STRUCTURE OF THE EASTERN HUALPAI INDIAN RESERVATION, ARIZONA

By

Donaldson Koons

Colby College, Waterville, Maine

INTRODUCTION

The eastern portion of the Hualpai Indian Reservation and adjacent areas (fig. 1) include the southern termini of the Hurricane and Toroweap faults, two of the major displacements of the Plateau country of northern Arizona, as well as the Aubrey fault and many minor displacements (fig. 2). The northern portions of the Hurricane and Toroweap faults have already received considerable attention, including studies by Powell (1875), Dutton (1882), Davis (1901, 1903), Huntington and Goldthwait (1903), Johnson (1909), Gardner (1941), Koons (1945), and Kenneth Hamblin (fieldwork in progress), but the extent and nature of these important structures in the region south of the Grand Canyon have received only passing mention by Newberry (1861), Gilbert (1875), Wheeler (1889), Robinson (1913), Darton (1915, 1925), and Moore (1925).

The present report is the result of fieldwork during the summers of 1946 and 1949 and is a continuation of earlier studies by the author of the Hurricane and Toroweap faults north of the Grand Canyon. The report, however, was written in 1950 and has received only a limited amount of updating since that time. Preliminary reports have already been published by the author (Koons, 1948a, 1948b). Two separate facets of the study received particular attention: (1) the character, distribution, and history of faulting; and (2) the character and origin of extensive gravel deposits of three different types. The study indicated that the gravel deposits in the western Grand Canyon area can be subdivided into geologic units, as can the consolidated sedimentary rocks. The fieldwork was not completed, nor could many aspects of the gravel problem be resolved at that time. However, because of renewed interest in the area, the results of this work are presented in a provisional form, realizing that recent studies will modify the tentative conclusions presented in this paper.

The project was made possible by grants from the Kemp Memorial Fund of the Geology Department of Columbia University and the trustees of Colby College. The author is indebted to Dr. H. S. Colton, Director of the Museum of Northern Arizona, Flagstaff, and now retired, who made available the facilities of that institution, and to Professor Edwin D. McKee, formerly Assistant Director of the Museum and now with the U. S. Geological Survey, for many helpful discussions and suggestions; to Mr. V. D. Smith, of the Hualpai Subagency, Peach Springs, for useful information and assistance; to Professor A. N. Strahler, for critical reading of the original manuscript; to Mr. M. E. Cooley, of the U. S. Geological Survey, for detailed review of the manuscript; and to Mr. John W. Koenig for field assistance.

Figure 2 was compiled from photomosaics of the Hualpai Indian

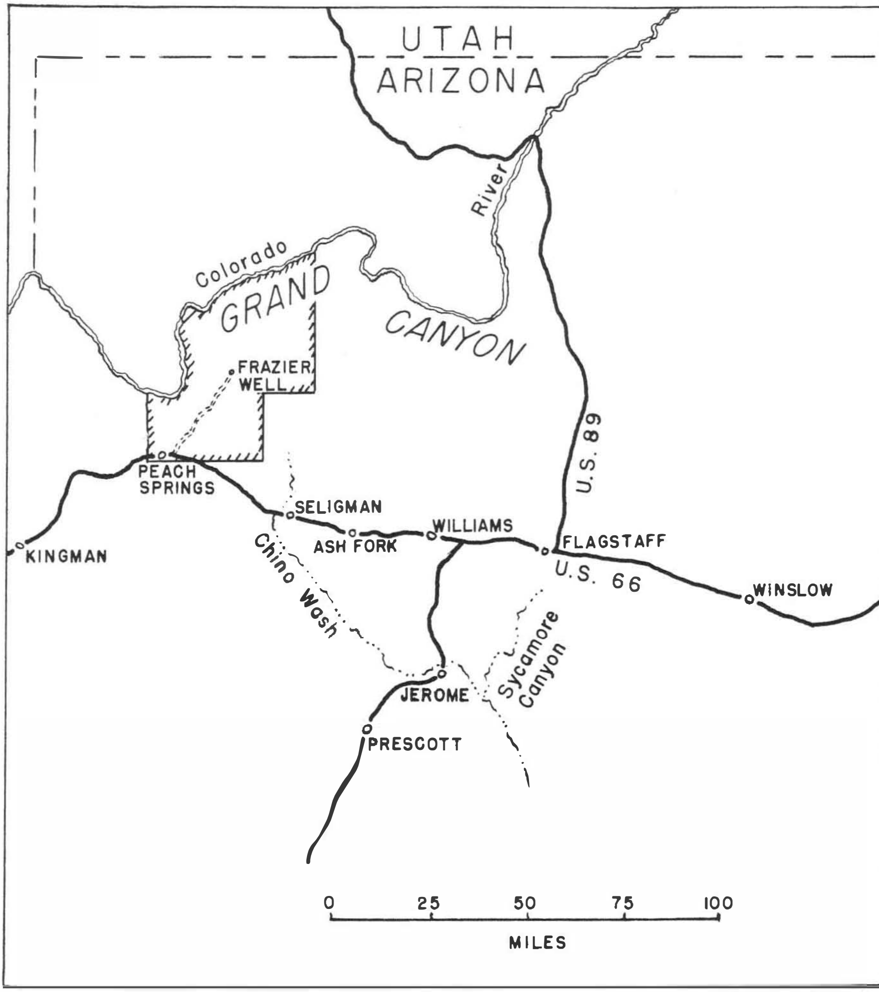


Figure 1.--Index map of northern Arizona, showing principal towns and highways.

Reservation provided by the U. S. Soil Conservation Service and from aerial photographs provided through the courtesy of Fairchild Aerial Surveys, Los Angeles, California.

