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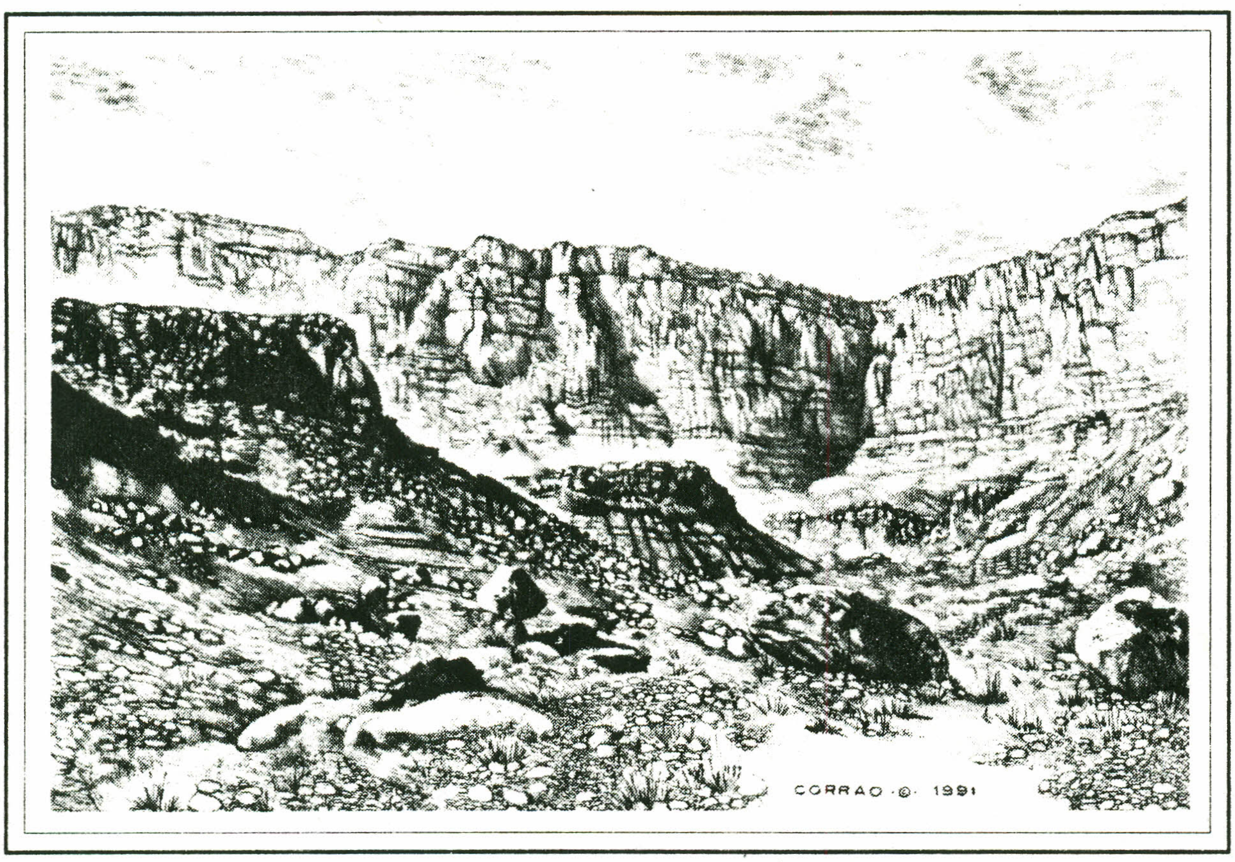
Geologic Review of Northwestern Arizona for Petroleum Exploration Investigators

Salvatore Giardina, Jr.



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GEOLOGIC REVIEW OF NORTHWESTERN ARIZONA
FOR
PETROLEUM EXPLORATION INVESTIGATORS

INTRODUCTION

Northwestern Arizona has a thick section of marine strata which exhibits all the basic geologic requirements for accumulation of petroleum deposits. The structure and lithology of this area are essentially an extension of the geology of the adjacent area of southern Utah, where modest production has been established by relatively limited exploration activities.

This report presents a geologic overview of northwestern Arizona. Geologic and petroleum exploration data of southwestern Utah are also included to provide information gained by previous exploration activities in a similar geologic setting.

LOCATION

This report discusses that portion of northwestern Arizona which lies north of the Colorado River and west of the Echo Cliffs Monocline in Mohave and Coconino Counties. It is bordered on the west by Nevada and on the north by Utah (fig. 1). The report area comprises about 8,000 square miles and is commonly known as the "Strip Country." Reference in this report to "northwestern Arizona" or "Strip Country" is analogous and refers to the area defined above.

Figure 1 illustrates the location and physiographic features of the Strip Country and the adjacent area of southwestern Utah. U.S. Highway 89A provides access to the eastern portion of the Strip Country, with U.S. Highway 91 crossing the northwest corner. Numerous secondary roads diverge from the main highways and provide ready access to most sections.

CLIMATE

Northwestern Arizona is predominantly a semidesert region with annual precipitation averaging 10 to 16 inches. The winter months are characterized by light snowfalls and temperature lows near 0°F. In early Spring, July, and August, the area receives some rain; and summer temperatures average about 90 to 95°F.

