GEOLOGY OF
NORTHWESTERN MOHAVE COUNTY, ARIZONA

by
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A Thesis Submitted to the Faculty of the
DEPARTMENT OF GEOLOGY
In Partial Fulfillment of the Requirements
For the Degree of
MASTER OF SCIENCE
In the Graduate College
UNIVERSITY OF ARIZONA

1958
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An area of approximately 4,200 square miles in northwestern Mohave County, Arizona was mapped at a scale of one inch equals two miles. This region is of both structural and stratigraphic interest because it contains the boundary zone between the two major physiographic provinces of the southwestern United States: (1) the Basin-and-Range Province, and (2) the Colorado Plateau Province. Consistent with observations made in other areas is the fact that the Colorado Plateau Province is structurally lower and stratigraphically higher than the adjoining Basin-and-Range Province.

Precambrian metamorphic rocks, igneous rocks of Precambrian and Cenozoic age, and sediments ranging in age from Cambrian to Recent were mapped. Paleozoic sedimentary rocks in the Plateau portion of the mapped area are approximately 5,500 feet thick and in the Basin-and-Range portion 6,500 feet thick. Most of the Mesozoic formations have been removed by erosion. Cenozoic sediments, consisting of basin fill material, are restricted to the Basin-and-Range portion of the area.
The stability of the basement complex under the Plateau is demonstrated by the slight deformation the post Precambrian sediments there have undergone. The instability of the basement complex under the Basin Ranges is demonstrated by the late Mesozoic to Recent orogeny in that area and it is suggested that the areal extent of the orogeny is controlled by ancient crustal weaknesses.
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INTRODUCTION

Situation and Extent of Area

The northwestern portion of Mohave County, as considered in this report, is an area of approximately 4,200 square miles extending east from the Arizona-Nevada boundary to longitude 113 degrees and south from the Arizona-Utah line to Colorado River (Fig. 1). It is the western part of the larger area extending from Nevada to Lee's Ferry which is known colloquially as the Arizona Strip because of the manner in which it is separated from the rest of the State by the Grand Canyon of the Colorado River.

St. George, Utah, nine miles north of the State line, is the nearest town of consequence and serves as a supply point for the few ranches in the area. A graded dirt road extends from St. George south some 60 miles to Mount Trumbull, the only settlement in the area. A graded dirt road also connects Mount Trumbull with Fredonia, Arizona, approximately 100 miles to the northeast. A number of unimproved dirt roads and "jeep" trails traverse other parts of the area. Two of these connect the St. George-Mount Trumbull road to the Grand Wash road which extends from Tassai, Arizona to Riverton, Nevada (Fig. 2).
Figure 1.— Index map of Arizona, showing location of northwestern Mohave County.
Figure 2 – Map of northwestern Mohave County, showing location of roads and principal geographic features.
Physiographically the area extends into two provinces. The eastern two-thirds is situated on the Shivwits Plateau and a portion of the Uinkaret Plateau, both of which are divisions of the Colorado Plateau Province. The remaining third which extends west from the Grand Wash Bench and includes the Virgin and Beaver Dam Mountains is in the Basin-and-Range Province.

In the western portion relief is fairly great. Elevations range from a high of 8,350 feet on Mount Bangs in the Virgin Mountains to a low of 1,200 feet at the surface of Lake Mead. Both of these locations are in the Basin-and-Range portion of the area. The average elevation of the Plateau portion is approximately 5,000 feet and ranges from 6,000 feet along the rim of Grand Canyon to 4,000 feet near the Utah line. A notable exception, however, is basalt-capped Mount Trumbull, situated at the south end of the Uinkaret Plateau near Grand Canyon, which attains a height of 8,028 feet.

Here in the western division of Grand Canyon, as in the vicinity of Bass Trail, an inner and an outer gorge are well developed and these extend downstream to approximately Andrus Canyon. Unlike at Bass Trail, however, where the floor of the outer gorge is carved on the Tapeats sandstone, in the western division the floor of the outer gorge is carved on the upper sandstone member of the Supai formation and forms the Esplanade as named by Dutton. Downstream
from Andrus Canyon the south wall of the outer gorge has been eroded away. However, on the north side of Grand Canyon the Esplanade is well developed and merges with the Grand Wash Bench farther west.

From a local point of view, drainage is divided between the Colorado River on the south and the Virgin River on the north. However, the entire area is a part of the Colorado River watershed since the Virgin empties into the Colorado farther west in Nevada.

Although the average surface gradient of the Plateau is to the north and east, at least half of the area mapped is drained to the south, directly to the Colorado River. This has resulted in the carving of the many deep tributary canyons such as Parashont, Andrus, and Surprise which cut the walls of Grand Canyon.

West of Grand Wash Bench the Virgin Mountains form a local drainage divide. The southeast flank of the range is part of the Grand Wash drainage system which flows south to the Colorado; the northwest flank of the range drains into Virgin River.

Previous Studies

Scientific explorations in northwestern Arizona were recorded by J. W. Powell as early as 1874. Marvine (1875) and Gilbert (1875) reported the results of reconnaissance studies made in conjunction with the Wheeler
Survey. However, both the Powell and the Wheeler surveys were primarily geographic in nature and the geologic studies were of necessity sketchy. Studies concerning the stratigraphy of the Plateau region were made by Walcott (1880, 1883) and later by Noble (1914, 1922). Some of the names assigned to various of the units by these men are still in use.

Davis (1901) published the results of a more detailed reconnaissance across the Uinkaret Plateau and the Hurricane Cliff. Huntington and Goldthwait (1904, 1905), members of Davis' party during his second trip, made in 1902, studied the Hurricane fault in still more detail.

With the exception of the very general map prepared by Gilbert, Marvine, and Howell (1876), no reliable geologic maps of the area were available until the Geologic Map of the State of Arizona was published (Darton et al., 1921).

In more recent years a number of studies of special problems have been made in this region. Stratigraphic studies have been made of the Cambrian System by McKee (1945) and Wheeler (1943), and of the Toroweap and Kaibab formation by McKee (1938). Correlations of the Paleozoic sediments have been made by McNair (1951) and Reeside and Bassler (1922). A study of the Uinkaret basalt field was made by Koons (1945). Longwell (1928) extended his work in the Muddy Mountains into the Grand Gulch area
and briefly correlated the rocks there with those farther west. McKee (1954-) published a detailed report on the stratigraphy of the Moenkopi formation and more recently has made stratigraphic studies of the Redwall limestone, Supai formation, and Hermit shale. This later work, however, has not been published.

Present Study

This report is based in part upon observations made during approximately six weeks of detailed reconnaissance carried on between July 1, 1957 and January 13, 1958, and in part upon the published and unpublished data of several other workers who have made studies in this region.

In view of the number of stratigraphic studies already made, the present study was directed toward obtaining a better understanding of the structural features of the area and in compiling a more detailed geologic map of the region.

Mapping was done on aerial photographs at a scale of approximately 1 inch equals 1 mile. Stereo coverage of the entire area was available and greatly facilitated the field work. The geologic map (Pl. I) was compiled at a scale of 1:125,000 on a topographic base prepared by the Army Map Service.
Acknowledgments

This study was made in conjunction with my work at the Arizona Bureau of Mines, from July 1, 1957 to January 1958. I wish to thank Dr. J. F. Lance, who directed this thesis, for his continued advice and helpful criticism in the field and on the manuscript. Dr. E. D. Wilson and Mr. H. W. Peirce made many helpful suggestions during the preparation of the manuscript and Dr. E. B. Mayo kindly went over the manuscript giving constructive criticism.

Appreciative thanks are extended Dr. E. D. McKee who kindly furnished me with several unpublished sections which he had measured in the Grand Canyon and which were very helpful. Thanks are due my wife, Elizabeth H. Moore, for field assistance and to Mrs. E. D. Wilson for typing this report.
STRATIGRAPHY AND LITHOLOGY

General Statement

Rocks ranging in age from Precambrian to Tertiary crop out in this part of the Arizona Strip (Pl. I, Fig. 3). Precambrian rocks are for the most part granite, schist, and granite gneiss. The Paleozoic era is represented by sediments deposited during the Cambrian, Devonian, Ordovician (?), Mississippian, Pennsylvanian, and Permian periods while the Mesozoic era is represented by the Moenkopi, Shinarump, and Chinle formations of Triassic age. Tertiary and Quaternary rocks include the lake beds of the Muddy Creek formation (?), alluvial fan materials, and basalt flows and cinder cones.

The various formations of Paleozoic age are well displayed in the walls of Grand Canyon and for the most part can be correlated quite easily on the basis of lithology and stratigraphic position with those occurring at Bass Trail (Noble, 1922). The only major departure from the nomenclature of the Bass Trail section is the introduction of the term Callville limestone between the Redwall and Supai formations (Fig. 3).

With the exception of the Kaibab limestone which forms the surface of much of the Plateau, outcrops of
Figure 3.—Columnar sections of Paleozoic rocks in eastern and western Grand Canyon.
Paleozoic rocks in the Plateau region are restricted to the Grand Canyon, the Grand Wash Cliffs and the Hurricane Cliff (Pl. I). West of Lower Grand Wash Cliff Paleozoic sediments are exposed in several tilted fault blocks and in faulted sections in the Virgin and Beaver Dam Mountains.

Mesozoic rocks are more prominent in the northern third of the area, although several remnants of Moenkopi strata do exist farther south.

Tertiary and Quaternary sediments are most highly developed in the Grand Wash valley with only thin, superficial deposits found on the Plateau. Volcanic rocks of Tertiary and Quaternary age are distributed throughout the area but are of greatest prominence at the head of Grand Wash, east of Mount Bangs and in the Mount Trumbull basalt field on the south end of the Uinkaret Plateau.