GENERAL DESCRIPTION

The Hualpai Indian Reservation is bounded on the north by the Colorado River; the southern, eastern, and western boundaries have been arbitrarily defined and bear no relation to topographic features. In the northeastern portion of the reservation, the Grand Canyon shows the cross-profile characteristic of this area. The upper walls of the canyon, rising from the Esplanade, are from 1,000 to 1,500 feet in height; the Esplanade is from 1 to 2 miles in width. Below the Esplanade is the narrow Inner Gorge, 3,000 to 4,000 feet in depth, and but a mile or less across. Several large side canyons have been cut to river level in this section, including Havasu Canyon, National Canyon, and Mohawk Canyon, the latter more or less closely following the line of the Mohawk fault (fig. 2). The Toroweap fault occurs in the floor of Prospect Valley, which is not cut to river level. West of Prospect Valley is the broad Ridenour Mesa, which corresponds structurally to the Uinkaret Plateau block on the north side of the Colorado. Ridenour Mesa is bounded on the east by the Toroweap fault and on the west by the Hurricane fault. Beyond Ridenour Mesa and the Hurricane fault there is an isolated mesa, here called Hurricane Mesa. In this section of the Grand Canyon, the Esplanade is not so well developed as farther eastward, the topography being complicated by the development of a complex of large and small cross faults related to the Hurricane fault. As a result, the descent from Ridenour Mesa to the river is by a series of platforms and small canyons, and the Inner Gorge is frequently absent or poorly developed.

The Aubrey Cliffs is a low escarpment near the southeastern boundary of the Hualpai Indian Reservation, but southward toward Seligman, it has heights of 800 to 1,200 feet. West of the Aubrey Cliffs is Aubrey Valley, a broad alluviated lowland bounded on the west by a low escarpment developed along the Blue Mountain fault, west of which is a broad irregular platform of low relief that breaks off into Peach Springs Wash on the west and Diamond Creek on the north.

STRATIGRAPHY

The Archean (older Precambrian) Vishnu Schist (Noble, 1914, p. 32-36) is part of the basement complex composed of granite and metamorphic rocks exposed in the Lower Granite Gorge of the Grand Canyon near the Hurricane fault (fig. 2). Overlying the basement rocks unconformably is the Early to Middle Cambrian Tonto Group named originally by Gilbert (1874, p. 109) and later divided by Noble (1914, p. 61-65) into three formations, which are, in ascending order, the Tapeats Sandstone, Bright Angel Shale, and the Muav Limestone. McKee (1945) has made a detailed study of the Cambrian strata of the Grand Canyon; the section described from Peach Springs Wash near Diamond Creek may be considered typical of the Cambrian in the eastern Hualpai Indian Reservation, although there are some local variations in thickness and character of the rocks. The Tapeats Sandstone is Early Cambrian in age, is 215 feet thick, and lies unconformably on the Vishnu Schist. It is succeeded by

326 feet of the Middle Cambrian Bright Angel Shale, generally a slope-forming unit. The Bright Angel is overlain by 639 feet of the Middle Cambrian Muav Limestone, a conspicuous cliff-forming unit.

The predominantly cliff-forming Devonian Temple Butte Limestone (Walcott, 1880, p. 221-225) overlies the Muav Limestone and is 359 feet thick. At the foot of Toroweap Valley, the Mississippian Redwall Limestone (Gilbert, 1875, p. 161) is 605 feet thick and forms a massive cliff. It is overlain by red beds of the Supai Formation.

The Supai Formation (Darton, 1910, p. 25) of Pennsylvanian and Permian age is the basal unit of the Aubrey Group (Gilbert, 1875, p. 176-185), named from Aubrey Cliffs near Seligman, Arizona. The other formations of the group are of Permian age and consist, in ascending order, of the Hermit Shale (Noble, 1922, p. 26), the Coconino Sandstone (Darton, 1910, p. 27), the Toroweap Formation (McKee, 1938), and the Kaibab Limestone (Darton, 1910, p. 28).

The Supai Formation contains thin limestone beds near the base but is characteristically composed of sandy shale and massive crossbedded sandstone, having a total thickness of 749 feet at Toroweap Valley. The Supai Formation is overlain by the Hermit Shale, which varies from nearly 1,100 feet at the foot of Prospect Valley to less than 500 feet in the Aubrey Cliffs. It is everywhere a conspicuously weakly resistant slope-forming unit, with the exception of the lower 200 feet, which contains several massive resistant crossbedded sandstones, responsible for the development of the Esplanade. The crossbedded Coconino Sandstone, 100 to 150 feet thick, overlies the Hermit and is typically displayed only in cliffs, although locally, as at Robbers Roost, it crops out over a relatively broad area. The Toroweap Formation ranges in thickness from 424 feet at Toroweap Valley to 320 feet in the Aubrey Cliffs near Seligman. The lower half of the formation is composed of cliff-forming limestone, and the upper half contains many sandy and gypsiferous beds and is usually slope forming. The Toroweap Formation is followed by the Kaibab Limestone, which is 571 feet thick at Toroweap Valley. The Kaibab is composed of a basal massive cherty cliff-forming limestone and 330 feet of interbedded limestone, shale, sandstone, and gypsiferous beds, which are generally slope forming. The uppermost Kaibab is marked by a thin nodular yellow limestone that serves as a useful key horizon. The surface of the plateau over broad areas is developed on the stripped surface of the Kaibab Limestone, from which the overlying weak Triassic Moenkopi Formation has been nearly removed. Scattered outcrops of the Moenkopi are preserved in a few places, generally not exceeding 10 feet in thickness.

Mesozoic rocks younger than the Moenkopi Formation have been eroded off by erosion that occurred mainly during Cenozoic time. As a result of this erosion, only a few deposits of Cenozoic age have been preserved in the area. Three of the deposits were given the names Robbers Roost and Frazier Well Gravels[1/] (Koons, 1948b) and the Cataract Creek Gravel, a name proposed in this paper.

1/ In a previous paper (Koons, 1948a, p. 58), the author referred to the deposits of the Frazier Well Gravel at Blue Mountain as the "Blue Mountain Gravel."

IGNEOUS ROCKS

In contrast with the Uinkaret Plateau and Toroweap Valley north of the Colorado River (Koons, 1945), igneous rocks occur in only a few isolated sections in the Hualpai Indian Reservation (fig. 2). The largest outcrop lies immediately around Peach Springs and comprises a series of basaltic lava flows. A group of small volcanoes and lava flows, having a total area of less than 1 square mile, appears at the southeastern boundary of the reservation, 1 mile north of U.S. Highway 66. The area covered by these lavas is so small that no correlation can be made on the basis of weathering or erosion. Blue Mountain consists of a small cone and associated lava flows, covering a total area of about 3 square miles. The lavas are olivine basalts, and the flows have a total thickness of 30 to 50 feet. A very small outcrop of lava appears on the western slope of Robbers Roost. Three small cones and associated lava flows are grouped at the mouth of Prospect Valley; the area of lava immediately east of Toroweap fault at the rim of the Inner Gorge may be connected with this group of cones, but deposits of alluvium in the valley floor conceal any such connection. A very small cone is present on the Hermit slope east of Yumtheska Point, and there are several disconnected basalt flows within the Inner Gorge of the Grand Canyon near the Toroweap and Hurricane faults (McKee and Schenk, 1942, p. 270; Moore, 1925, p. 156, pl. 79-B; Koons, 1945, pl. I). The extensive volcanic field surrounding Mount Floyd and Round Mountain north of Seligman and south of Rose Well is not included in the present study.