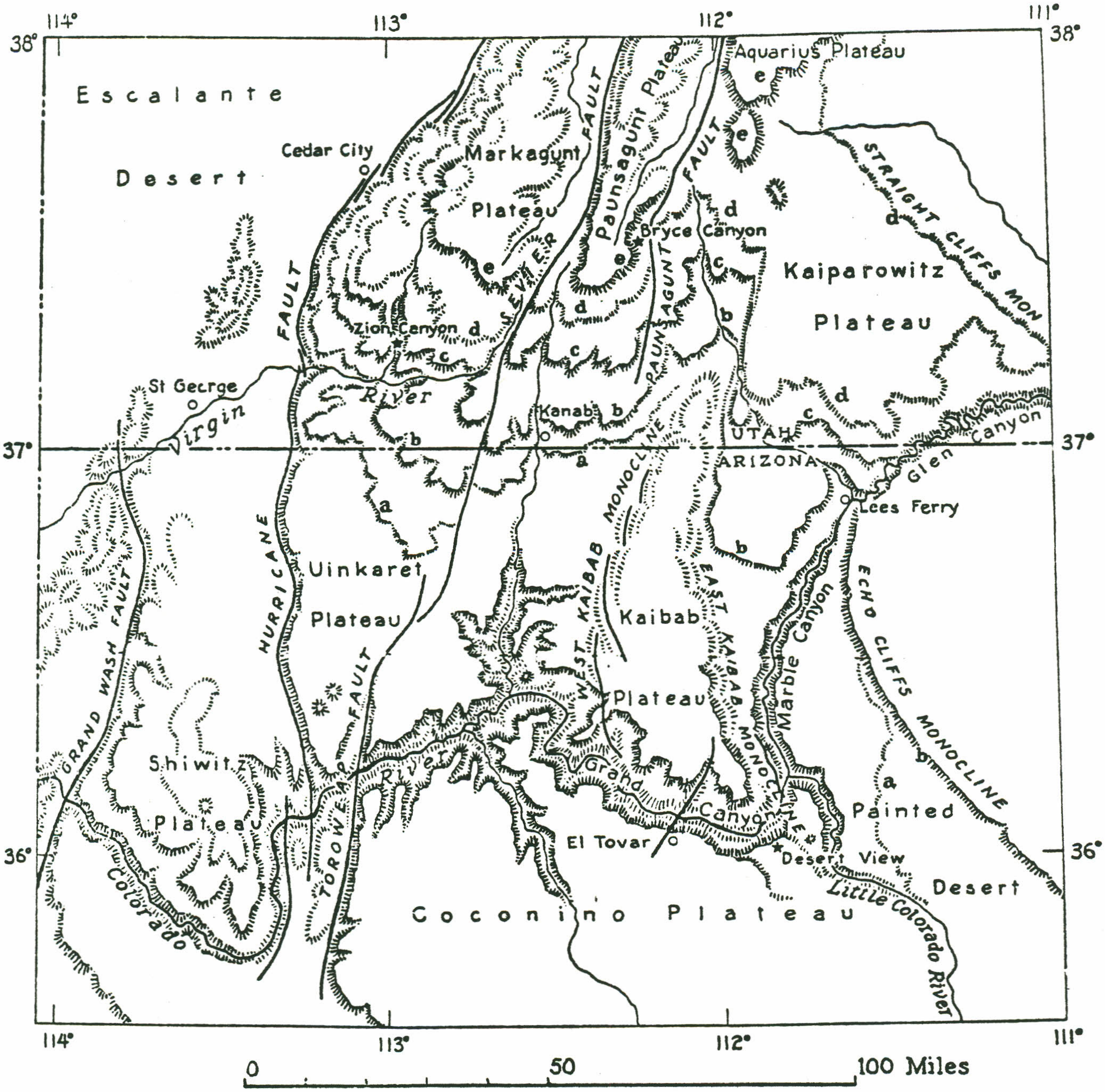


Figure 1. Map of western part of Colorado Plateau in Arizona and Utah, showing cliff lines produced by erosion of formations and fault lines. Letters indicate the following: (a) Chocolate Cliffs, (b) Vermillion Cliffs, (c) White Cliffs, (d) Gray Cliffs, and (e) Pink Cliffs (from King, 1959).

GEOLOGIC STRUCTURE

General

Petroleum exploration requires careful consideration of the structural elements which characterize a potential target area. Therefore, the principal elements related to the structural setting are presented so that comparison may be made with similar geologic structures of southwestern Utah. Because the chronologic sequence of tectonic events will often influence the factors controlling petroleum accumulation and preservation, the geologic age or relative sequence associated with development of the principal regional structures is cited whenever possible.

Within the Strip Country the morphology of existing folds, sense of displacement on faults, and orientation of lineaments and structural trends have been directly influenced by preexisting, regionally extensive, Precambrian fractures. The local subsurface expression of these structures is therefore similar to broad areas of the Colorado Plateau as a result of regional tectonic interaction of the basement complex with the Phanerozoic strata, as well as the common influence of wide-scale crustal stresses imposed by the intense Cenozoic orogenies.

During the Cenozoic Era the area was modified by major crustal activity in contrast to the relative quiescence of epeirogenic movements which characterized earlier eras. Although large-scale cratonic uplifts and geosynclinal subsidence produced changes in regional sedimentation patterns which ultimately influenced the accumulation of petroleum, it remained for Cenozoic deformation to produce discrete structural traps.

The major geologic structures of the Strip Country and adjacent areas are shown on the generalized tectonic map in figure 2.

Basin and Range Province

The area located west of the Grand Wash Fault lies on the eastern edge of the Basin and Range province. This portion of the area experienced massive crustal collapse, resulting in typical structures of the Basin and Range.

The structural style of the Basin and Range province is not abruptly terminated against the relatively undeformed strata of the Colorado Plateau. Basin and Range elements transition into typical plateau folds within a zone generally bounded by the Grand Wash and Hurricane Faults (Moore, 1958, 1972). In southwestern Utah the transition zone is bounded on the west by the Paleozoic Hinge Line (fig. 2) and extends east to the Paunsaugunt Fault (Stokes and Heylmun, 1963). Representative structures of this area are shown in figure 3.

During the Paleozoic Era, tectonic activity was limited to epeirogenic subsidence and uplift. Rocks of the Virgin and Beaverdam Mountains indicate that the site was essentially a westernmost edge of the stable shelf which extended to the east. Details of the structural development during the Mesozoic and Cenozoic Eras, including descriptions of the prominent faults which transect this area, are presented by Moore (1972). A brief summary of the principal structural events is shown in figure 4