Precambrian Rocks

In western Grand Canyon the Colorado River has carved its channel downward through the Paleozoic sediments to the extent that now a long stretch of its course is cut in older Precambrian granite and granite gneiss. Starting at a point about 10 miles above Diamond Creek these Archean rocks are continuously exposed for a distance of 50 miles downstream and in places rise more than 300 feet above river level.
To the northwest, the main mass of the Virgin Mountains, culminating in Mount Bangs, is composed of similar crystalline rocks composed predominantly of hornblende and mica with minor amounts of quartz and feldspar. Occurring in fault contact with the gneiss is a gray to tan, coarsely crystalline granite. The assignment of a Precambrian age to this granite is based on the erosional surface between it and the overlying Cambrian sandstones and quartzites.

Intruding the gneiss is a pink granitic rock that occurs as thin sheets and pegmatitic masses generally following planes of schistosity and weaknesses along the gneissic banding. Although here considered Precambrian, some evidence suggests that the pink granite may be of younger age. In the vicinity of the Virgin Mountains the schistosity and banding in the Precambrian gneiss and schist is nearly parallel to the structures developed during the late Cretaceous-early Tertiary orogeny and therefore these granite dikes could as well be associated with this later period of orogeny as with the Precambrian. The fact that similar pink granite dikes and sills are common in the Precambrian rocks in the Lower Granite Gorge (Moore, 1925) and are definitely pre-Tapeats sandstone (Cambrian sandstone), however, makes a Precambrian age more probable.
Although no younger Precambrian rocks were recognized in the area, the possibility of their presence cannot be discounted. Longwell (1936, p. 1409) describes a thick sequence of sediments near what is now the site of Hoover Dam which he considers to be of possible younger Precambrian age, "perhaps equivalent to part of the Grand Canyon series."

Cambrian System

Cambrian sandstone, shale, and limestone are exposed in the Grand Canyon along the southern margin of the area, from the lower Grand Wash Cliff to the east boundary and beyond. Gilbert (1875) referred these sandstones and shales exposed at Grand Wash Cliff to the Tonto group which he had defined farther east in the Grand Canyon. Noble (1914) proposed the names, from older to younger, Tapeats sandstone, Bright Angel shale, and Muav limestone respectively for the sandstone, shale, and limestone of the Tonto group. McKee (1945) made a detailed study of these sediments and measured a number of stratigraphic sections along Grand Canyon.

The rocks of the Tonto group have been assigned variously to the Devonian, Silurian, Ordovician, and Cambrian systems. However, McKee (1945) offers good evidence for a Lower through mid-Middle Cambrian age for the group. He also shows that the boundary between Lower
and Middle Cambrian passes from within the Bright Angel shale at Grand Wash Cliff down into the Tapeats sandstone in the central part of the Grand Canyon region.

When viewed from the Esplanade rim, the contact between the Tapeats sandstone and the underlying Precambrian granite gneiss appears remarkably planar for many miles. Noble (1914, p. 61) describes the surface upon which the Tapeats was deposited as "... a surface base-leveled by erosion. ... not nearly so even as that represented by the more ancient pre-Unkar unconformity. Yet ... a comparatively level plain."

The Muav limestone and Bright Angel shale both thicken to the west, having aggregate thicknesses of 960 feet and 1,215 feet at Toroweap Canyon and Diamond Bar, respectively (McKee, 1945). The Tapeats sandstone does not show such a regional thickening in the western Grand Canyon region. Instead, its thickness, which ranges from 0 to 325 feet, seems to be controlled more by the unevenness of the surface upon which it was deposited. However, west of Grand Wash Cliff, the Prospect Mountain quartzite, which is considered the correlative of the Tapeats by Wheeler (1943, p. 1793), thickens rapidly from 295 feet (Wheeler, 1943, p. 1807) in the Virgin Mountains, approximately one mile west of the Arizona line, to 800+ feet in the Mormon Range, Nevada, 33 miles northwest (Wheeler, 1943, p. 1806).
Exposures of Tonto group rocks are also present in the Virgin Mountains in Arizona. Cambrian sandstone outcrops near the base of the scarp east of Virgin fault, south of Mount Bangs, and can be traced for approximately three miles in a north-south direction. North of Mount Bangs, the quartzites of the Tonto group are exposed at the base of the sequence of lower Paleozoic rocks that form the arcuate outcrop pattern appearing on the north to northeast flank of the peak (Pl. I).

Undifferentiated Cambrian, Ordovician (?) and Devonian Systems

In western Grand Canyon a thick series of limestones and dolomites, containing minor beds of conglomerate, occupies the interval between the Cambrian Muav limestone and the Redwall limestone of Mississippian age. Dr. E. D. McKee (unpublished sections) found this series to be 1,340 feet thick at Iceberg Canyon, 1,156 feet thick at Quartermaster Canyon, and 442 feet thick at Granite Park.

Longwell (1928) briefly described this series as it appears at Whitney Ridge, in the Virgin Mountains, Nevada, approximately one mile west of the area of this report. Here he measured some 2,500 feet of sediments overlying the Muav; however, the upper part of this section is probably of Mississippian age. At approximately
the same place on Whitney Ridge, the Muav is overlain by 1,420 feet of limestones and dolomites which McNair (1951) subdivided to include 651 feet of undifferentiated Cambrian, 216 feet of Pogonip (?) limestone (Ordovician), and 552 feet of Devonian Muddy Peak limestone.

There appears to be general agreement concerning the assignment of the lower, dolomitic limestones, of this series to the Cambrian system (Schenk and Wheeler, 1942; Wheeler, 1943; McKee, 1945; McNair, 1951) and McKee (1945) offers evidence to the effect that these dolomitic limestones represent deposition during a regression of the Cambrian sea.

The type locality of the Ordovician Pogonip limestone is in the White Pine district, Nevada (Hague, et al, 1877), and Ordovician rocks as far south as the Death Valley region have been assigned to the formation (Hazzard, 1937). McNair's (1951) assignment of 216 feet of pink to light gray dolomitic limestone to the Pogonip (?) was admittedly tentative and based principally on lithologic differences between these beds and the dolomitic limestone below and the massive bedded limestone above. The rapid westward thickening of the lower Paleozoic section (Fig. 4) and the presence of a fairly thick sequence of Ordovician sediments not far to the west (Hewett, 1931), however, lend support to the assignment. If the assignment is correct, Ordovician rocks probably extend into the western
Figure 4.—Isopach map of the Cambrian through Devonian systems, reference numbers (-2-, etc.) refer to source list on page.
fringe of the Arizona Strip, wedging out under the
Shivwits Plateau.

The massive bedded limestone above the Pogonip
(? ) corresponds closely in lithology and stratigraphic
position to the Devonian Muddy Peak limestone which
Longwell (1928) described in the Muddy Mountains, Nevada.
It is also similar to the Devonian Martin limestone and
can be traced to the southeast where it has been identi-
ified as Martin (McNair, 1951). To the east, in the Grand
Canyon, the name Temple Butte limestone (Walcott, 1883)
has been assigned to a thin sequence of sandstones and
limestones which are at least in part Devonian. The
relations between these beds and the Muddy Peak limestone,
however, have not been established.

In the Virgin Mountains, Arizona, beds occupying
the interval between the Muav and Redwall can be observed
in the scarp south of Mount Bangs and in the domal struc-
ture on the north and east flanks of that Peak. Here they
consist of a conformable sequence of brown-weathering
dolomite approximately 1,500 feet thick.

Mississippian System

In Grand Canyon, the Devonian strata are succeeded
by the massive, cliff-forming Redwall limestone. The name
Redwall was first applied to this unit by Gilbert (1875).
As originally defined it included rocks of both
Mississippian and Pennsylvanian age; however, it was later restricted by Noble (1922) to include only the massive limestone of Mississippian age, the Pennsylvanian portion being assigned to the Supai formation. On the basis of fossils collected by Noble (1922), Girty referred the Redwall to the lower Mississippian.

The Redwall limestone, which is some 600 feet thick at Toroweap Canyon, can be traced west continuously to the Grand Wash Cliff where it is approximately 850 feet thick (Fig. 5). At Iceberg Canyon McKee (unpublished section) measured 864 feet of dolomites and limestones which he assigned to the Redwall limestone.

In the Muddy Mountains, 40 miles west in Nevada, Longwell (1928) describes some 1,500 feet of Mississippian limestones. The lower 600 feet are of lower Mississippian age and for these he proposed the name Rogers Spring limestone. The upper 900 feet, for which he proposes the name Bluepoint limestone, are of upper Mississippian age. He further states that fossil evidence indicates a break of such magnitude that the two formations may be separated by an erosion surface although it was not detected.

In the Virgin Mountains, McNair (1951) measured 577 feet of limestone which he referred to the Rogers Spring. He did not recognize upper Mississippian sediments in the section.
Figure 5.—Isopach map of the Mississippian system, reference numbers (-7-, etc.) refer to source list on page
Pennsylvania and Permian Systems

Callville limestone

At Grand Wash Cliff, near Hidden Canyon, 900 feet of Callville limestone is exposed resting on Mississippian Redwall limestone and overlain by cross-beded sandstone. These beds have been considered the upper part of the Redwall (Gilbert, 1875; Lee, 1908; Hill, 1915); however, both Hill (1915) and Longwell (1928) found Pennsylvanian fossils in the series. On the basis of this evidence Longwell (1928) considered these limestones to be the basal Supai formation as redefined by Noble (1922) and to be younger than any part of the Callville limestone which he described in the Muddy Mountains.