MAJOR STRUCTURES

The Hurricane Fault

Moore (1925, p. 157) describes the Hurricane fault as having a displacement of approximately 300 feet where it crosses the river (fig. 2). While physical limitations prevented study of this section by the author, measurements on stereopairs of aerial photographs of the fault 2 miles south indicate that displacement here is at least 1,100 feet, eastern side upthrown. Between Hurricane Mesa and Big Spring (fig. 3), the eastern side is upthrown 1,500 feet. Southward, the fault divides into two parallel branches (figs. 2 and 4-A) connected by several cross faults with displacements as much as 600 feet. The intervening blocks are somewhat tilted, showing dips of as much as 6° E. Displacement along the two branches is approximately the same, 1,500 feet on the eastern branch and 1,000 to 1,100 feet on the western branch. Locally, strong drag is displayed along the eastern branch of the fault, with dips of as much as 15° W., reversing the general dip of 3° E. on the upthrown block near the fault. To the southwest, the western branch dies out near the Colorado River; the eastern branch continues, passing east of Diamond Peak where displacement is 600 feet, and thence up Peach Springs Wash with constantly diminishing throw, finally dying out 6 miles north of Peach Springs.

Direct evidence of the age of faulting in this section is absent. It seems probable that the greatest amount of movement took place at the same time as farther to the north and is Pliocene or early Pleistocene (Koons, 1945, p. 163-164) or perhaps earlier.