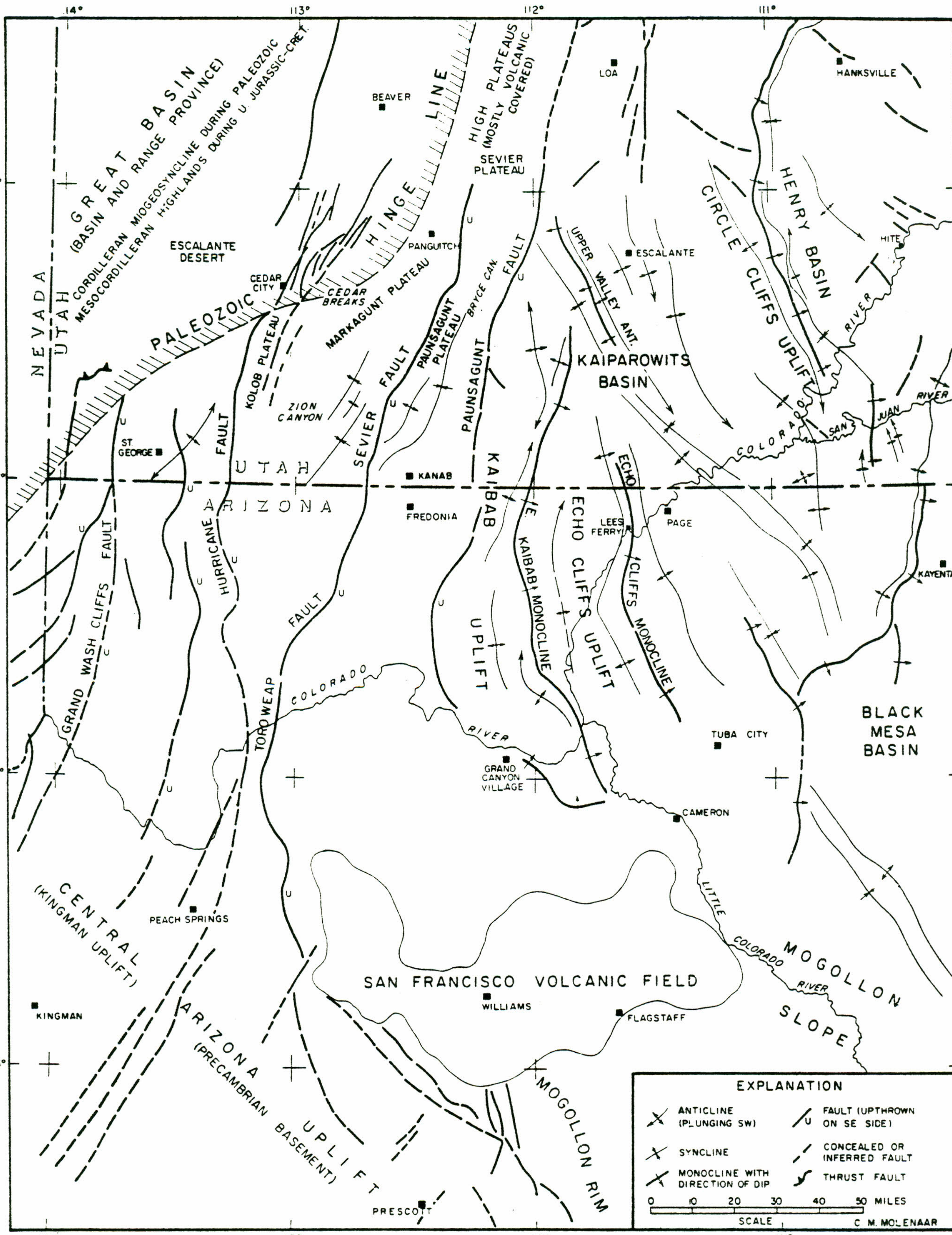


Figure 2. Tectonic map of NW Arizona-SW Utah (extended from Kelley and Clinton, 1960, by Molenaar, 1969).

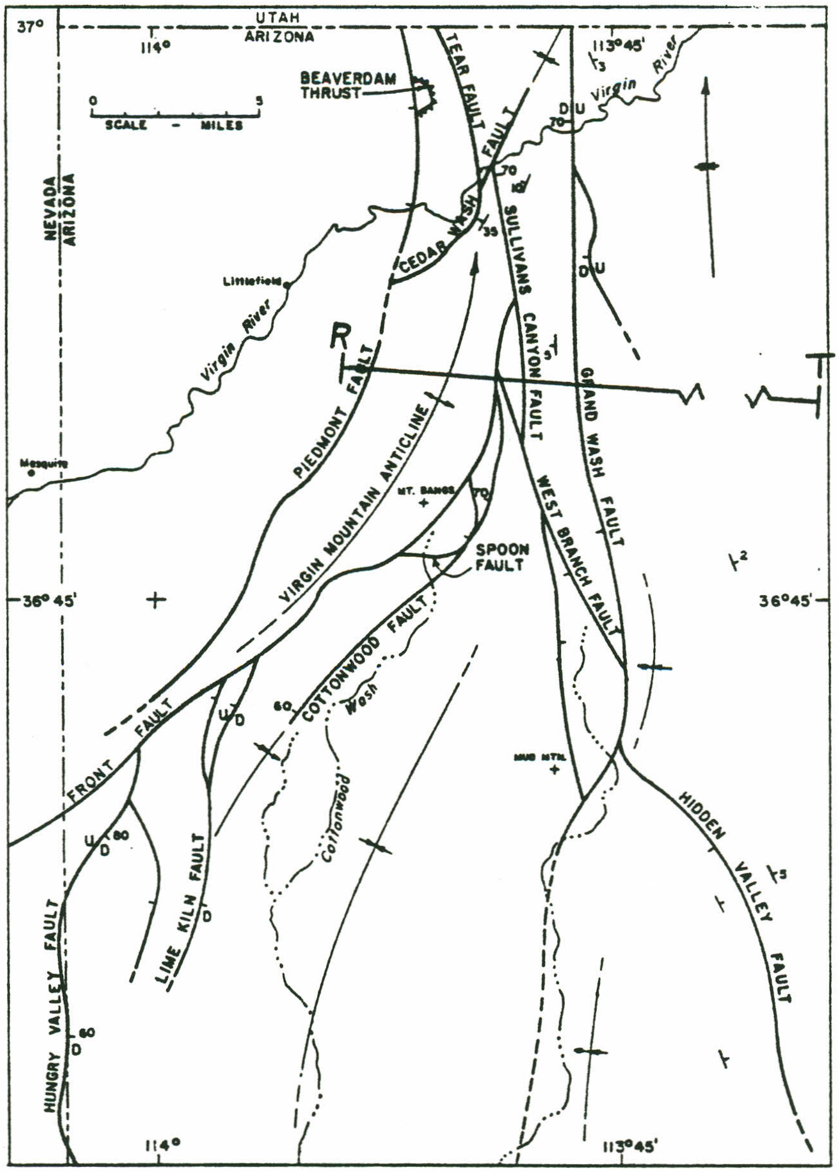


Figure 3. Structure diagram of the Virgin and Beaverdam Mountains, Basin and Range Province, northwestern Arizona (from Moore, 1972).

Principal Mesozoic and Cenozoic Structural Events.

GROUP	STRUCTURES	DIAGNOSTIC FEATURES	AGE	PRINCIPAL STRAIN
I	Beaverdam thrust and associated folds and imbricate faults.	Faults and fold axes strike north-south; have been affected by later folding.	Post-Jurassic to mid-Cretaceous(?).	East-west shortening
II	Virgin Mountain anticline, Cedar Wash fault, Cottonwood fault, and associated faults and folds. Left lateral(?) component on Hungry Valley and Lime Kiln faults.	Faults and fold axes strike northeast, faults display reverse movement and produced overturned beds. Movement involved Cottonwood Wash Formation but not Muddy Creek Formation.	Late Cretaceous to pre-Middle Miocene; possibly pre-Late Eocene.	Northwest-southeast shortening
III	Grand Wash, Piedmont, West Branch, and Sullivans Canyon faults. Normal displacement on Hungry Valley and Lime Kiln faults.	Large amounts of normal displacement, involve late Cenozoic rocks, produced graben and horst blocks.	Late Pliocene(?) to Recent	Northwest-southeast and east-west extension