McNair (1951) found both Pennsylvanian and Permian fossils in a section of these limestones, 1,361 feet thick, on Pakoon Ridge, west of Grand Wash. He assigned the Pennsylvanian portion to the Callville limestone and proposed the name Pakoon limestone for the Permian portion. McNair reports the Callville to be predominantly limestone and the Pakoon to be more dolomitic. When examined, however, the entire sequence was found to be composed of dolomitic limestones and this observation was confirmed by Dr. E. D. McKee (oral communication). In view of the absence of a mapable lithologic break the justification for recognizing the Pakoon limestone as a separate
formation is questioned and both the Pennsylvanian and Permian beds are here considered a part of the Callville limestone.

East of the Hidden Canyon section, at Parashont Canyon on the east side of Shivwits Plateau, McKee (unpublished section) reports 1,068 feet of Supai formation between the Redwall limestone and the Hermit formation. On the basis of lithology this sequence can be divided into three units. The basal 107 feet of these Supai sediments consists of limestone with minor amounts of reddish brown claystone near the base and locally a basal conglomerate filling erosion channels. Next above the limestone is a sequence of \(3\frac{1}{4}\) feet of alternating limestone and claystone which may be considered a cyclic zone, and above that 616 feet of predominantly cross-bedded sandstone interbedded with lesser amounts of shaly, fine-grained sandstones, siltstones, and mudstones.

When viewed from the south rim of Grand Canyon, near Bridge Canyon, the three units described at Parashont Canyon can be traced continuously to the west, along the north face of Grand Canyon, to Grand Wash Cliff. The basal 107 feet of limestone thickens to the west at the expense of the overlying cyclic zone and is the Callville limestone; the cyclic zone thins to the west and pinches out between Bridge Canyon and Grand Wash Cliff; the 616 feet of cross-bedded sandstone maintains its thickness.
with only minor variations and is the equivalent of the cross-bedded sandstone overlying the Callville limestone at Grand Wash Cliff. East of Parashont Canyon the Callville limestone wedges out and at Toroweap Valley the cyclic beds rest on Redwall limestone.

The transition from Callville lithology through that of the cyclic beds to the lithology of the cross-bedded sandstone above is well displayed on the north side of Grand Canyon, opposite Bridge Canyon, and the area appears to be worthy of both detailed lithofacies studies, and detailed studies concerning the nature and position of the Pennsylvanian-Permian boundary in this area.

West of Grand Wash Cliff, in the Muddy Mountains, Nevada, Longwell (1928) reports an incomplete section of the Callville limestone to be 2,000 feet thick demonstrating the thickening of the formation to the west. He also notes in a more recent paper (Longwell, 1949, p. 930) that the upper part of the Callville is possibly Permian in age. In the Beaver Dam Mountains, Utah, about 20 miles northwest of St. George, Utah, Reeside and Bassler (1921, p. 77) report an occurrence of Marginifera aff. M. splendens, and Chaetetes milleporaceous approximately 700 and 1,000 feet, respectively, below the top of the "Redwall limestone." The presence of these fossils suggests an age no greater than Pennsylvanian for at least the upper 1,000 feet of this limestone and suggests a correlation with the
Callville limestone found farther south. Such a correlation is further substantiated by the presence of sandstone above the limestone which is similar in some respects to the sandstone overlying the Callville limestone at Grand Wash Cliff. If this correlation is correct then the Callville extends north into Utah along the trend of the Cordilleran geosyncline at least as far as northern Beaver Dam Mountains and probably considerably farther.

Supai formation

As originally defined (Darton, 1910) the Supai formation included the entire sequence of sediments between the Mississippian Redwall limestone and the Permian Coconino sandstone. Noble (1922) redefined the formation on the basis of detailed sections measured at Bass Trail in the Shinumo quadrangle, Arizona. He included in the Supai the thin-bedded limestones and shales formerly considered the upper part of the Redwall and excluded, at the top, a sequence of red, shaly sandstones to which he applied the name Hermit shale. As defined by Noble, the Supai consists of three units which he designated from youngest to oldest: A, 306 feet of massive, cross-bedded, red to buff sandstone alternating with platy, red, fine sandstone; B, 439 feet of massive cross-bedded sandstone separated by thin beds of limestone and red shale; and C, 208 feet of red sandy shale interbedded
with red and gray limestone, the limestone becoming more abundant at the base. He also reports a 28-foot limestone conglomerate 66 feet below the top of unit B (Noble, 1922, p. 61) which he has recognized in a section 70 miles southwest of Bass Trail, in the Aubrey Cliff near Seligman.

Comparing the section measured by McKee (unpublished section) at Parashont Canyon and described above (see p. 22) with Noble's description of the Supai formation, it is apparent that the 616 feet of cross-bedded sandstone at the top of the Parashont section is equivalent to Noble's unit A. The exact relation of the cyclic beds in the Parashont section to the units defined at Bass Trail is not so obvious. In lithology the cyclic beds are more nearly equivalent to unit C than to unit B. However, McKee notes a limestone conglomerate 75 feet below the top of the cyclic beds which is very similar to the 28-foot thick conglomerate, 66 feet below the top of unit B, which Noble reported. No other similar conglomerates are reported in either section and as the conglomerate reported by Noble is an extensive unit it seems reasonable to assume that the conglomerate in the two sections is the same unit. Based on this assumption, the top of the cyclic beds is at essentially the same horizon as the top of unit B of the Supai at Bass Trail and the cyclic beds are equivalent to both unit B and unit C of the Supai formation.
At the foot of Queantoweap Canyon, approximately ten miles east of Parashont Canyon, McNair (1951) measured 393 feet of sandstone to which he applied the name Queantoweap sandstone, stating he felt it equivalent to unit A of the Supai. Both the stratigraphic position of the sandstone and the relation of McNair's section to McKee's section at Parashont Canyon bear out this correlation; therefore, the older name, Supai formation is used here.

West of Parashont Canyon the cyclic beds of the Supai formation thin and wedge out between Bridge Canyon and Grand Wash Cliff. Unit A maintains its thickness in a westerly direction and at Grand Wash Cliff is 645 feet thick, as measured by McNair (1951), and rests on Callville limestone. North of Grand Wash Cliff, in the Virgin River canyon east of the Beaver Dam Mountains, Reeside and Bassler (1921, p. 76) report 1,490 feet of Supai formation. In the Beaver Dam Mountains, Utah, Reeside and Bassler (1921, p. 77) report, 1,420 feet of combined Coconino sandstone and Supai formation. These last two thicknesses, however, include sediments at the top which are possibly equivalent to the Hermit formation which is discussed below and which had not been defined when Reeside and Bassler measured their sections.

Wherever it has been observed in northwestern Mohave County unit A of the Supai formation contains beds of cross-laminated sandstone, usually of large scale and
everywhere dipping to the south or southeast. In the Beaver Dam Mountains, Arizona, immediately north of the Virgin River, cross-bedding is well displayed. Here, the Supai consists of medium to coarse-grained sandstone, buff to light brown in color with a few streaks and patches of red. The cross-bedding is of the wedge type with individual wedges up to 30 feet in length and 10 feet in depth. The dip of the laminae is consistently to the south and southeast. Farther north, in the Beaver Dam Mountains, Utah, the sandstone overlying the Callville limestone (?) (see p. 23) and correlated with the Supai by Reeside and Bassler (1921, p. 77) does not exhibit the marked cross-bedding characteristic of the formation in northwestern Mohave County. The changes in sedimentary structures taking place to the north undoubtedly indicate differences in the condition of deposition of the Supai formation in that direction and detailed studies concerning the nature of these changes should be of considerable interest from the points of view of paleogeography and of the environments of sedimentation.

**Pennsylvanian-Permian boundary**

The problem of defining the Pennsylvanian-Permian boundary in much of southwestern United States has faced stratigraphers and paleontologists for many years and in
most of northern Arizona this problem still exists but to a limited extent.

McNair (1951) on the basis of fossils found in the northern part of the Grand Wash Cliffs has been able to place the boundary within a zone from 260 to 400 feet below the top of the Callville limestone as defined here. At Bass Trail unit C of the Supai formation is considered to be of Pennsylvanian age (Noble, 1922, p. 62) and White (1927-28) reports fossil plant remains of Permian age in the Supai, within 60 feet of the Supai-Redwall contact which would indicate that units A and B of the Supai formation are of Permian age. No detailed studies of this problem have been made in the intervening area but if the above data are correct, then the Supai-Callville contact transgresses the Pennsylvanian-Permian boundary and is progressively younger to the west.

Permian System

Hermit formation

The bright red to maroon slopes of the Hermit formation are a prominent feature of the walls of the outer gorge of Grand Canyon. Protected by the resistant Coconino sandstone and Kaibab limestone above, the Hermit rises from the Esplanade surface and is continuously exposed in northwestern Mohave County throughout a distance of over 100 miles, extending from the northern end of the
upper Grand Wash Cliff, south to Grand Canyon and thence generally east, parallel to Colorado River, to the eastern extent of the area, and beyond.

As originally defined (Noble, 1922) the name Hermit shale was applied to this formation. Actually the name shale is not appropriate for the unit. It is composed mainly of thin-bedded, fine-grained sandstone with only minor beds of thinly laminated siltstone. Noble (1922, p. 64) was obviously aware of this but did not think it of consequence. McNair (1951), on the other hand, feels that Hermit formation is a more appropriate name for the unit and that term is used here.

At the type locality, Hermit Basin, the Hermit formation has a maximum thickness of 317 feet (Noble, 1922). To the west the unit thickens steadily attaining a maximum in the vicinity of Toroweap Valley where McKee and Schenk (1942) report 1,053 feet. Continuing west, the Hermit formation thins slightly. At the foot of Queantoweap Valley, near the Hurricane fault, McNair (1951) reports 933 feet and in the Grand Wash Cliff 698 feet.