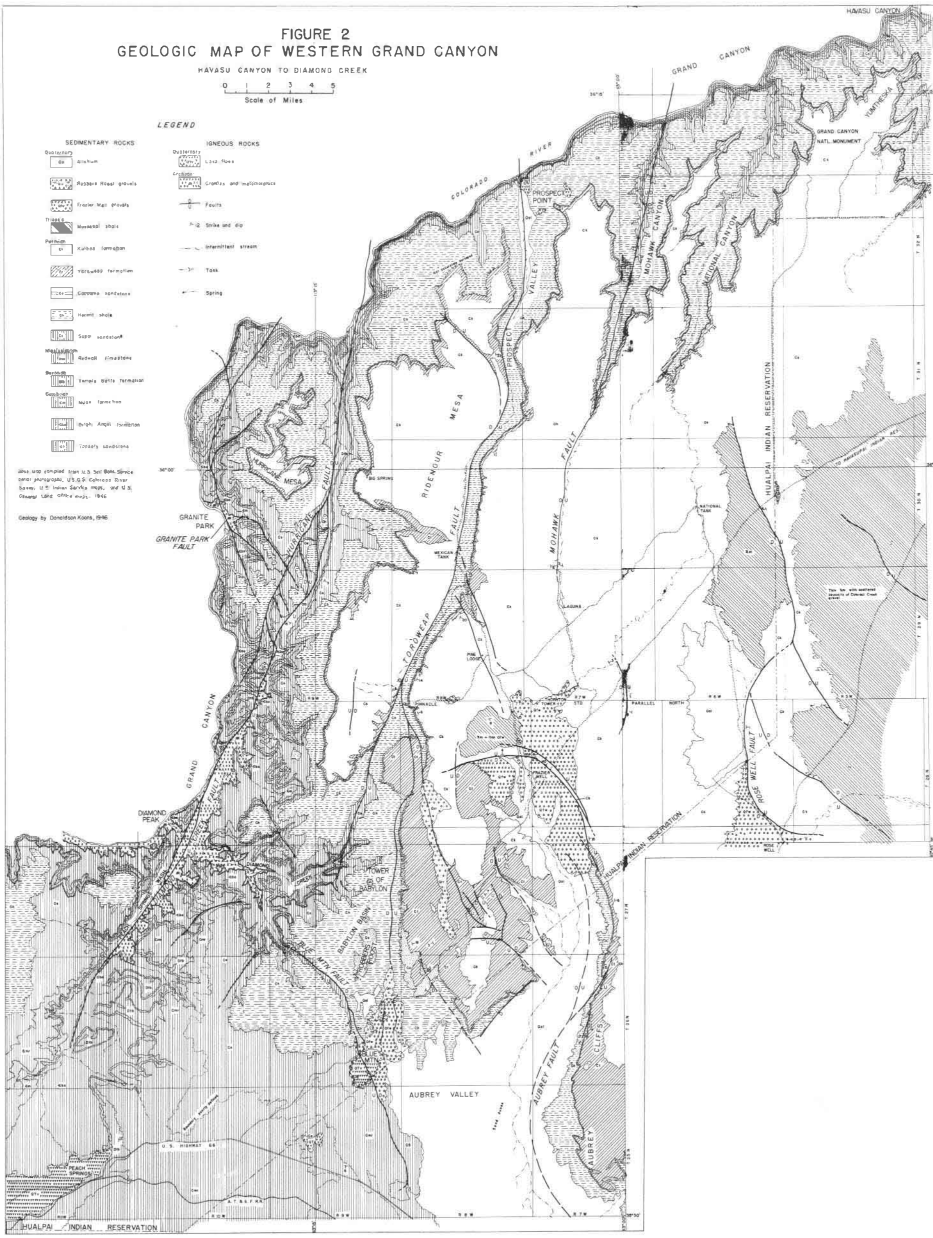


FIGURE 2
GEOLOGIC MAP OF WESTERN GRAND CANYON
HAVASU CANYON TO DIAMOND CREEK
0 1 2 3 4 5
Scale of Miles
LEGEND
SEDIMENTARY ROCKS
IGNEOUS ROCKS
Alluvium
Faults
Strike and dip
Intermittent stream
Tank
Spring
Geology by Donaldson Koons, 1946
HAVASU CANYON
GRAND CANYON
COLORADO RIVER
PROSPECT POINT
PROSPECT VALLEY
MOHAWK CANYON
NATIONAL CANYON
GRAND CANYON NATL. MONUMENT
HURRICANE MESA
HURRICANE FAULT
BIG SPRING
RIDENOUR MESA
TOROWEAP FAULT
GRANITE PARK
GRANITE PARK FAULT
MOHAWK FAULT
HUALPAI INDIAN RESERVATION
MEXICAN TANK
NATIONAL TANK
LAGUNA
PINE LODGE
PINNACLE
ROSE WELL FAULT
ROSE WELL
DIAMOND PEAK
TOWER OF BABYLON
BABYLON BASIN
BLUE MTN FAULT
AUBREY VALLEY
AUBREY FAULT
AUBREY CLIFFS
U.S. HIGHWAY 66
PEACH SPRINGS
A.T.&S.F.R.R.

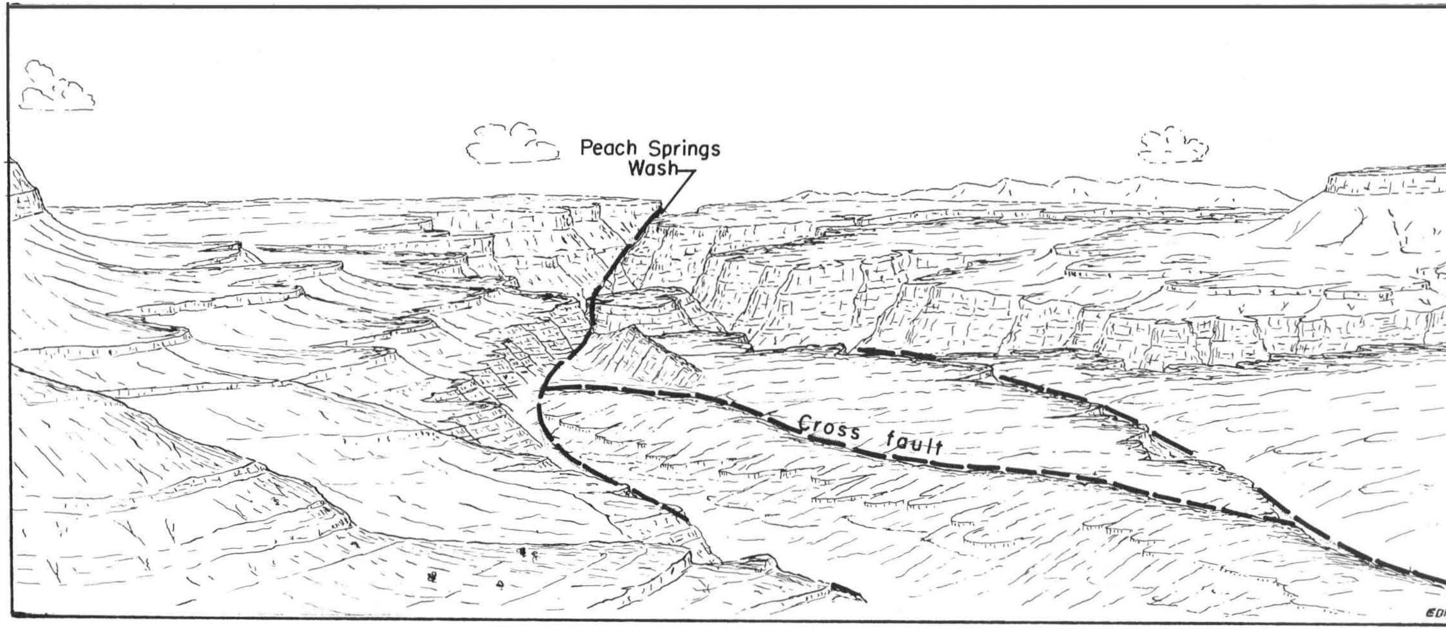


Figure 3. --Grand Canyon and the Hurricane fault, south of Big Spring. (Drawn from photographs.)

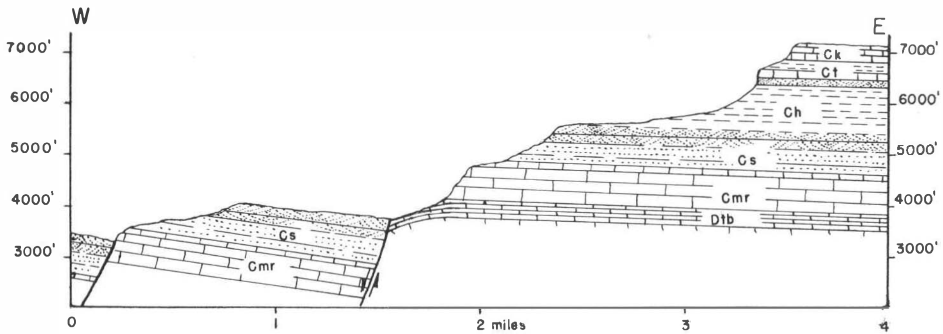
The Toroweap Fault

At the Colorado River the Toroweap fault shows a throw of 632 feet, divided into two stages: 486 preceding the lava flows, and 146 feet following extrusion of lavas (McKee and Schenk, 1942, p. 262). At the mouth of Prospect Valley there is some suggestion of faulting of about 30 feet in the lavas just west of Prospect Point, as mentioned by Davis (1903, p. 20), but the indications are obscured by alluvium that mantles the valley floor. Southward along the fault there is no critical evidence that shows that faulting occurred in two or more stages. The fault may be traced southwestward past the Pinnacle, where it divides (fig. 2). Here, displacement amounts to 1,000 feet, eastern side upthrown (fig. 4-B). The western branch of the fault continues down Diamond Creek, finally disappearing 2 miles west of the Tower of Babylon. Between the Colorado River and the Pinnacle the fault is simple. A small branch curves northwestward across the northern end of Ridenour Mesa but dies out in a short distance. On the downthrown block, the Kaibab Limestone shows dips of 3^{o} to 8^{o} E., locally increasing to as much as 23^{o}. The Kaibab Limestone dips 20^{o} E. 2-1/2 miles northwest of Pine Lodge on the upthrown block; a mile north of the Pinnacle, dip on the upthrown block is 14^{o} E., decreasing to 6^{o} half a mile south of the Pinnacle. This phenomenon of apparent "reverse drag" has been recognized elsewhere in the Plateau region (Koons, 1945, p. 164-166; Strahler, 1948, p. 522-524). It seems probable that this phenomenon may be explained in part at least as the result of faulting of an earlier monocline. However, the eastward dip of 23^{o} on the downthrown block, noted 7 miles south of Prospect Point, is not matched by any correspondingly strong dip on the western side of the fault, and it appears that here downflexing of beds on the downthrown block may have occurred in the manner suggested by Gardner (1941, p. 254-259).