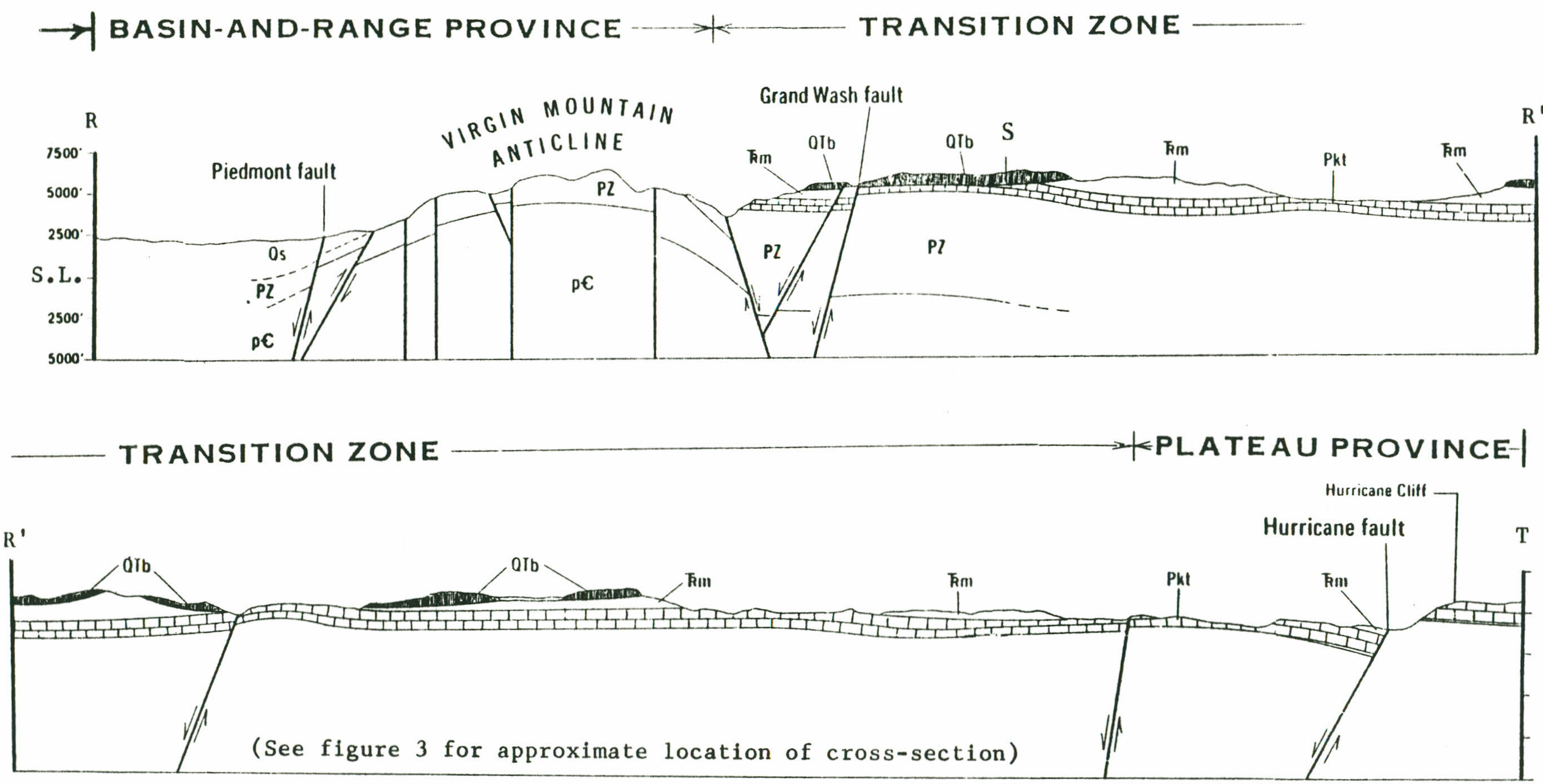


Figure 4. Generalized cross section, Basin and Range Province (modified from Moore, 1972).

along with an east-west cross section which provides insight into the complex structure representative of this area.

Moore (1972) recognizes the Beaverdam Thrust and its related folds as the earliest episode of deformation. A post-Jurassic to mid-Cretaceous age interval is inferred but efforts to date the thrust more accurately have not proved satisfactory. Field evidence does demonstrate that the Beaverdam Thrust predates folding of the Virgin Mountain Anticline.

The Cedar Wash Fault was initiated early in the second episode, followed by folding of the Virgin Mountain Anticline. These structures are shown as Group II events in figure 4 and are dated by Moore between late Cretaceous(?) and Miocene(?). These ages agree with those established by Cook (1963) for similar structures in the St. George region of Utah.

A third episode of high-angle normal faulting followed the compressional deformation which formed the Group II structures. Several Group III faults (fig. 4) have undergone large displacements in excess of 1,500 feet with faulting persisting into Recent time. The Grand Wash, West Branch, and Piedmont Faults are included in this group. Although the absolute ages of Group III faults could not be established in this area, Moore suggests that deformation was probably restricted to the late Cenozoic Era.

Colorado Plateau Province

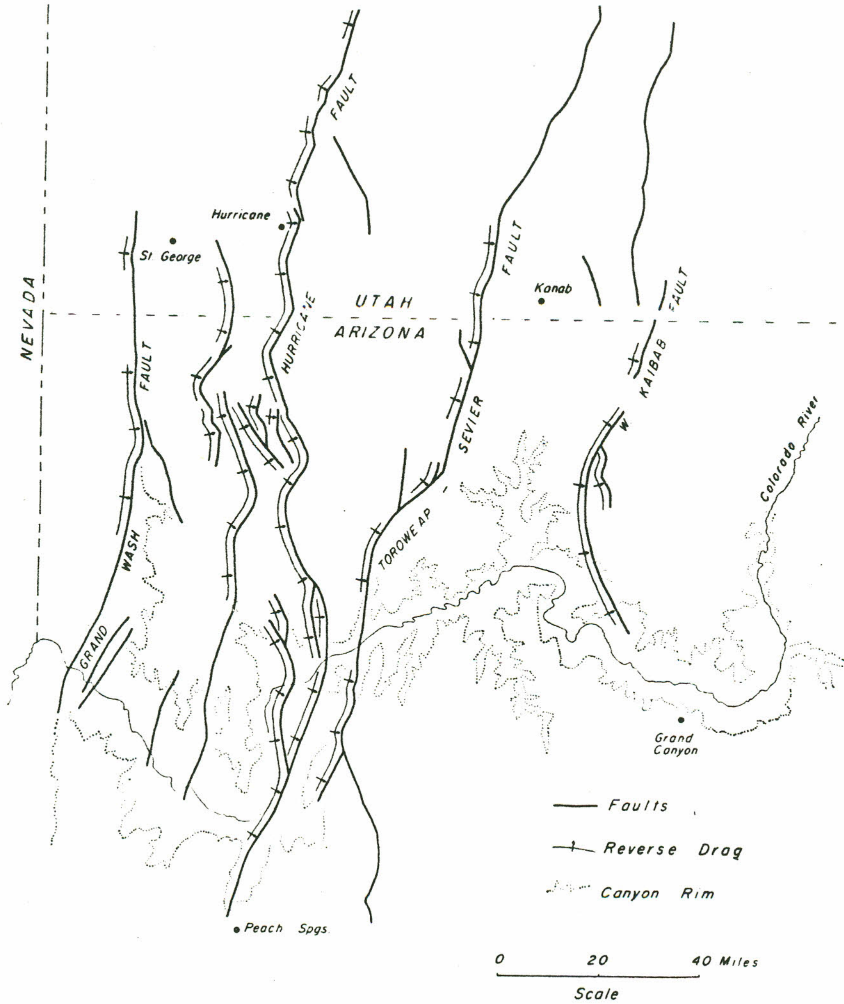
The area east of the Grand Wash Fault consists of several structural blocks bounded by major north-trending normal faults. These structural blocks dip very gently northeast and are known as the Shivwits and Uinkaret Plateaus. The regional dip of these blocks combined with a marked increase in the dip of strata at the westernmost edge of the Colorado Plateau are the result of structural upwarping of the western edge of the transition zone (Lucchitta, 1974).