In the Beaver Dam Mountains, west of St. George, Utah, either the Hermit formation is not present or it has changed greatly in lithology. The sediments between the Callville limestone and the Kaibab limestone in the Beaver Dam Mountains, Utah, consist of white to buff, flat-bedded sandstone with only minor zones of pink-colored sand;
nothing in the section suggests the dark maroon slopes of the Hermit found farther south. In the Muddy Mountains, Nevada, Longwell (1928, p. 35) reports a marked thinning of the upper red shaly member of the Supai (Hermit formation) with a proportionate increase in the thickness of the buff, cross-bedded sandstone below (Supai formation). To the south, in the vicinity of Seligman, Arizona, Noble (1922) notes a similar thinning of the Hermit formation with only 80 feet being present.

Coconino sandstone

The massive white to buff colored cliff formed by the Coconino sandstone contrasts strongly with the underlying red slopes of the Hermit formation and marks the base of the cliffs which form the top rim of most of Grand Canyon.

The Coconino is composed mainly of fine to medium grained quartz sand, cross-bedded on a massive scale. The nature of the cross-bedding has led some geologists to the belief that the sandstone is of aeolian origin.

Unlike most of the other Paleozoic formations of northwestern Mohave County, the Coconino sandstone thins markedly to the north and west. From a thickness of 335 feet at Havasupai Point (Noble, 1914), it thins to only 30 feet in northern Grand Wash Cliff and wedges out entirely between there and the Beaver Dam Mountains to the
northwest and the Muddy Mountains to the west. At the foot of Toroweap Canyon Reeside and Bassler (1922) report the Coconino to be 96 feet thick and at the mouth of Rock Canyon, 15 miles south of Hurricane, Utah, 17 feet thick. McNair (1951) measured 10½ feet of Coconino near the mouth of Queantoweap Valley, on the Hurricane fault, thus demonstrating the thinning of the unit to the north.

Although much thinner in its western extent, the Coconino sandstone maintains its distinctive cross-bedding throughout. In Grand Wash Cliff it displays massive cross-bedded wedges dipping to the south and southeast exactly like those observable in the formation near Pine, Arizona, where Barton (1925) reports nearly 1,000 feet of Coconino sandstone.

**Kaibab limestone**

The Kaibab limestone which forms the platform upon which much of the Shivwits and Uinkaret Plateaus are carved is the youngest Permian formation in northwestern Mohave County. It is continuously exposed from Lee's Ferry at the eastern end of Grand Canyon to the Upper Grand Wash Cliff near the Arizona-Nevada boundary and forms the uppermost cliff which rims Grand Canyon throughout the Canyon's extent.

As developed in the western Grand Canyon region, the Kaibab consists of five units. These are, from
youngest to oldest: (1) upper redbed member, (2) upper limestone member, (3) middle redbed member, (4) lower limestone member, (5) basal redbed member. Darton (1910) applied the name Kaibab limestone to this sequence which prior to 1910 was named the Upper Aubrey limestone. McKee (1938), after detailed studies, restricted the name Kaibab to the upper redbed and limestone members and proposed the name Toroweap formation for the lower three members. Although the distinction made by McKee is valid when considered from the point of view of conditions of deposition, the spatial relations of the two formations in northwestern Mohave County are such that the two formations are more easily discussed when considered as one unit. Therefore the older name, Kaibab limestone is used here to signify all five members.

The thickness distribution of the Kaibab limestone is best illustrated by the isopach map, figure 6. Maximum Kaibab deposition in northwestern Mohave County took place in an embayment extending south from Utah to approximately the foot of what is now Toroweap Valley. South and east of the embayment the Kaibab thins steadily to a shore line which is shown by McKee (1938) in his figures 7, 22, and 23. West of the embayment, and parallel to it, a ridge apparently extended north into the Kaibab sea with its axis centered along what is now the Virgin Mountains for in this area Kaibab deposition was less than to either
Figure 6.— Isopach map of Kaibab formation. Reference numbers (-13-, etc.) refer to source list on page.
the east, in the embayment, or to the west. It is unlikely
that the thinning over the postulated ridge is caused by
post Kaibab erosion because in all cases the recorded
thicknesses upon which the isopach map is based include the
upper redbed unit which presumably represents the same
horizon of deposition throughout the area.

Triassic System

Moenkopi formation

Excellent exposures of the Moenkopi formation oc­
cur on the Uinkaret Plateau, immediately south of the
Arizona-Utah state line. Here, along the southwestern face
of Little Creek Terrace, all six of the members of the
formation recognized in western Arizona are present and
appear as prominent, alternating red and white bands. The
members are designated from youngest to oldest: (1) Upper
redbeds, (2) Shnabkaib member, (3) Middle redbeds, (4)
Virgin limestone member, (5) Lower redbeds, and (6) Timpo­
weap member.

Throughout the area the Moenkopi formation rests
on an eroded surface carved on Kaibab limestone. The pre­
Moenkopi relief developed on the Kaibab, although not
great, is locally quite steep. In places conglomerate in
the Timpoweap member fills channels cut completely through
the upper redbed sequence of the Kaibab and in other
places the lower redbeds of the Moenkopi rest on the upper
redbeds of the Kaibab. In areas where the latter situation exists it is difficult to establish accurately the position of the contact because of the similarities in lithology of the two units and the absence of any measurable angular discordance.

The predominantly soft nature of the Moenkopi formation has fostered rather rapid removal of the formation by erosion whenever it has not been protected by more resistant strata. Consequently, it has been completely stripped from most of the Shivwits Plateau, south of Wolf Hole Mountain, with only thin remnants outcropping where basalt flows covered it before complete removal. Typical remnants are exposed in Poverty and Grassy Mountains, Diamond Butte, and under the basalt flow extending from the head of Andrus wash to the vicinity of Price Butte.

On most of the Uinkaret Plateau, south of Little Creek Terrace, only the lowermost Moenkopi redbeds remain but these can be traced to the south, under the Uinkaret basalt field, almost to Grand Canyon. In Mount Trumbull a complete section of the Moenkopi and a wedge of the overlying Shinarump conglomerate are exposed, capped by basalt.

Outcrops of the lower part of the Moenkopi formation also occur along the east face of the Virgin Mountains, south of the Virgin River. Here the Shnabkaib member and underlying redbeds are exposed in a down-dropped
fault block and are capped by basalt. Extending south under the basalt, the Moenkopi again outcrops in several fault blocks in the vicinity of Mud Mountain and Bunkerville Mountain and passes under Shinarump conglomerate still farther south.

Complete, unfaulted sections of the Moenkopi formation are rare in northwestern Mohave County and thickness trends can be ascertained only in a general way. The average thickness of the formation in the vicinity of Little Creek Terrace, based on measurements reported by Gregory (1950), is about 1,600 feet and Koons (1945) reports approximately the same thickness at Mount Trumbull to the south. In the Muddy Mountains, Nevada, 75 miles west of Mount Trumbull, Longwell (1928) reports 1,634 feet and Reeside and Bassler (1921) report sections of Moenkopi near St. George, Utah, between 1,700 and 2,000 feet thick. Based on these few, wide-spaced measurements and a knowledge of the nature of the contact of the Moenkopi formation with the Kaibab limestone the only definite statement that can be made is that in this area, at least, the Moenkopi maintains a fairly constant thickness of approximately 1,600 feet, but may thicken somewhat, northwest of the area. Actually such thickening does occur for McKee (1954, fig. 7), on the basis of regional studies, has shown that the Moenkopi formation thickens in a west-northwesterly direction from its eastern boundary
near the Arizona-New Mexico state line to a probable trough of maximum deposition extending from northern Utah to southern Nevada.

**Shinarump conglomerate and Chinle formation**

Erosion has largely removed the Shinarump conglomerate and the Chinle formation from northwestern Mohave County; however, three separate exposures remain, attesting to the fact that these units once extended over much of the area.

Little Creek Terrace, which was mentioned earlier in connection with the Moenkopi formation, is capped by from 50 to 150 feet of Shinarump conglomerate and in fact owes its existence to the resistant nature of the Shinarump which has protected the softer underlying Moenkopi from erosion. Northeast of Little Creek Terrace a regional northeast dip of two degrees to five degrees carries the Shinarump under the Chinle formation which in turn passes under Jurassic sandstone a short distance northeast of the area.

The exposures of the Shinarump conglomerate and Chinle formation at Little Creek Terrace are the most westerly of a series of outcrops which can be traced almost continuously along the Vermillion and Echo Cliffs to the Painted Desert of the Navajo Country in northeastern Arizona.
West of Little Creek Terrace rocks in two exposures, one at Mud Mountain and one south of Bunkerville Mountain, are mapped as Shinarump conglomerate and Chinle formation. Although not directly traceable to areas in which these two units are definitely recognized, the similarity of the lithology of the rocks at Mud and Bunkerville Mountains to that of the Shinarump and Chinle and the fact that the rocks at Mud and Bunkerville Mountains directly overly the Moenkopi, argue strongly in favor of the correlation.

Tertiary and Quaternary Systems

Sedimentary rocks

East of Lower Grand Wash Cliff, on the Shivwits and Uinkaret Plateaus, post-Mesozoic sediments consist almost entirely of recent, locally derived gravels and soils forming thin, superficial deposits restricted to stream channels and shallow structural troughs developed in the older rocks. The only exception observed is found in the thin gravels intercalated with the basalt flows in lower Toroweap Valley and these represent fossil stream gravels deposited behind the temporary dams formed by the basalt flows.