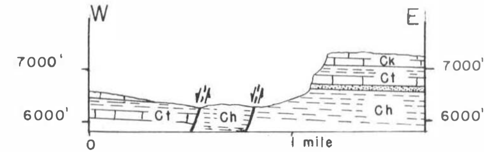
The eastern branch of Toroweap fault again divides 1 mile south of the Pinnacle (fig. 2). The main fault continues southward, passing east of the Tower of Babylon and Robbers Roost. Absence of key horizons in the Hermit Shale makes accurate measurement of displacement impossible in this section, but the throw at Robbers Roost is estimated to be 300 feet. A portion of the fault is buried under Robbers Roost Gravels in the Babylon basin, but is seems probable that small faults northeast of Blue Mountain, which cut Frazier Well Gravels, are the southern termination of this branch. The easternmost branch of the fault passes beneath Robbers Roost Gravels 3 miles south of the Pinnacle, but the fault line may be traced to the complex 6 miles east of Robbers Roost.

From Mexican Tank, a small graben extends southeastward past Pine Lodge. Displacement on the faults on either side of this graben is between 75 and 150 feet.

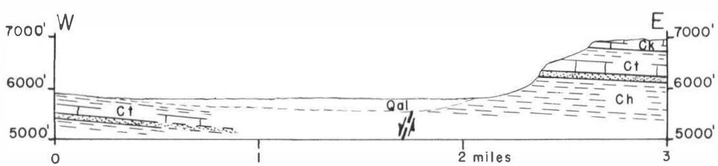
At the Colorado River, the major movement along the Toroweap fault is pre-lava; southward there is no critical evidence by means of which the time and distribution of movement may be determined. The southern end of the fault appears to be buried by Robbers Roost Gravels in Babylon basin, and the doubtful continuation of this fault displaces the somewhat older Frazier Well Gravel in the same area.



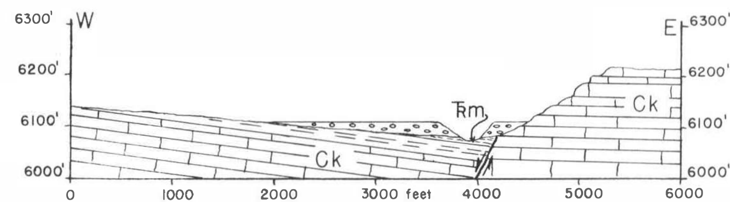
A. Hurricane fault, 8 miles southwest of Big Spring.



B. Toroweap fault at the Pinnacle.



C. Aubrey fault at boundary of reservation southeast of Frazier well.



D. Rose well fault 2 miles north of Rose well.

Figure 4.--Profiles and structure sections. (Formation symbols are the same as those shown on fig. 2.)

The Aubrey Fault

The Aubrey fault enters this area from the south, first appearing at Chino Point 4 miles west of Seligman on U. S. Highway 66. It was mentioned briefly by Darton (1915, p. 134) and by Robinson (1913, p. 36-37), but it seems probable that the fault described by Robinson as being located between Ash Fork and Seligman and having a displacement of 1, 000 feet is a separate fault; it is so delineated on the geologic map of Arizona by Darton and others (1924). Northward from U. S. Highway 66, displacement along the fault cannot be accurately determined because of extensive alluvial deposits covering the floor of Aubrey Valley, but the eastern side is upthrown not less than 1, 000 feet and perhaps considerably more (fig. 4-C). Minor fault splinters develop east of the main fault line, but these are small; displacement along any one of them is not more than 250 feet.

A mile north of the reservation boundary, the fault cuts the Frazier Well Gravel and begins to curve westward, passing a mile north of Frazier Well, finally disappearing 4 miles west of the settlement (fig. 2). This curved portion of the fault is more complex than that to the south and here consists of two parallel faults, with the intervening beds strongly tilted, showing dips of as much as 45° NE. Beginning about at the reservation boundary line, the limestone beds of the Kaibab and Toroweap Formations have been altered to very resistant quartzite. The zone of alteration generally is limited to 100 yards on either side of the faults, but at the western end of the fault silicified beds are found 1 mile south of the fault and 1 mile to the north. No marked mineralization has occurred in this zone, and the sedimentary structures and fossils of the Kaibab and Toroweap Formations are undisturbed. It seems probable that silicification resulted from movement of heated solutions along the fault zone, although it is not clear why this alteration should be limited to this area.

Movement along the northern portion of the Aubrey fault took place after deposition of the Grazier Well Gravel; how much later it is impossible to tell, although sufficient time has lapsed for the broad lowland of Aubrey Valley to be developed.

MINOR STRUCTURES

Granite Park Fault

West of Hurricane Mesa and nearly parallel to the Colorado River, a small fault developed, trending northwestward from the Hurricane fault then curving to the northeast before crossing the river (fig. 2). The eastern side of this fault is upthrown, the maximum displacement being 600 feet at Granite Park (Moore, 1925, p. 159). As far as could be determined, there is no direct connection between this fault and the Hurricane fault, but it may represent a continuation of the cross faults developed between the eastern and western branches of the Hurricane fault in this section. Age of the fault cannot be determined, since the youngest deposits displaced are the Permian Hermit Shale, but the Colorado River ignores the fault line, cutting its canyon somewhat to the west; it seems probable that faulting took place some time after establishment of the present course of the river.

Blue Mountain Fault

The Blue Mountain fault first appears 4 miles west of Robbers Roost in Blue Mountain Wash (fig. 2). It may be traced southeastward for about 12 miles past Blue Mountain, disappearing near U. S. Highway 66. The fault reverses the usual rule in this part of the plateau, the eastern side being downthrown with a maximum measured displacement of 150 feet. At Blue Mountain, the fault cuts both Frazier Well Gravel and the overlying lavas capping Blue Mountain and, hence, is of special significance in determining the chronology of events in this area.