Strata of the Shivwits and Uinkaret Plateaus have not been folded into prominent anticlines, similar to the Kaibab and Echo Cliffs Uplifts, or monoclines similar to those located in the eastern portion of the area. However, folding due to "reverse drag" on the major faults has been described by Hamblin (1965), Koons (1945), Huntoon (1969), and others. Figures 5 and 6 show the location of these unique folds and their postulated origin, respectively.

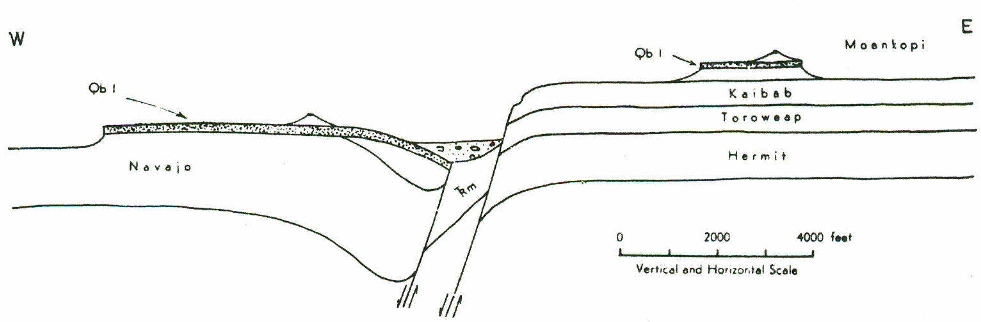
Shivwits Plateau

The Shivwits Plateau represents a structural transition zone between the Basin and Range and Colorado Plateau provinces. Included herein are descriptions of this area based upon Lucchitta (1974) and McKee and others (1967).

The Shivwits Plateau (fig. 7) is bounded on the west by the Grand Wash Fault, on the south by the Colorado River, and on the east by the Hurricane Fault. Local recurrent movement on the Hurricane Fault (extending into the Holocene) has been documented by displaced Cenozoic lava flows and the presence of fault scarps in alluvium (Huntoon, 1977). The sequence of events along this fault has been studied by many investigators

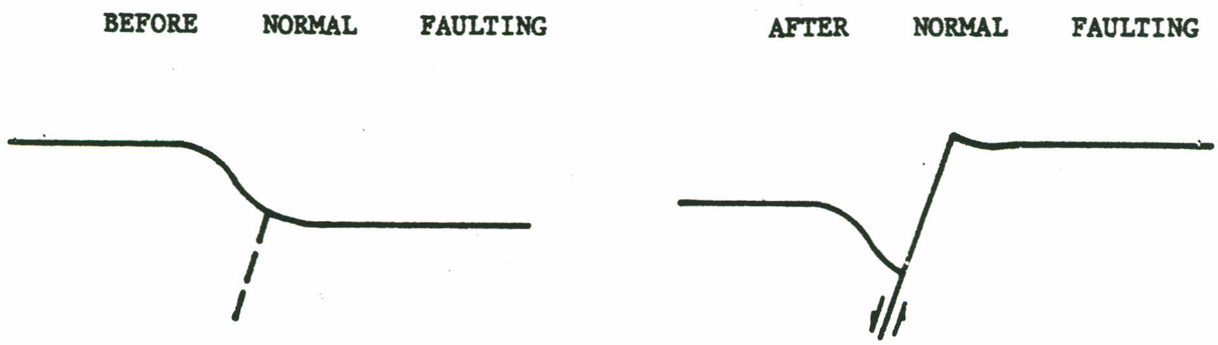


Map showing major faults and reverse-drag flexures in the western Grand Canyon region

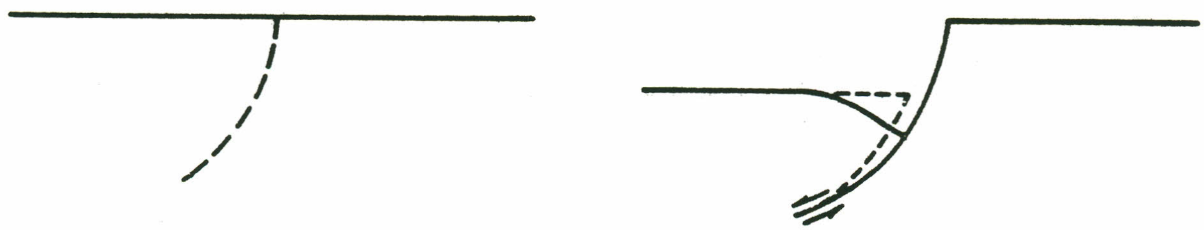


Section across the Hurricane fault approximately 8 miles south of Hurricane, Utah, showing variations in reverse-drag flexures in the Navajo Sandstone and older Quaternary basalts (Qbl)

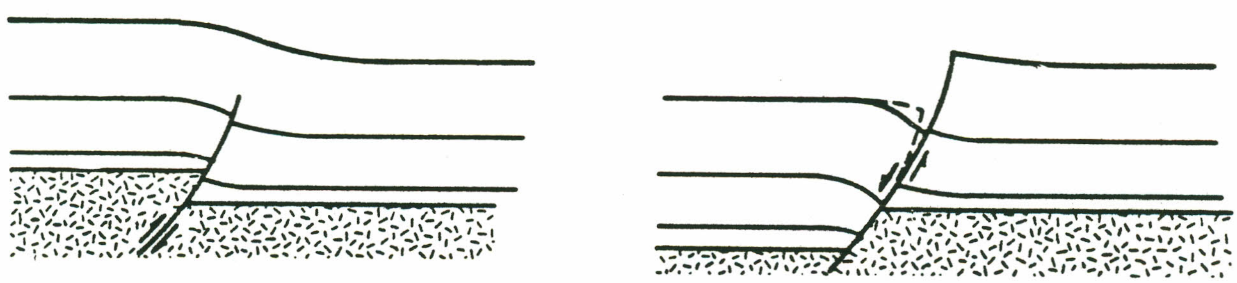
Figure 5. Location of reverse-drag flexures in the western Grand Canyon area (from Hamblin, 1965).



a) Faulted monocline hypothesis. Fault must always have same position with respect to monocline.



b) "Reverse drag" hypothesis of Hamblin (1965). No upwarping on upthrown block. Recurrent movement causes varying amount of flexing in units of different age, e.g. lava flows.



c) Hypothesis combining two hypotheses above. Old monocline, corresponding to reverse fault in basement at depth, is cut by normal movement along the same fault. Initial monoclinal warp on downthrown block is accentuated by flexing resulting from pull apart mechanism proposed by Hamblin (1965).