West of Lower Grand Wash Cliff, in the intermontane valleys of the Basin-and-Range Province, the history of sedimentation during Tertiary and Quaternary time is considerably more varied than on the plateaus.
Whereas present conditions on the plateaus indicate a prolonged period of erosion and removal of material, the variety and thickness of sediments in the intermont valleys and basins indicate several episodes of deposition under a diversity of conditions. In Grand Wash Trough streams have been particularly active and downcutting has exposed Cenozoic sediments representing six phases of deposition. Longwell (1936) made a detailed study of these sediments as exposed near the mouth of Grand Wash during his survey of the Boulder Reservoir floor and his findings are tabulated below by unit designation, age, and important features.

<table>
<thead>
<tr>
<th>Unit</th>
<th>Age</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Recent deposits</td>
<td>Recent</td>
<td>Surficial sand and gravel in stream channels.</td>
</tr>
<tr>
<td>2. Terrace gravels</td>
<td>Pleistocene (?) and/or Recent</td>
<td>Sand and gravel forming benches and terraces.</td>
</tr>
<tr>
<td>3. Hualpai limestone</td>
<td>Miocene (?)*</td>
<td>Freshwater limestone, essentially flat lying, crosses Grand Wash fault without break south of Colorado River.</td>
</tr>
<tr>
<td>4. Muddy Creek formation (?)</td>
<td>Miocene (?)*</td>
<td>Playa deposits, essentially flat lying, cross Grand Wash fault uninterrupted but are displaced by Tassai fault.</td>
</tr>
<tr>
<td>5. Fanglomerates</td>
<td>Miocene (?)*</td>
<td>Predominantly granite boulders and gravels derived from Virgin Mountain mass, not affected by Grand Wash fault, displaced by Tassai fault.</td>
</tr>
</tbody>
</table>
6. Tassai Wash series  
   pre-Miocene, Tertiary (?)*  
   Silt, sandstone, and limestone, flat bedded, dips 30 degrees east and is conformable with underlying Kaibab limestone.

* In a more recent paper, Longwell (1946) revised his original age classification and the revised age is used here.

North of the area investigated by Longwell stream deposits and terrace gravels are more widespread and most of the older Tertiary sediments are concealed. However, flat lying red silts and fine sands very similar in appearance to the upper parts of the Muddy Creek formation (?) are exposed in the bottoms of the deeper washes and can be traced nearly to Bunkerville Mountain where they are exposed in north trending ridges, dipping nearly 15 degrees to the east.

Northeast of Virgin River, a considerable area is occupied by mesas and buttes capped by terrace gravels indicating that higher base levels have existed. Currently a badlands type of topography is being developed and older sediments very similar to the Muddy Creek formation are being exhumed.

Volcanic rocks

The only record of igneous activity in northwestern Mohave County, with the exception of the Precambrian
intrusives, is that afforded by basalt flows and associated cinder cones and dikes of Tertiary and Quaternary age. These lavas, however, are scattered throughout the area and account for perhaps ten percent of the surface rocks.

The series of basalt flows in Toroweap Valley have been described by McKee and Schenk (1942). According to them four periods of extrusive activity were involved in the emplacement of these lavas, the sequence of events being essentially as follows:

1. Development of Toroweap fault.
2. Basalt flows of Lower Canyon group, alternating with thin deposits of river gravels, dam Colorado River to a height 600 feet above present river level.
3. River cuts through lava dam.
4. Lavas of Middle and Upper Canyon groups flow down Toroweap Canyon building its floor up to more than 2,000 feet above river level.
5. Additional movement on Toroweap fault, displacing all three groups of lava.
6. Valley surface flows cascade over edge of Upper Canyon group and are probably contemporaneous with the development of Vulcan's Throne, a prominent cinder cone at mouth of Toroweap Valley.

The southern end of the Uinkaret Plateau is largely covered by a basalt field which extends north from the rim of Grand Canyon, to near latitude 36 degrees 51 minutes, a
distance of nearly 45 miles. Powell (1875) recognized two periods of volcanic activity in this field; an older episode in which the flows capping Mounts Trumbull, Logan, and Emma were extruded, and a younger episode during which the now more extensive flows that surround the remnants of the older flows were extruded. Koons (1945) divided the flows of Powell's younger group into three major stages, basing his subdivision mainly on the degree of weathering displayed by the various flows and cinder cones.

Basalt occurs capping several platforms on the Shivwits Plateau notable of which are Poverty Mountain, Grassy Mountain, and Sanup Plateau. Time did not permit detailed study of the basalt caps; however, several features common to all three stand out. In each area the cap appears to consist of only one flow. The surfaces, however, are quite weathered and evidence of overlapping flows may have been obliterated. The surface exposures consist of rounded basalt boulders in a matrix of caliche soil. Most of the boulders are a rusty brown color but a few are dark gray and most of the boulders are vesicular. Generally the edges of the flows cap steep slopes or cliffs but at no point is there any indication of the flows having spilled over the edge nor are there any remnants on the surfaces below the cliffs and slopes.

Although the basalt caps on the individual platforms are not now connected it is quite probable that
they are all the product of the same volcanic episode. All three caps are essentially horizontal and the base of each is on a surface close to 6,000 feet in elevation. Since most of that surface is carved on the soft Moenkopi formation it is doubtful if much time could elapse between the emplacement of individual flows without some differences in elevation being developed.

Mount Dellenbaugh, rising nearly 1,000 feet above the surrounding area, is a prominent peak on the Sanup Plateau. It is a volcanic neck and probably supplied much of the basalt which is found on the southern part of the Shivwits Plateau.

In the northern part of the area mapped extensive flows cap Wolf Hole Mountain, Seegmuller Mountain, and the platform east of Mount Bangs. In contrast with the flow farther south, the surfaces of these flows appear quite fresh. The surface boulders are more blocky than rounded and are uniformly black in color.

In the vicinity of Mud Mountain four dikes of basaltic composition were mapped. The dikes, striking N 45 degrees W, range from 25 to 75 feet thick and undoubtedly were feeders for the basalt caps in that area.

In Grand Wash Trough extensive lava flows extend from the basalt field east of Mount Bangs south to Lake Mead. From the vicinity of Pakoon Spring south to the lake the flows are resting on sediments of the Muddy
Creek formation (?) and are overlain in places by terrace gravels. Throughout the southern half of their extent they average 50 to 75 feet thick.
STRUCTURE

General Statement

As stated earlier, northwestern Mohave County includes parts of both the Plateau Province and the Basin-and-Range Province. Although usually considered as physiographic divisions, these provinces are of equal importance as structural divisions, and in fact, the structural differences between the two provinces are largely responsible for the differences in physiography.

The boundary between the two provinces in northwestern Mohave County is for the most part sharp and well defined, in contrast with the nature of the boundary in central Arizona, where at least structurally, it is rather ill defined and appears to be a relatively broad zone of transition. In the vicinity of Colorado River the Grand Wash fault marks the boundary between the two provinces. East of Grand Wash fault the Paleozoic strata show little deformation. As exposed in the Lower and Upper Grand Wash Cliffs they appear as long unbroken bands, one upon another. East of the cliffs they form the high platforms of the Shivwits and Uinkaret Plateaus and extend for many miles broken only by gentle folds and occasional faults. The country west of Grand Wash fault is typical of the Basin-and-Range Province; tilted faultblock ridges
separated by gravel filled valleys are prominent features and thrust faults and complex folds are common.

Approximately 30 miles north of Grand Canyon the Grand Wash fault passes under a cover of basalt which obscures the structural pattern and locally conceals the boundary between the two provinces. Five or six miles farther north, however, it is again exposed and separates the Beaver Dam Mountains on the west from the gently dipping Plateau on the east.

Plateau Province

Regional dip

The most persistent structural feature in the western part of the Colorado Plateau and probably the most important from a physiographic standpoint is the regional east to northeast dip of the sediments. This dip, which averages two degrees to five degrees, and the differences in resistance of the various sedimentary strata to erosion are largely responsible for the location and configuration of the many benches, cliffs, and terraces which, beginning with the Little Creek Terrace, step up to the northeast for many miles into Utah.

Toroweap fault

The Toroweap fault, which marks the boundary between the Uinkaret and Kanab divisions of the Colorado Plateau, extends from about ten miles north of the head of
Toroweap Valley, south to Grand Canyon and continues south, across the Colorado River, where its trace is marked by Prospect Canyon. As is the case with most of the major faults of the western Plateau region, the Toroweap fault displays apparent normal displacement in which the western block is relatively downthrown.

The first report of the Toroweap fault was made by Powell (1875) who estimated its throw at 800 feet. Dutton (1882), after a more detailed examination determined the throw to be between 600 and 700 feet, all of which he felt was post-basalt. Shortly after Dutton's work Davis (1903) re-examined the fault near the foot of Toroweap Valley and found evidence indicating displacement had occurred along the fault during two periods, one post-basalt and the other considerably before the extrusion of the basalt. McKee and Schenk (1942) confirmed Davis' contention that two periods of movement had occurred and noted that the throw amounts to 486 feet for the pre-lava movement and 146 feet for the post-lava movement.

In Toroweap Valley the fault is buried by alluvium throughout most of its length but appears to strike essentially north-south. At the head of the valley the fault turns, striking N 30 degrees E. The throw on Toroweap fault decreases northward from 632 feet at Grand Canyon to about 50 feet near its northern end where it passes into
a westward dipping monocline which disappears a few miles farther north.