Mohawk Fault

The Mohawk fault first appears near Laguna (fig. 2), where the eastern side is upthrown less than 100 feet. It continues northward down Mohawk Canyon, always with small displacement. At the Colorado River the eastern side is downthrown 100 feet. Although the displacement is small, the fault has acted as a line of weakness along which the large Mohawk Canyon has developed. North of the river the fault dies out rapidly. No evidence of the age of faulting was found; the youngest formation cut by the fault is the Kaibab Limestone.

Rose Well Fault

Near Rose Well the eastern side of the Rose Well fault is upthrown 300 feet. The fault follows an irregular curving path northward for 22 miles until it disappears 4 miles northeast of National Tank (fig. 2). Throughout this distance throw is less than 300 feet, and frequently it is not more than 100 feet. From Rose Well to the boundary of the reservation Cataract Creek Gravel occupies the lowland along the fault line. The gravel extends across the fault line 2 miles north of Rose Well, being at the same elevation on either side of the fault (fig. 4-D), indicating that in this section faulting preceded deposition of the gravel.

Other Minor Faults

Other minor faults of limited extent occur throughout the area. A small fault and monocline trend southeast from a point 2 miles east of Robbers Roost. The fault complex 6 miles east of Robbers Roost is composed of several faults that together produce a group of horsts and grabens. Other small faults, generally with the eastern side upthrown less than 100 feet, occur in several places over the plateau.

SUMMARY OF STRUCTURES

Although there is little critical evidence of age relations of the various faults, it seems probable that the conditions already described north of the Grand Canyon apply here and that the major movement along the larger faults took place sometime in the late Tertiary, perhaps late Miocene or early Pliocene. It seems probable also that later movement of a few hundred feet at the most has also occurred along some of the major faults, as suggested in the case of the Toroweap fault, and that the development of at least some of the minor faults took place at this time. Blue Mountain fault is an outstanding example of this latter group.

The orientation of faults is suggestive; study of the map (pl. I) shows two distinct families of faults—one having a trend of N. 15°-25° E., the other having a trend of N. 30°-40° W. The Hurricane, Toroweap, and Mohawk faults belong to this first group, as does part of the Aubrey fault; most of the minor faults, including the Blue Mountain and part of the Granite Park faults, belong to the second group. It is not clear whether these two families of faults represent two entirely different sets of stresses originating at different times or whether they are both the result of stresses produced by the same major deformation. The fact that the second family, trending N. 30°-40° W., is composed of smaller faults, generally somewhat younger than those of the first family, suggests that two different periods of deformation are represented. It is perhaps significant that the same pattern is observable north of the Colorado (Koons, 1945, pl. I).

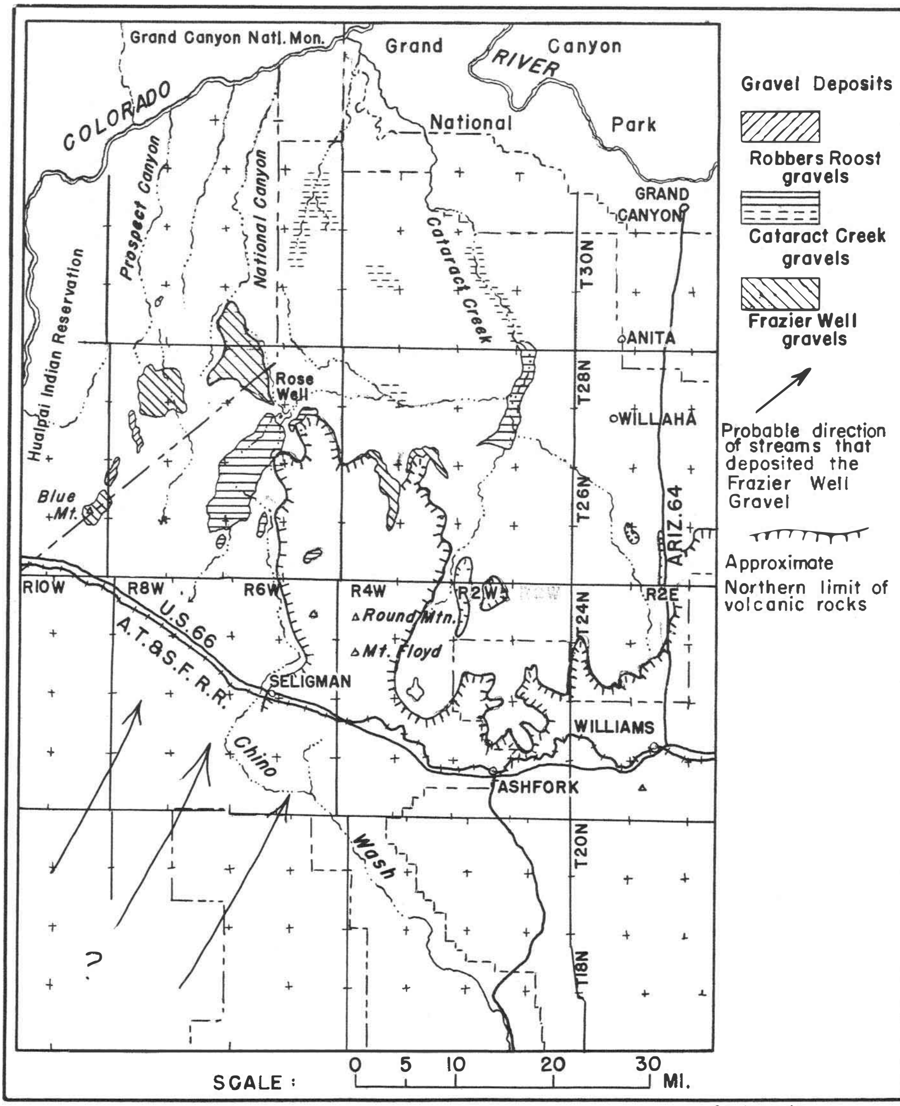
GRAVEL DEPOSITS

The presence of gravel deposits (figs. 2 and 5) in the area around Frazier Well was first noted by Darton (1925, p. 190), who described the location as an outlier of the Moenkopi Formation capped with gravel deposits. On the geologic map of Arizona (Darton and others, 1924), two small areas were outlined, one at the Frazier Well and the other at Blue Mountain. In the legend, these deposits are assigned to the "Quaternary and Tertiary" formations, which include the Chemuhuevis Formation and the Gila and Temple Bar Conglomerates. This designation was probably intended simply as a convenience in describing deposits that had not been carefully studied. It has already been noted by the author (Koons, 1948a, p. 58-59; Koons, 1948b) that the gravel deposits may be subdivided. The Frazier Well Gravel is composed of foreign derivation, consisting of varying percentages of igneous, metamorphic, and sedimentary fragments. The Cataract Creek Gravel is reworked Frazier Well Gravel, and the locally derived Robbers Roost Gravel consists mostly of limestone and sandstone fragments.