Figure 6. Hypotheses on the origin of "reverse drag" (from Lucchitta, 1974).

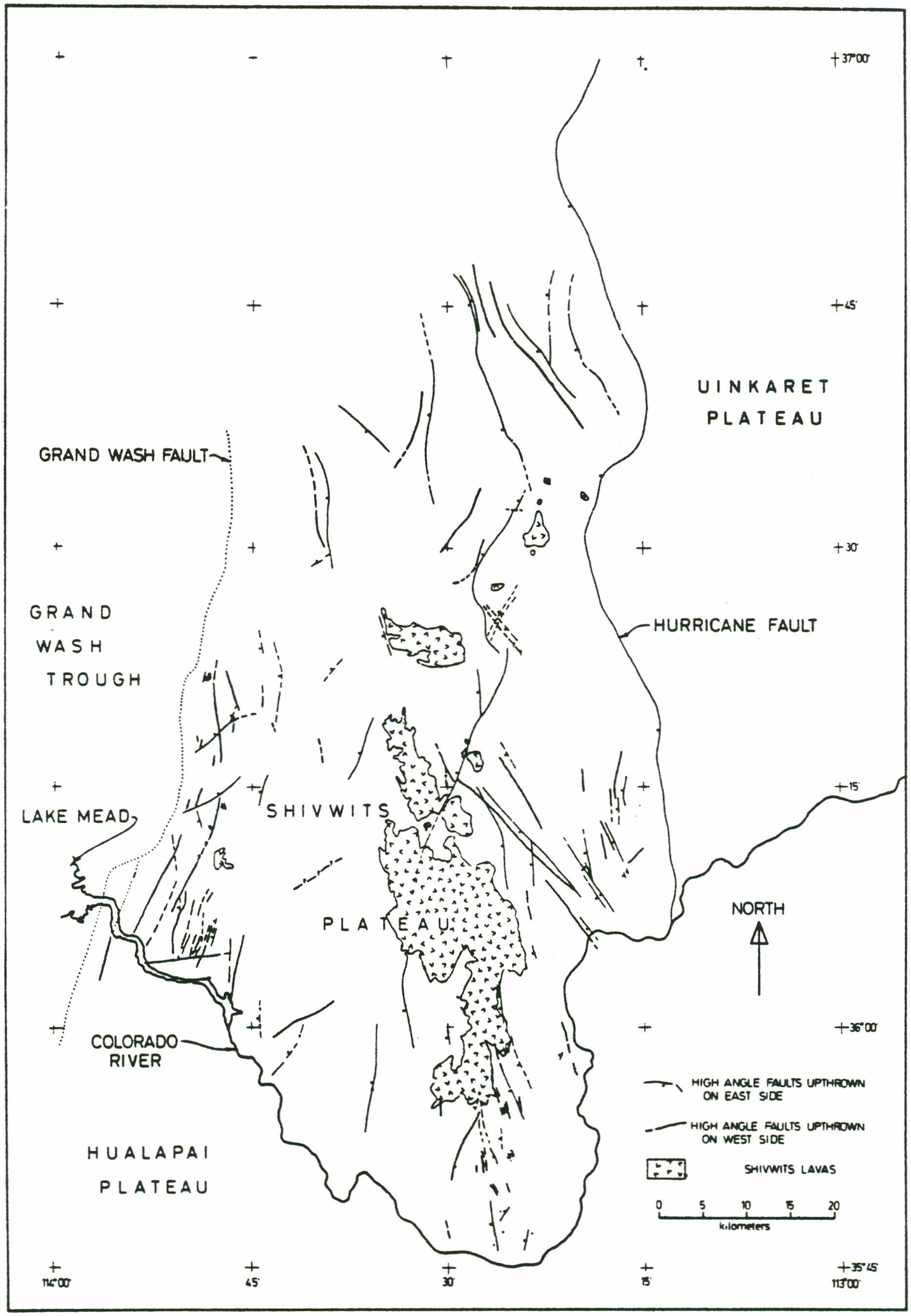


Figure 7. Tectonic map of the Shivwits Plateau, Arizona (from Lucchitta, 1974).

with related events summarized by Averitt (1964). The consensus of most investigators indicates that faulting began during Miocene time and has continued to Recent time. The Hurricane Fault is a sinuous, northerly trending, high-angle normal fault. The west side is displaced down and is characterized by reverse drag flexure north of the Colorado River. Vertical displacement on the fault increases from about 1,500 feet near the Colorado River to 8,000-10,000 feet near Cedar City, Utah.

In addition to the major boundary faults of the Shivwits Plateau, the plateau strata are broken and warped by many faults and folds which are generally parallel to the trends of the Grand Wash and Hurricane Faults. Faults exhibit high-angle dip-slip movement and are measured in kilometers to tens of kilometers along strike. Grabens are common, especially in the eastern part of the plateau. Throughout most of the plateau the downthrown sides of faults are common on both the east and west fault blocks, but near the western boundary faults are consistently up to the west. Small-scale monoclinal flexures associated with the western faults also exhibit elevated west limbs which transition along strike into faults in many instances. The combined elevation of the west side of faults and monoclines produces a resultant structural elevation of the west edge of the Shivwits Plateau which is reflected in an increase in dip from nearly horizontal to as much as four degrees.

Uinkaret Plateau

The Uinkaret Plateau is bounded on the west by the Hurricane Fault, on the south by the Colorado River, and on the east by the Toroweap Fault. The early tectonic history of the Toroweap Fault is uncertain. The oldest dated lava flow displaced by this fault is 1.2 million years but initial movement was probably earlier. Local evidence of Holocene movement has been described by Huntoon (1972) and others.

The Toroweap Fault is an extensive, north-trending, high-angle normal fault that has displaced Paleozoic rocks down on its west side. Displacement has been estimated at about 650 feet near its intersection with the Colorado River (McKee and Schenk, 1942). The Paleozoic rocks of the Uinkaret Plateau are also cut by numerous smaller high-angle faults that trend generally northwest and are folded into long sinuous open folds which are subparallel to the major boundary faults (fig. 29).

Grand Canyon Region

The Grand Canyon region includes the area located between the Toroweap-Sevier Fault and the general vicinity of the Echo Cliffs Monocline. The primary structures of this region are reflected in the exposed Paleozoic rocks and include major large-scale folds and prominent faults which extend along strike into southern Utah. Huntoon (1972) delineates three systems of post-Paleozoic structures in the Grand Canyon region. The major portion of this section is summarized from his study.

A system of north-trending, subparallel monoclines is shown in figure 8. These monoclines apparently predate normal faulting of the plateau strata. Their genesis is directly related to the compressional stresses generated during the Laramide orogeny between 50 and 60 million years ago.