**Parashont fault**

Parashont fault, located midway between Parashont and Andrus Canyons near the south margin of the Shivwits Plateau, marks an important line of displacement in the western Grand Canyon region. Where displayed on the Esplanade surface, north of Colorado River, it consists of two branch faults diverging slightly to the north, with the east branch striking N 20 degrees W and the west branch N 30 degrees W. One and one-half miles north of the intersection of the branch faults with Parashont Canyon the total displacement, as seen in the Supai sandstone, amounts to about 1,100 feet with the west blocks having moved relatively downward. Of the total displacement the west branch accounts for 300 feet and the east branch 800 feet. Slightly north of this point the faults pass into the steep slope of the Hermit formation and then into Coconino sandstone and Kaibab limestone above. At this point, only one quarter mile north of the area displaying 1,100 feet of displacement, the trace of the west branch is completely lost and the east branch is marked by a line of low monoclinal flexures and intermittent scarps on the Kaibab surface having a displacement of only 25 to 50 feet.
Very probably the Parashont fault dies out to the north but to decrease from 1,100 feet to only 50 feet in less than one quarter of a mile seems hardly reasonable, particularly when the line of low scarps and flexures continues unabated at least four miles farther north along the strike. Therefore an alternative explanation is suggested which seems to be in accord with the facts.

Although the cumulative displacement on the two branch faults is about 1,100 feet, the downthrown blocks dip about ten degrees into the faults (northeast) adjacent to the fault planes and flatten to about two degrees northeast, one mile west of the west branch (Fig. 7). Thus the displacement on the faults is cancelled out by the opposite and nearly equal displacement of a monoclinal fold west of the faults. Even so it might be thought that the rather competent Kaibab limestone should show more indication of adjustment across the nearly two mile zone of strong displacement. That it does not can be explained by the incompetency of the Hermit formation which by its weak nature acted as a cushion under the Kaibab limestone and absorbed most of the displacement by squeezing and slipping.

South of Parashont Canyon, one mile north of Colorado River, the two branch faults coalesce, forming a single fault, still with about 1,100 feet of displacement. Here again the northeast dipping monocline
Figure 7.— Structure section of Parashont fault and monocline. Ps—Supai formation, Ph—Hermit formation, Pc—Coconino sandstone, Pk—Kaibab limestone.

Figure 8.— Structure section of Sunset graben. Qal—alluvium, Tm—Moenkopi formation, Pk—Kaibab limestone.
compensates for the displacement on the fault within a short distance.

Where Parashont fault crosses Colorado River it changes abruptly in strike, swinging from S 30 degrees E to S 25 degrees W and it maintains this southwesterly trend at least as far south as the mouth of Peach Spring Canyon. South of Colorado River the displacement also changes, increasing to at least 1,500 feet and probably more.

With the abrupt change in strike of the fault south of the river the compensating monocline to the west disappears. This could be an important relationship in determining the type of displacement along the fault. By at least one method of analysis the parallel monocline associated with the northwest trending portion of the fault can be attributed to compression acting in a line normal to the monocline, or in a northeasterly direction. As this force would be active in the west block of the southwest trending part of the fault it would impart a clockwise, or right lateral movement, to the fault.

Sunset graben

Sunset graben, on the Shivwits Plateau north of Diamond Butte, forms a valley about 1½ miles long and from one to two miles wide. The walls are of Kaibab limestone as is the floor at the northern end of the structure.
In the southern two thirds of the graben the floor is concealed by a veneer of soil. The west wall is formed by a single fault striking N 30-35 degrees W throughout most of its length but veering to due north at its northern end. Displacement on this fault amounts to about 300 feet at the southern end, increases to nearly 500 feet midway along its length and then decreases to about 200 feet near the north end where it dies out and the graben becomes a syncline. Adjacent to the fault the western rim rocks dip at from 10 degrees to 30 degrees into the graben but flatten out to only two degrees one mile west (Fig. 8).

Along the southern half of Sunset graben the eastern wall is also formed by a single fault which strikes essentially parallel to the west boundary fault. The maximum displacement on the east fault, however, is only about 150 feet. Near the halfway point along the graben's length the east boundary fault splits, forming two faults, and the displacement is distributed about equally between them. Four miles farther north both branch faults turn rather sharply, striking N 10-15 degrees E, and within the next three miles die out. At its south end, near the Hurricane fault, the east boundary fault is replaced by a complex pattern of small anticlines and synclines which mark the end of the graben. The strata on the east rim and also between the two branch faults dip at between two and four degrees northeast.
Hurricane fault

Possibly the most prominent structurally controlled feature in the western Plateau region is the scarp developed along the Hurricane fault. This fault which marks the boundary between the Shivwits and Uinkaret divisions of the Colorado Plateau, extends from Granite Park, south of Grand Canyon, north to the Arizona-Utah state line and then north-northeast into Utah for many miles.

Powell (1875) first reported the Hurricane fault and estimated its displacement at from 2,000 to 3,000 feet. Dutton (1882), after examining the fault in detail, reported the throw as 1,500 feet or more at Colorado River. He also observed that the fault breaks into several branches immediately north of the river and stated that one of the branches cuts the older lavas of the Emma Platform and that the younger lavas cross the fault unbroken. Davis (1903) after examining the area decided that the old lavas were not cut by the faults but flowed across the scarp uninterrupted. More recently, Koons (1945), after a detailed study of the Uinkaret basalt field, agreed with Dutton in his conclusion that the Hurricane fault is younger than the older lavas of the Emma Platform and cited two locations where he could demonstrate displacement of the older lava. No new evidence was found to prove or disprove either of the above
contentions; however, two features dealing with another aspect of the fault were noted.

In practically all published accounts of the Hurricane fault it has been portrayed as a normal fault along which the western block has been downthrown. Obviously there has been a large component of throw involved in the adjustments along the fault if the stratigraphic displacement is to be taken at face value. Evidence for a certain amount of right lateral movement, however, is also present.

The west wall of Sunset Graben, which strikes N 30-35 degrees W, is certainly in part a monoclinal flexure as evidenced by the manner in which the Kaibab limestone changes dip from two degrees northeast to 30 degrees northeast as the graben is approached from the southwest. At its north end the graben is replaced by a syncline and at its south end it dies out at the Hurricane fault in a series of tight folds which strike parallel to the axis of the graben. These three features all suggest compression along a northeast line which, acting in the western block of the Hurricane fault, would lend a clockwise movement to the fault.

Where Navajo Trail crosses the Hurricane Cliff it follows a series of spurs which Davis (1903) noted and termed rock slivers. These rock slivers, which bring uppermost Kaibab limestone down nearly to the level of the
Shiwits Plateau, are actually fault wedges produced by faults which have branched north northeast from the main Hurricane fault and have broken into the eastern wall a distance of three or four miles. Both in configuration and effect these branch faults suggest tension breaks adjacent to a plane of shearing in which the rotational forces are clockwise.

Certainly these two features are not conclusive evidence of right lateral displacement but they are suggestive and the possibility should be considered if more detailed studies are made of the fault.

Main Street fault

If it were not for its length, Main Street fault might be considered a minor feature for at no place where it was examined does its throw exceed 200 feet. However, it is over 60 miles long and can be traced almost continuously from Seegmuller Mountain south along Main Street Valley to Grassy Mountain and then under the Sanup Plateau basalt field to Grand Canyon and beyond. In trend its outcrop is remarkably similar to that of the Hurricane fault; if Main Street fault were shifted northeast about eleven miles it would fall on the Hurricane fault, duplicating it almost turn for turn.

Main Street fault has apparently been a zone of weakness through which basalt has been extruded in at
least two places. One of these is at the north end of the fault where a large dike has been injected along the fault and undoubtedly supplied much if not all of the basalt which caps Seegmuller Mountain. The second place is at Mount Dellenbaugh, a volcanic neck on the fault near Grand Canyon, which probably supplied most of the basalt in the Sanup Plateau lava field.

Northeast faults

North of Seegmuller Mountain, three northeast trending fault segments are locally rather important features. The more westerly two of the three are essentially parallel, spaced about two miles apart, and each has about 1,000 feet of throw in which the northwestern block is downthrown. Both of these faults drop Moenkopi strata against Kaibab limestone and the more southeasterly of the two has brought down a segment of basalt from the cap on Seegmuller Mountain. The third fault of the trio is somewhat east of the other two, assuming an en echelon pattern with them, and the displacement on it is considerably less, being only about 300 feet. The relative displacement, however, is the same as on the other two.

In the vicinity of these faults structural deformation is intermediate between that characteristic of the Plateau Province and that of the Basin-and-Range Province.
The very trend of the faults is unlike that of most other faults on the Plateau and the dip of the strata, although still northeast, increases to as much as 15 degrees over rather wide areas which is unusual on the Plateau. A few miles north, in Utah, there are several domes and anticlines which indicate more severe deformation there than on the true Plateaus. Considering these features in light of the knowledge that the Hurricane fault, to the east, marks the boundary between the two provinces farther north in Utah, it seems probable that the area north of the northeast faults and between the Grand Wash and Hurricane faults is a transition zone between the Plateau and Basin-and-Range Provinces and not completely within either.

**Basin-and-Range Province**

**Grand Wash fault**

Grand Wash fault, which marks the eastern edge of the Basin-and-Range Province, extends from north of Mud Mountain south along the Lower Grand Wash Cliff to the Colorado River and thence up Grapevine Wash an unmeasured distance to the south. Throughout its extent south of Hidden Canyon it is concealed beneath the Muddy Creek formation (?) but its presence is demonstrated by the relations found in Tassai Ridge to the west and the Grand Wash Cliff to the east. Longwell (1936) says of these relations:
"Evidence for the reality and the magnitude of the fault is found in Tassai Ridge, where the upper Paleozoic formations dip steeply eastward. Along the east base, the Kaibab limestone has an average dip of 30 degrees, from the river to the north end of the ridge. The probable position of the fault is about 3½ miles east of the ridge. By projecting the dip uniformly to this position, the top of the Kaibab is carried to a level about 10,500 feet below the floor of Grand Wash trough. As the same horizon on the plateau lies 5500 feet above the river, the throw of the fault by this computation is about 16,000 feet. Dutton's (1882, p. 19-20) estimate of 6000 feet either was based on observations farther north or did not take account of dip in the dropped block. It is possible, of course, that more than one fault lies between Tassai Ridge and the Cliffs, in which case the total throw is exhibited."