Frazier Well and Cataract Creek Gravels

Large deposits of Frazier Well Gravel are found near Blue Mountain, surrounding Frazier Well, and northward from Rose Well (figs. 2 and 3). Smaller deposits occur in a number of places over the surface of the plateau, notably near the Pinnacle and east of the reservation boundary. Cataract Creek Gravel outcrops are near Rose Well, Cataract Creek, and in isolated places north of Rose Well (fig. 5). Both gravel units consist of bedded but poorly sorted rounded pebbles, cobbles, and small boulders as much as 20 inches in the long diameter composed of red and white quartzite, vein quartz, granitic and gneissic rocks, chert, and sandstone (pl. II, fig. 2, table I).

Table I shows the distribution of rock types at typical outcrops of the



Geology by
Donaldson Koons, 1948

Figure 5.--Map showing generalized distribution of gravel deposits in the eastern Hualpai Indian Reservation area.

TABLE I
PERCENTAGES OF ROCK TYPES IN FRAZIER WELL GRAVEL
AT TYPICAL LOCALITIES

Location	Red quartzite	White quartzite	Vein quartz	Granitic	Gneissic	Sand-stone	Lime-stone	Chert	Lava	Meta-morphic	Elevation (feet)
Pinnacle	29	17	31	0	0	0	0	23	0	0	7, 125
2 mi. N. of Frazier Well	13	22	3	0	0	11	1	7	1	42	6, 575
2.5 mi. NE. of Frazier Well	11	8	13	40	19	3	0	6	0	0	6, 325
Blue Mtn., W. of fault	9	10	0	10	0	25	20	25	0	0	5, 850
Blue Mtn., E. of fault	0	0	16	45	35	1	2	1	0	0	5, 700
2 mi. E. of Blue Mtn.	0	4	24	29	21	16	0	0	0	4	5, 775

gravel; granitic and gneissic pebbles comprise as much as 80 percent of the material at the lower elevations, while at the highest deposit, no granitic pebbles are found, and quartzite comprises 46 percent of the total. In places the gravel is decomposed, pebbles 3 or 4 inches in diameter crumble easily in the hand, and staining and decomposition have penetrated the deposit to a depth of at least 15 feet. Fragments of vein quartz are uniformly yellow on the surface but when broken are milky inside.

The deposits range in thickness from a thin veneer to more than 200 feet; however, reworking of gravel around the margin of outcrops and the lack of knowledge concerning the surfaces on which it rests make it impossible to measure the thickness accurately at most occurrences.

Deposits are found at elevations of 5, 660 feet east of Blue Mountain to as high as 7, 125 feet east of the Pinnacle. Near Frazier Well, gravel is exposed continuously from 6, 325 feet to 6, 800 feet at Thornton Tower, but this does not necessarily represent a thickness of nearly 500 feet, since the underlying surface may be irregular. In the eastern part of the reservation scattered deposits are found at 6, 125 to 6, 300 feet, occupying broad shallow depressions. North of Rose Well the gravel fills a broad shallow valley along the Rose Well fault (fig. 5). Here the gravel forms a distinct terrace that slopes northwest, opposite to the present direction of streamflow. South of Rose Well, gravel and sandy silt are exposed under the lava flows of the Mount Floyd-Round Mountain volcanic field, and they show a thickness of 250 feet. This gravel deposit, however, may be older than the Frazier Well Gravel. This area was beyond the scope of the present study, however, and no detailed measurements of these deposits were made.

At the present time the nearest outcrops of rocks of the type found in the Frazier Well Gravel are near Prescott and in other parts of the mountainous area south and southeast of the Hualpai Indian Reservation. It seems probable that the gravel was deposited by northward-flowing tributaries of the Colorado River, originating in the mountains near Prescott. At the present time this area is drained by southward-flowing streams tributary to the Gila and Salt Rivers, because drainage reversal probably followed basin-and-range faulting and uplift. E. D. McKee (personal communication, 1946) reported similar gravel within Cataract Canyon; however, this gravel has not been studied in detail and may be in place or recently deposited reworked material from the plateau to the south. It seems to be clear, however, that the Colorado River was at or near its present position at the time the Frazier Well Gravel was deposited, and it is possible that the Grand Canyon had already been cut to some depth.

Age of Frazier Well Gravel

At Blue Mountain, the Frazier Well Gravel and the overlying lava flows are involved in both the Blue Mountain and Aubrey faulting and probably in at least part of the Toroweap faulting. The range in elevation from 5, 660 feet at Blue Mountain to 7, 125 feet at the Pinnacle exceeds, however, the total displacement along the Toroweap fault, and at least part of this difference in elevation must be original.

Price (1950) describes gravel deposits in Sycamore Canyon that resemble in many ways the Frazier Well Gravel, which he estimates to be late

Miocene or early Pliocene in age. It is the author's opinion that at the present time there is insufficient evidence on which to base a reliable date for the Frazier Well Gravel and that it may have been deposited at any time during Miocene or Pliocene time but is probably no younger than early Pleistocene.