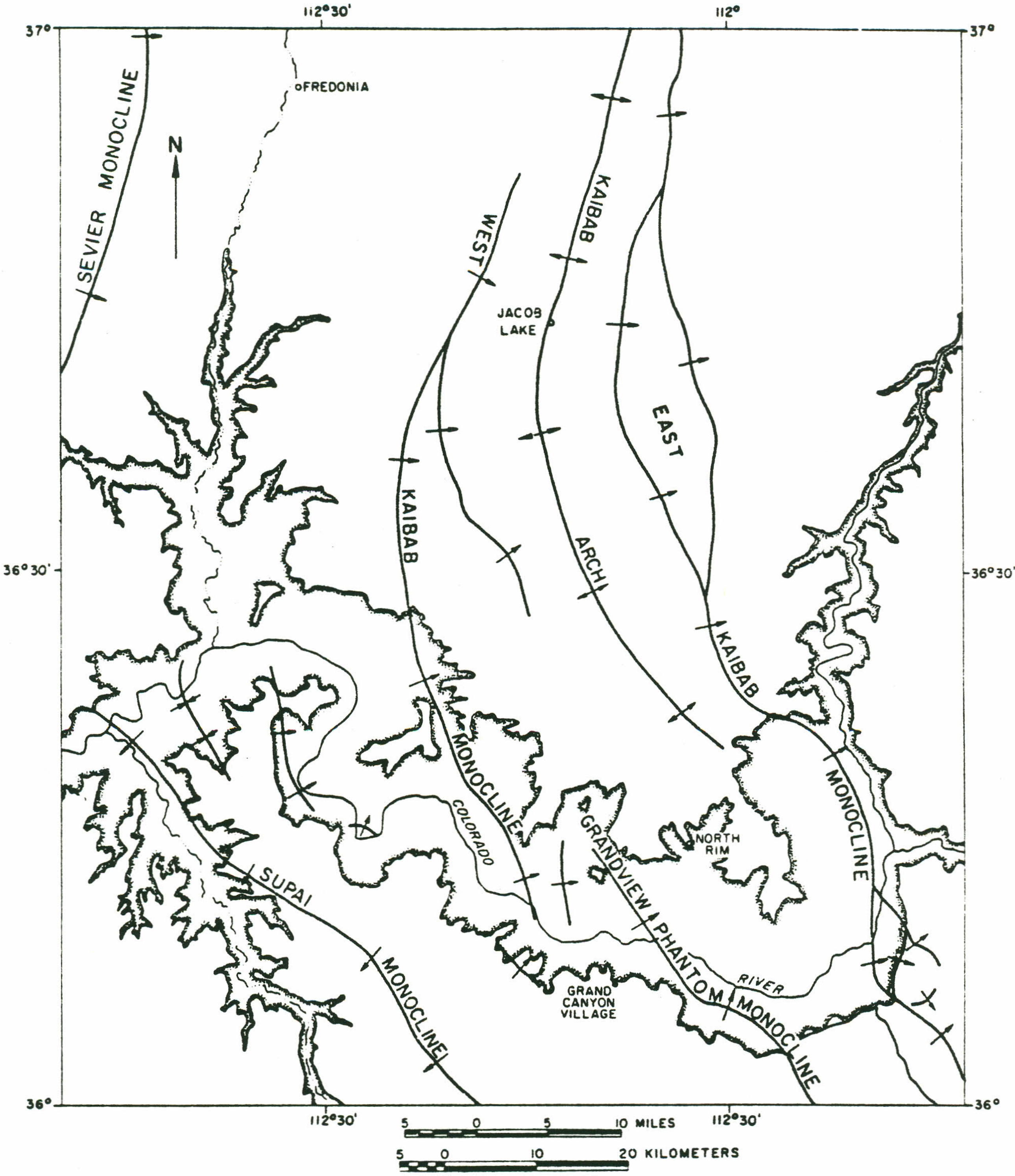


Figure 8. North-trending monoclines in the eastern Grand Canyon region. Reverse faults underlying monoclines omitted (from Huntoon, 1972).

Folding of the sedimentary rocks exhibits a geometric pattern consistent with flexural slip and flexural flow (Davis, 1975) initially induced by reverse faulting within the basement complex. The subsurface reverse faults commonly terminate upward in the Cambrian Bright Angel Shale, although they may extend as high as the Permian Supai Group. As a result of upward attenuation of the reverse fault displacement and the flexural flow mechanism of folding, dips of the middle limb strata appear to be directly related to the proximity of the basement complex. Dips range from a few degrees to moderately steep in the upper Paleozoic strata to slightly overturned near the base of the section.

The second major tectonic event was responsible for the development of several north-trending normal fault zones within the Kaibab Plateau and displacement of the preexisting monoclines along normal faults. The generalized spatial distribution of these structures is illustrated in figure 9. Displacements on the system of central Kaibab faults are usually less than 400 feet but increase to about 1,300 feet along the west Kaibab fault zone. The west Kaibab faults parallel the West Kaibab Monocline with the faults usually coinciding with the lower hinge of the folds. In addition, the surficial fault plane which dissects a monocline does not extend completely to the basement complex along many segments of monoclines as illustrated in figure 10. Normal faults dissecting the lower hinge of southern segments of the West Kaibab Monocline, Phantom-Grandview Monoclines, and other localities terminate in the upper Redwall Limestone. The underlying lower Paleozoic rocks are commonly intensely jointed but not displaced. It should be noted that normal faulting associated with the monoclines of the Kaibab Plateau is not encountered in the large folds located east of the Kaibab Uplift.

Huntoon (1972) states that the north-trending system of faults postdates the formation of the anticlines (fig. 10) and associates these structures with the tensional environment produced by the Basin and Range orogeny, initiated during Miocene time about 26 million years ago. It is believed that the major activity of this orogeny occurred in late Miocene or early Pliocene as normal faulting reached peak intensity concurrent with epeirogenic uplift of the Colorado Plateau as a whole.

A system of northeast-trending faults comprise the most recent major structures of the Grand Canyon region (fig. 11). Displacements on these normal faults rarely exceed 300 feet; but unlike previously described structures, they do not exhibit a preferred downthrown side. Although direct evidence for dating these faults is lacking, earliest movement may have occurred in Pliocene time.

The two largest anticlinal structures of the Grand Canyon region consist of the Kaibab and Echo Cliffs Uplifts. Structural elevation of strata in these folds is primarily accommodated by monoclinal folding along the flanks of these structures.