North of Mud Mountain the Grand Wash fault passes under a cover of basalt but what appears to be a continuation of the fault reappears on the north side of the lava flow and continues north into Utah. The throw, north of the basalt, is about 1,000 feet, the west block being downthrown.

**Tassai fault**

Tassai fault extends along the west base of Tassai Ridge which has been uplifted along the fault. The fault can be traced from south of Lake Mead to a point about seven miles northeast of Tassai Ridge where it is concealed by terrace gravels which pass over it undisturbed.

In the fault scarp that forms the west wall of Tassai Ridge sediments from the Callville limestone through the Kaibab limestone, and above that the Tassai Wash series, are exposed dipping 30 degrees to the east. Four miles
north of Tassai Ridge the Muddy Creek formation (?) outcrops on the upthrown side (east) of the fault. This formation, which is essentially horizontal throughout most of its extent, steepens abruptly adjacent to the fault, and locally dips as much as 60 degrees into the fault. This indicates that the Tassai fault is younger than the Muddy Creek formation (?) and therefore younger than the Grand Wash fault. The hanging wall block does not outcrop north of the Colorado River and therefore no measurement of the displacement could be made. Longwell (1936), however, obtained a measurement of 5,000 feet of stratigraphic displacement on Tassai fault near the south side of the river.

Virgin Mountain anticline

The main mass of the Virgin Mountains, Arizona, culminating in Mount Bangs, is a structural as well as a topographic high. As evidenced by the outcrop pattern of the Paleozoic sediments on the north and east flanks of the mountain (Pl. I), it is a north-northeast to north trending anticline plunging to the north. Paleozoic sediments on the northwest flank of Mount Bangs dip 30 to 40 degrees northwest and strike N 45 degrees E. On the north end of the structure the sediments strike east-west, dipping to the north, and on the east flank they strike north-south and dip 35 to 50 degrees to the east.
The central core of the mountain mass which is composed of Precambrian granite and gneiss also gives indication of having been arched. The banding in the gneiss, which at other places in the area is nearly vertical, displays a regular pattern of change in Mount Bangs from a dip of 60 degrees east on the west, through vertical at the crest, to approximately 50 degrees west on the east flank (Pl. II, sec. A).

Only an estimate can be made concerning how high the Virgin Mountain anticline was raised above the neighboring country because of faulting since the formation of the fold. However, the base of the Paleozoic sediments on the east (upthrown) side of Grand Wash fault as shown at the mouth of Grand Canyon is now 1,000 feet above sea level and the top of Mount Bangs is 8,350 feet above sea level. This gives a difference of over 7,000 feet not taking into account the unknown thickness of material removed by erosion between the present top of Mount Bangs and the base of the Paleozoic sediments. If the displacement on the Grand Wash fault, which Longwell (1936) calculated to be as much as 16,000 feet, is added, it raises the original Virgin Mountain mass to over 23,000 feet above the surrounding area.
Virgin fault

The large fault bounding the Virgin Mountain anticline on the west is here referred to as the Virgin fault. It is traceable from its north end, near where the Grand Wash fault crosses the Virgin River, for over 30 miles in a southwesterly direction to the north end of Whitney Ridge. Throughout most of its extent it strikes N 30 degrees E and is nearly vertical. Near Virgin River the northern block has been relatively upthrown and limestones of the undifferentiated Cambrian and Devonian series have been brought into contact with the Callville limestone across the fault in the south block. Along the west flank of Mount Bangs the fault is largely concealed by gravel at the foot of the mountain but there is no question as to its position for it can be followed continuously through a series of scarplets or piedmont scarps which mark its trace until it reenters the crystalline rocks. Where the fault reenters the mountain mass, Precambrian gneiss outcrops in both walls. As the fault is traced to the south, however, progressively higher rocks in the stratigraphic sequence are exposed in the downthrown block, faulted against the gneiss in the upthrown block. West of Bunkerville Mountain the gneiss is in fault contact with Kaibab limestone and here also the fault crosses the divide which separates the north block of the Virgin Mountains from the central block which is in Nevada.
Except for the stratigraphic displacement by which the relative throw was determined, no evidence was found along the fault to indicate what type or types of movement might have been involved in its genesis.
GEOLOGIC HISTORY

A resume of sedimentation in northwestern Mohave County has been given above. Based on this information, certain conclusions can be drawn concerning the geologic history of the area. Such an endeavor, however, must be based on insufficient data concerning many points, and therefore is certain to be in part conjecture. The following discussion, therefore, is offered only as a possible history of geologic events in northwestern Mohave County although it is thought to be a plausible one.

The history of events during most of PreCambrian time has been largely obliterated; however, six major episodes in the evolution of the area during this time stand out. The oldest rocks, the older Precambrian complex of gneiss and schist, show by their composition a prior history of sedimentation and volcanism (Anderson, 1951; Campbell and Maxson, 1938; Wilson, 1939) and this period of sedimentation and volcanism represents the first recognizable episode.

The second episode was the period of structural deformation which probably caused much of the dynamic metamorphism that produced the gneiss and schist we now find. Wilson (1939) made the first noteworthy study of this older Precambrian orogeny which he named the Mazatzal
Revolution. Anderson (1951) summarized the work of Wilson and of the several other geologists who had worked on the older Precambrian in Arizona and concluded that structural trends probably attributable to the Mazatzal Revolution include northwest, north, and northeast trending folds and faults, indicating east-west compressive forces. The Mazatzal Revolution culminated with the emplacement of great masses of intrusive granite and related igneous rocks. Most of the work summarized by Anderson was somewhat far removed from northwestern Arizona. However, the foliation in the older Precambrian gneiss and schist of the Lower Granite Gorge trends predominantly north-south (Moore, 1925, p. 163, 164) and the same direction also prevails in the Virgin Mountains, thus fairly well establishing at least north-south as a structural direction of the older Precambrian orogeny in the western Grand Canyon region.

The great unconformity between the older and younger Precambrian rocks indicates the nature of the third episode. After the Mazatzal Revolution, mountains must have stood high, yet the surface upon which the younger Precambrian rocks were deposited was practically a level plain. Thus a long period of erosion must have occurred, gradually wearing down the mountains and preparing the area for the fourth episode.
The record of the fourth episode is contained in the sediments of the Grand Canyon series. Although these younger Precambrian rocks were not recognized in the area mapped, they occur some 25 or 30 miles east at Kanab Creek and are almost 12,000 feet thick at Little Colorado River, less than 70 miles east of the area. This series of quartzites, sandstones, shales and limestones comprising the Unkar and Chuar groups indicate a long period of near shore and marine deposition during which the only deformation was slow downwarping.

The fifth episode in the Precambrian history was another phase of orogeny. Unfortunately evidence for this episode is limited in the Grand Canyon region to a few outcrops in the bottom of the Canyon and it can only be surmised as to how wide spread the event might have been. From the evidence at hand (Noble, 1914), however, there appears to have been little metamorphism involved, the predominant features being tilted block faults trending northwest.

The final chapter in Precambrian history is that represented by a second great period of erosion in which the block mountains were nearly leveled prior to the deposition of the first Paleozoic sediments.

With the advent of the Paleozoic era comes a more complete record of the events which have transpired. During the part of the Paleozoic era from the Cambrian period
through the Pennsylvanian period the Precambrian surface under what is now the Colorado Plateau must have been a relatively stable platform dipping gently to the west and northwest. In the vicinity of the junction of Little Colorado River with Grand Canyon some 2,000 feet of Cambrian through Pennsylvanian sediments accumulated, mostly under marine conditions. At Grand Wash Cliff, 125 miles west, some 3,700 feet of marine limestones and dolomites accumulated during the same span of time. In the intervening area the thickness increases quite uniformly and this averages an increase of only slightly more than 13 feet per mile.

The lithology of the older Paleozoic sediments and the implications of the types of contacts between them also attest to the overall stability of the Precambrian basement under the Plateau, although periodic gentle, widespread uplift and subsidence are suggested. The first Cambrian sediments were deposited in the western Grand Canyon region somewhat after sedimentation had started in the developing trough of the Cordilleran geosyncline to the west, with the late Precambrian erosional episode extending into early Cambrian time throughout most of the area, undoubtedly supplying material to the basal Cambrian sandstone. By mid-middle Cambrian time, however, the transgressing sea completely covered the shelf which occupied the present Plateau area, and marine limestone was
deposited. The Cambrian sea then retreated, leaving a westerly thickening deposit of dolomites as it withdrew.

The sequence of events during the next 150 million years, or until Devonian time, is largely conjectural. With the exception of a thin wedge of possible Ordovician marine limestone near Grand Wash Cliff neither the Ordovician nor the Silurian period are represented by sediments and it will never be known how much deposition took place in the Plateau region during these periods and was then removed. Throughout the area Devonian limestone rests disconformably on Cambrian rocks. The disconformity itself, however, furnishes a clue to the structural history of the area.