Robbers Roost Gravel

The Robbers Roost Gravel is found in two localities (pl. I)—cropping out in the Babylon basin northeast of Blue Mountain and in a long relatively narrow exposure 5 miles west of the Frazier Well (fig. 2). It is typically composed of poorly sorted subangular fragments of limestone, sandstone, and chert in a sandy matrix (pl. II and fig. 1). Fossils contained in the pebbles indicate that the limestone blocks are derived from both the Toroweap and Kaibab Formations; the sandstone pebbles and boulders are similar to the Coconino Sandstone and to some of the thin sandstone members of the Toroweap and Kaibab Formations and may have been derived from either source. Where the base of the gravel is exposed, it rests on slopes of as much as 20°; absence of stratification, poor assortment, and presence within the gravel of pitted weathered limestone boulders that show no evidence of stream abrasion suggest that the Robbers Roost Gravel accumulated as slope wash and talus deposits at or near the bases of cliffs. The outcrops of the gravel are close to fault lines, and it seems probable that the deposits are closely associated with the faulting and while the relief was still strong. No fossils other than those reworked from Permian rocks were found within the gravel; the deposits are equivalent to or later than faulting along the southern branches of the Toroweap fault, but how much later cannot be determined.

SUMMARY AND CONCLUSIONS

On the basis of this study, the author concludes that the history of this area has been as follows:

1. The course of the Colorado River was established prior to the main displacements of the Hurricane and Toroweap faults. It is significant in this connection that the river parallels the Hurricane fault for many miles but does not follow this conspicuous line of weakness.

2. Deposition of Frazier Well Gravel by tributaries to the Colorado River originating in an uplift in the mountainous region to the south, possibly during the early cutting of the Grand Canyon.

3. Volcanism.

4. Faulting; it is possible that some faulting also preceded deposition of Frazier Well Gravel, but there is no critical evidence.

5. Deposition of Robbers Roost Gravel near fault lines.

6. Deposition of Cataract Creek Gravel.

7. Erosion, gradual reversal of some drainage, development of present drainage, and deposition of alluvium in Aubrey Valley and elsewhere.

REFERENCES CITED

Colton, H. S., 1937, The basaltic cinder cones and lava flows of the San Francisco Mountain volcanic field, Arizona: Mus. Northern Arizona Bull. 10.

Darton, N. H., 1910, A reconnaissance of parts of northwestern New Mexico and northern Arizona: U. S. Geol. Survey Bull. 435, 88 p.

__________ 1915, Guidebook of the western United States, Part C, the Santa Fe route: U. S. Geol. Survey Bull. 613.

__________ 1925, A resume of Arizona geology: Arizona Bur. Mines Bull. 119.

Darton, N. H., and others, 1924, Geologic map of the State of Arizona: prepared by the Arizona Bur. Mines in cooperation with the U. S. Geol. Survey.

Davis, W. M., 1901, An excursion to the Grand Canyon of the Colorado: Harvard Univ., Mus. Comp. Zool. Bull., v. 38, p. 107-201.

Dutton, C. E., 1882, The Tertiary history of the Grand Canyon district: U. S. Geol. Survey Mon. 2.

Gardner, L. S., 1941, The Hurricane fault in southwestern Utah and northwestern Arizona: Am. Jour. Sci., v. 239, p. 241-260.

Gilbert, G. K., 1874, On the age of the Tonto Sandstone (abs.): Philos. Soc. Washington Bull. 1, p. 109.

__________ 1875, Report on the geology of portions of Nevada, Utah, California and Arizona: U. S. Geog. and Geol. Survey W. 100th Mer. (Wheeler), v. 3, pt. I, p. 17-187.

Huntington, E., and Goldthwait, J. W., 1904, The Hurricane fault in the Toquerville district, Utah: Harvard Univ., Mus. Comp. Zool. Bull., v. 42, p. 199-258.

Johnson, D. W., 1909, A geological excursion to the Grand Canyon district: Boston Soc. Nat. History Proc., v. 34, p. 135-161.

Koons, Donaldson, 1945, Geology of the Uinkaret Plateau, northern Arizona: Geol. Soc. America Bull., v. 56, p. 151-180.

__________ 1948a, Geology of the eastern Hualpai Reservation: Mus. Northern Arizona Bull. (Plateau), v. 20, no. 4, p. 53-60.

__________ 1948b, High-level gravels of western Grand Canyon: Science, v. 107, no. 2784, p. 475-476.

McKee, E. D., 1938, The environment and history of the Toroweap and Kaibab Formations of northern Arizona and southern Utah: Carnegie Inst. Washington Pub. 492.

———— 1945, Cambrian history of the Grand Canyon region: Carnegie Inst. Washington Pub. 563.

McKee, E. D., and Schenk, E. T., 1942, Lower canyon lavas and related features at Toroweap in Grand Canyon: Jour. Geomorph., v. 5, p. 243-273.

Moore, R. C., 1925, Geologic report on the Inner Gorge of the Grand Canyon of Colorado River: U.S. Geol. Survey Water-Supply Paper 556, p. 125-171.

Newberry, J. S., 1861, Geological report on the Colorado River of the West: Ives report of Colorado exploring expedition of 1857-58, pt. III, p. 1-154.

Noble, L. F., 1914, The Shinumo quadrangle, Grand Canyon district, Arizona: U. S. Geol. Survey Bull. 549, 100 p.

———— 1922, A section of the Paleozoic formations of the Grand Canyon at Bass trail: U. S. Geol. Survey Prof. Paper 131-B, p. 23-73.

Powell, J. W., 1875, Exploration of the Colorado River of the West and its tributaries, 1869-1872: Washington, D. C., Smithsonian Inst.

Price, W. E., 1950, Cenozoic gravels on the rim of Sycamore Canyon, Arizona: Geol. Soc. America Bull., v. 61, no. 5, p. 501-508.

Robinson, H. H., 1913, The San Franciscan volcanic field, Arizona: U.S. Geol. Survey Prof. Paper 76.

Sharp, R. P., 1942, Multiple Pleistocene glaciation on San Francisco Mountains, Arizona: Jour. Geology, v. 50, p. 481-503.

Strahler, A. N., 1948, Geomorphology and structure of the West Kaibab fault zone and Kaibab Plateau, Arizona: Geol. Soc. America Bull., v. 59, p. 513-540.

Walcott, C. D., 1880, The Permian and other Paleozoic groups of the Kanab Valley, Arizona: Am. Jour. Sci., 3rd ser., v. 20, p. 221-225.

Wheeler, G. M., 1889, Itinerary of the Colorado Grand Canyon and river trip, with map: U. S. Geog. and Geol. Survey W. 100th Mer., chap. II, p. 147-171.