44.0
Sandstone; clean; well sorted; medium size quartz grains; cream; sub-angular.	11.4
Sandstone; dirty; sub-angular to sub-rounded; orange; quartz; medium grains.	127.4
Sandstone; cream to white; clean; well sorted; fine grains; quartz; sub-angular to sub-rounded	88.6
Sandstone; cream; well sorted; clean; quartz; fine grains; sub-angular. . . .	59.0
Sandstone; orange-buff; quartz; fine grains; angular to sub-angular; iron stains . .	7.0
Sandstone; clean; fine grained; quartz; sub-angular; cream-buff.	5.4
Sandstone; sub-rounded; buff; fine to medium quartz grains; iron stain in veins	43.8
Sandstone; cream; sub-rounded; fine to medium quartz grains	6.8
Sandstone; clean; compact; fine quartz grains; sub-rounded; cream	11.6
Total Coconino	628.7

LOWER SECTION

NW$\frac{1}{4}$SW$\frac{1}{4}$S23T15NR6E

Measured by Jackson and Thompson

	Feet
Tertiary basalt:	
Supai-Tertiary basalt contact: erosional unconformity of low relief (3' - 5').	
Supai formation:	
"A" member (after McKee):	
Concealed; basalt talus covered slope. .	30.0
Sandstone; moderate orange grown; fine grained; cement weak; non calcareous; medium scale cross-laminations; weathers smooth, blocky; forms cliff.	36.0
Siltstone; light brown; mottled gray to white in part; cement weak, calcareous; bedding massive; exfoliates upon weathering; forms vertical cliff	8.0
Sandstone; moderate orange brown; fine grained; cement weak; non calcareous; medium scale cross-laminations; weathers smooth, blocky; forms cliff.	10.0
Sandstone; moderate reddish orange; medium grained; small-scale cross-laminations grade upward into medium scale cross laminations; weathers smooth rounded; forms cliff.	22.0
Sandstone; moderate orange grown; fine grained; cement weak, non calcareous; medium scale cross-laminations; weathers smooth, blocky; forms cliff.	10.0
Sandstone; moderate reddish orange; medium grained; small scale cross-laminations grade upward into medium scale cross laminations; weathers smooth rounded; forms cliff.	44.0
Siltstone; light brown; mottled gray to white in part; cement weak, calcareous; bedding massive; exfoliates upon weathering; forms vertical cliff.	8.0
Sandstone; moderate orange brown; medium grained; cement weak; friable; non calcareous; weathers gnarly; forms ledge. . . .	1.0

Sandstone; moderate reddish orange; medium grained; small scale cross-laminations grade upward into medium scale cross-laminations; weathers smooth rounded; forms cliff. 66.0

Sandstone; moderate reddish orange; medium grained; cement firm, calcareous; bedding massive; exfoliates upon weathering; contains small irregular lenses of gray siltstone at base; weathers rounded; bedding irregular; forms cliff. 32.0

Sandstone; light gray; cement weak; friable; calcareous; medium grained; weathers smooth rounded; forms small ledge. 0.5

Sandstone; moderate reddish orange; medium grained; cement firm, calcareous; bedding massive; exfoliates upon weathering; contains small irregular lenses of gray siltstone at base; weathers rounded; bedding irregular; forms cliff. 11.0

Sandstone; moderate orange brown; fine to very fine grained; cement weak, non-calcareous; contains calcite seams(¼") normal to bedding;small scale cross-laminations; weathers rounded; forms ledge 16.5

Total "A" member 295.0

"B" member(after McKee):

Siltstone; moderate orange brown; thin irregular bedding; cement weak; non-calcareous; weathers rounded; forms slope . . 41.0

Sandstone; light gray; medium to fine grained; cement weak, non-calcareous, friable; bedding massive; weathers smooth rounded; forms ledge. 2.0

Sandstone; moderate orange brown; fine to very fine grained; cement weak, con-calcareous; contains calcite seams(¼") normal to bedding; small scale cross-laminations; weathers rounded; forms ledge. 11.0

Siltstone; moderate orange brown; thin irregular bedding; cement weak; non-calcareous; weathers rounded; forms slope. . 22.0

Siltstone; light gray; cement firm, non-calcareous; thin bedded(½"-- 2") weathers smooth rounded; exhibits jointing; forms ledge. 16.5

Mudstone; grayish purple; thin, irregular bedding; grades upward into grayish green mudstone; weathers hackly; forms slope ..	8.0
Siltstone; moderate orange brown; thin irregular bedding; cement weak, non-calcareous; weathers rounded; forms slope. . .	38.0
Siltstone; grayish green; thin bedded; cement weak; calcareous; forms slope ...	0.5
Siltstone; moderate orange brown; thin irregular bedding; cement weak; non-calcareous; weathers rounded; forms slope . .	4.5
Total incomplete "B" member	143.5