Certainly no orogenic disturbances occurred during this hiatus for the Cambrian rocks are undisturbed. That material was removed during the hiatus, thus demonstrating a lowering of base level, is obvious from the manner in which Devonian strata truncate Cambrian rocks progressively lower in the section to the southeast. Two possible explanations are apparent for the lowering of the base level: (1) regression of the sea because of subsidence elsewhere or through a local reduction in water because of climatic conditions or (2) absolute uplift of the shelf area above base level. If the first explanation is correct then obviously the shelf was a stable area in that it did not move. If the second explanation is correct and the shelf
was uplifted the degree of instability is a function of
the amount of uplift and whether or not the uplift was
equal throughout the area. The absence of any abrupt
changes in thickness of the Cambrian sequence and the ab­sence of any pre-Devonian folding in the Cambrian rocks
both rule against any major local inequalities in uplift.
The lack of any great relief carved upon the Cambrian
surface indicates that it was near base level most of the
time and therefore no profound uplift could have occurred.
From these observations it can be concluded that the area
must have been equally low throughout the hiatus indicat­ing a stable platform moving only as a unit.

During upper Devonian time the sea again flooded
the area depositing marine sediments, indicating a change
in base level. Again two explanations are possible and
in this case are essentially the reverse of the postulates
used to explain lowering of base level. If base level was
raised because of the shallowing of a basin elsewhere or
by the addition of water from other sources, then stability
in the flooded region is implied. If base level rose be­cause of subsidence in the plateau region then the uniform­ity of the Devonian deposits indicates uniform subsidence
and again implies that the shelf acted as a unit.

The disconformity between the Devonian and Missis­sippian sediments indicates another cyclic change in base
level. Here again no deformation took place during the
hiatus and the erosion surface developed on the Devonian limestone indicates only a mild lowering and then raising of base level, thus implying relative stability of the shelf region.

After the deposition of the Mississippian sediments the sea again retreated for a time as indicated by the disconformity between the Mississippian and Pennsylvanian systems. Again all evidence indicates a slow cyclic change with no great instability developed in the shelf area.

The instability of the Precambrian basement rocks under what is now the Basin-and-Range Province, west of Grand Wash Cliff, stands in marked contrast with the stability of the basement complex upon which Paleozoic rocks were deposited east of Grand Wash Cliff. In the Muddy Mountains, Nevada, only 40 miles west of Grand Wash Cliff, the sediments which accumulated from Cambrian through Pennsylvanian time have a thickness of approximately 6,500 feet which amounts to an increase of 70 feet per mile between Grand Wash Cliff and the Muddy Mountains. In the northern Spring Mountains, Nevada, 60 miles farther west, nearly 30,000 feet of sediments (Longwell, 1950) accumulated during the same time. This indicates a thickening at the rate of nearly 400 feet per mile for the interval between the Muddy Mountains and Spring Mountains. These rates contrast markedly with the
average of slightly more than 13 feet per mile from Grand Wash Cliff to Little Colorado River, and suggest almost continuous subsidence of the basement in the basin west of Grand Wash Cliff. Further evidence for more continuous subsidence in the basin than on the shelf to the east is offered by the continuity of sedimentation. Whereas only about 40 percent of the elapsed time is represented by sediments on the shelf, over 90 percent is represented in the Northern Spring Mountains, Nevada.

During the last part of the Paleozoic era, that is, during the Permian period, 4,300 feet of sediments were deposited in the vicinity of Spring Mountains, Nevada. During the same period 3,000 and 2,200 feet of sediments accumulated near the Muddy Mountains and Grand Wash Cliffs respectively, and 2,000 feet are recorded at the junction of the Little Colorado River with Grand Canyon.

Based only on these thicknesses it would appear that the entire area had become more or less stable with only slight subsidence throughout. Consideration of the types of sediments deposited in various parts of the area, however, rules out this conclusion. Whereas marine sediments continued to be deposited to the west, continental sedimentation alternated with near shore deposition across the shelf region. The distribution of the Hermit shale suggests an area of local subsidence in the western Grand
Canyon region and the cross-bedding in the Coconino sandstone suggests an uplifted source area to the north and northwest. With the deposition of the Kaibab limestone another local basin or embayment developed on the shelf (Fig. 6) centered along the present Hurricane fault trend, suggesting some dislocation along a possible Precambrian weakness in that region. With the advent of Kaibab deposition in the area to the west, subsidence there slowed, as is evidenced by the uniform thickness of the formation across the area. This was a turning point in the history of the geosyncline, as will be shown.

The record of events in northwestern Mohave County during the Mesozoic era is vaguely known, as erosion has removed most of the sediments which were deposited during that time. A regional picture is given by McKee (1951), however, and a few inferences can be drawn from it. In general, continental and near shore sediments account for the greater proportion of deposition; central Arizona was an uplifted area shedding sediments into a basin or basins to the north. The trough to the west, in southern Nevada, which had started to deteriorate in Permian time, ceased to be the important basin of deposition and conditions there were similar to those prevailing on the shelf, suggesting some uplift west of the shelf. During early Cretaceous time probably little deposition occurred on the shelf area and erosion may have been the dominant agent.
During late Cretaceous time sedimentation again occurred both on the shelf and to the west (Longwell, 1949) but the main basin of deposition had retreated to the north and northwest.

Consideration of the factors leading up to the destruction of the basin to the west and of the happenings immediately after are of interest.

Nolan (1943) has shown that not all parts of the Cordilleran geosyncline subsided together and in fact at least two geanticlines developed subparallel to the axis of the trough and within the geosyncline. The earlier geanticline, which persisted from late Devonian to Permian time was centered in western Nevada. A younger geanticline started to develop about 100 miles east of the older one about the same time the older one subsided and lasted into the middle of the Mesozoic era.

The crustal warping represented by the development of the geanticlines and the Cordilleran geosyncline, even though gentle and of very broad dimensions, indicates crustal shortening. This in turn suggests horizontal compression perpendicular to the axis of the folds or, in this case, approximately east-west forces. If then, the geosynclinal trough and associated geanticlines were developed through compressive forces, it is not hard to visualize the gradual broadening to the east of the younger geanticline by further upwarp or even the development of
a third upwarp still farther east that destroyed the geosynclinal basin in southern Nevada in the Mesozoic era. Actually good evidence for the existence of east-west compressive forces during this time has been established. Longwell (1928) has demonstrated that the Muddy Mountain thrust and the Arrowhead fault are the result of strong east-west compressive forces and that the thrust probably occurred during either late Jurassic or early Cretaceous time (Longwell, 1949).

With the advent of deformation on an orogenic scale in the region previously occupied by the Cordilleran geosyncline the permanent destruction of the geosyncline was accomplished and the orogeny has continued, intermittently, to the present.

Proof that the effects of the orogeny extend into northwestern Mohave County is amply furnished by the Virgin Mountain anticline, the Virgin fault, and many other structural features. The sequence of events associated with the orogeny in northwestern Mohave County and nearby parts of Nevada has been recorded by Longwell (1946, 1949). The question arises: why do not these effects extend farther east or, conversely, why do they extend as far east as they do?

Since the orogeny started in the geosyncline it might logically be considered genetically related to the geosyncline. This of course is not a new idea. The point
that is being made, is that if the orogenic disturbances are genetically related to the geosyncline, then the effects of the disturbance might well be localized within the area once occupied by the geosyncline and be controlled by the same factors that determined the boundaries of the geosyncline.

An idealized cross-section of the Paleozoic formations (Fig. 9) shows that the margin of the basin was located very closely along a line down the present Grand Wash. The structure map (Fig. 10) shows that the boundary between the Basin-and-Range Province and the Plateau Province is located along essentially the same line (Grand Wash fault). Therefore it may be concluded that the major effects of the orogeny are confined to the region once occupied by the geosynclinal basin, at least in northwestern Mohave County.

This, of course, brings up the question of what determined the location of the margin of the geosyncline. An answer to that question would involve the highest order of speculation. However, four comments will be made: (1) It has been shown that northwest, north, and northeast folds and faults were developed during the older Precambrian orogeny, and that these features were probably the result of east-west compressive forces possibly acting as couples. (2) Northwest faults resulted during the younger Precambrian orogeny. (3) Renewed movement has
Figure 9.— Idealized cross-section of the Paleozoic formations from Little Colorado River, Arizona, to northern Spring Mountains, Nevada.
Figure 10 - Tectonic map of northwestern Mohave County, Arizona.
occurred along at least a few Precambrian structures as evidenced by the East Kaibab monocline along the Butte fault (Walcott, 1890) and the West Kaibab monocline and fault (Noble, 1914). \(^4\) A comparison of the stability of the Precambrian platform under what is now the Plateau with the relative instability of the basement under the geosyncline suggests a zone of weakness along the axis of the trough, probably dating from the older Precambrian orogeny. East-west forces active during the Paleozoic era acted in a line nearly normal to the axis of the zone of weakness and brought about downwarping, thus forming the geosyncline.
KEY TO REFERENCE NUMBERS ON ISOPACH MAPS

-1- Hewett (1931)
-2- Hewett (1956)
-3- Humphrey (1945)
-4- Johnson and Hibbard (1957)
-5- Longwell (1928)
-6- Longwell (1949)
-7- Longwell (1950)
-8- McKee (1938)
-9- McKee (1945)
-10- McKee (unpublished notes)
-11- McNair (1951)
-12- Noble (1922)
-13- Reeside and Bassler (1922)
-14- Westgate and Knopf (1932)
REFERENCES CITED


Topographic base compiled from Army Map Service Grand Canyon, Las Vegas, and Williams 2° sheets

Geology by Richard T. Moore 1957-1958

Geologic Map of Northwestern Mohave County, Arizona
STRUCTURE SECTIONS OF NORTHWESTERN MOHAVE COUNTY, ARIZONA

For geologic explanation see plate I

Scale 1: 62,500

Datum is mean sea level