The Kaibab Upwarp, indicated in figures 2 and 8, includes several elements. The sinuous east-facing East Kaibab Monocline forms the east flank of the upwarp. It extends about 15 miles in length and elevates strata about 3,000 feet above the adjacent Marble Platform. The West Kaibab Monocline and associated faults form the west flank of the Kaibab

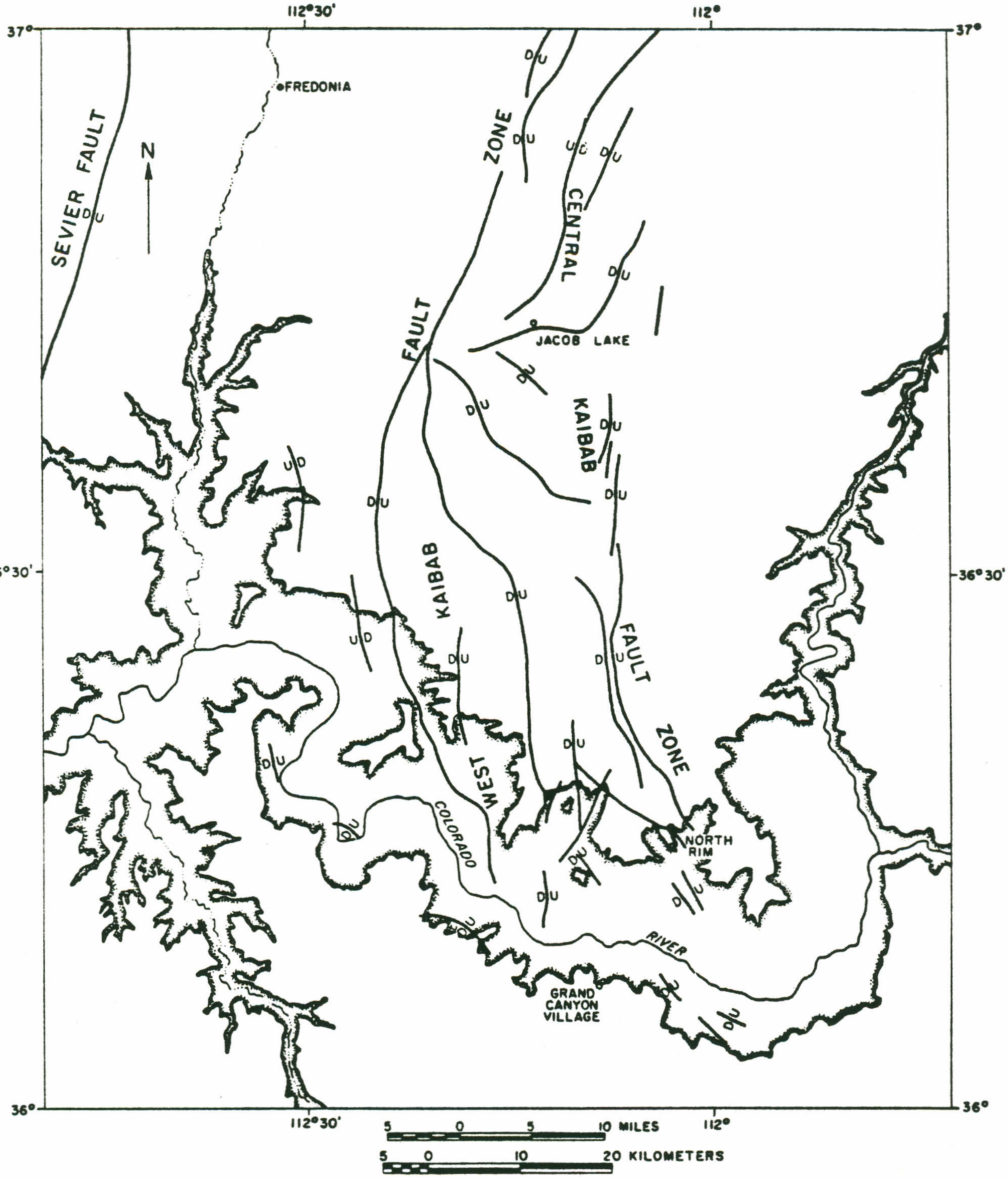
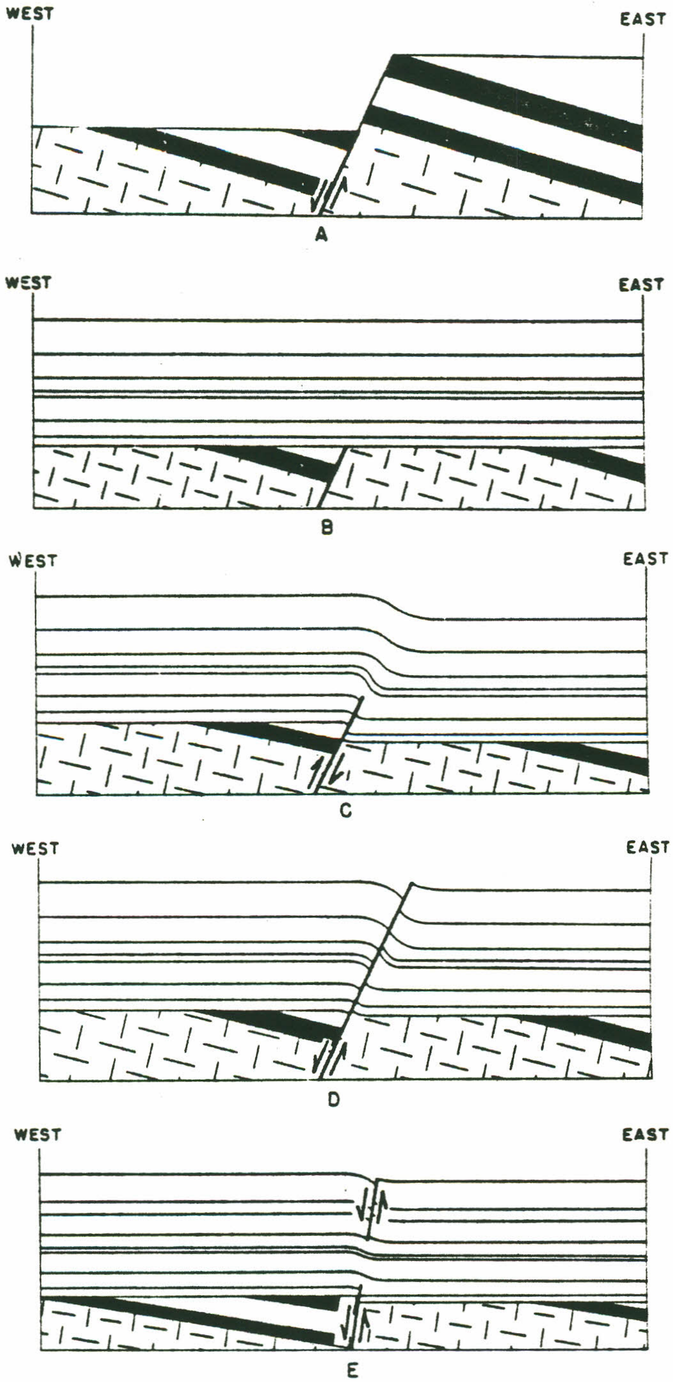


Figure 9. Principal north-trending normal faults in the eastern Grand Canyon region (from Huntoon, 1972).



Recurrent deformation along the north-trending structures:

A. Precambrian normal faulting

B. Erosion of Precambrian rocks and deposition of Paleozoic and Mesozoic strata

C. Monoclinal folding of Paleozoic and Mesozoic strata due to reverse faulting at depth

D. Normal faulting along the monoclines

E. Incomplete normal faulting along some monoclines due to slight normal movement along the underlying faults

Figure 10. Association of faults and monoclines (from Huntoon, 1972).

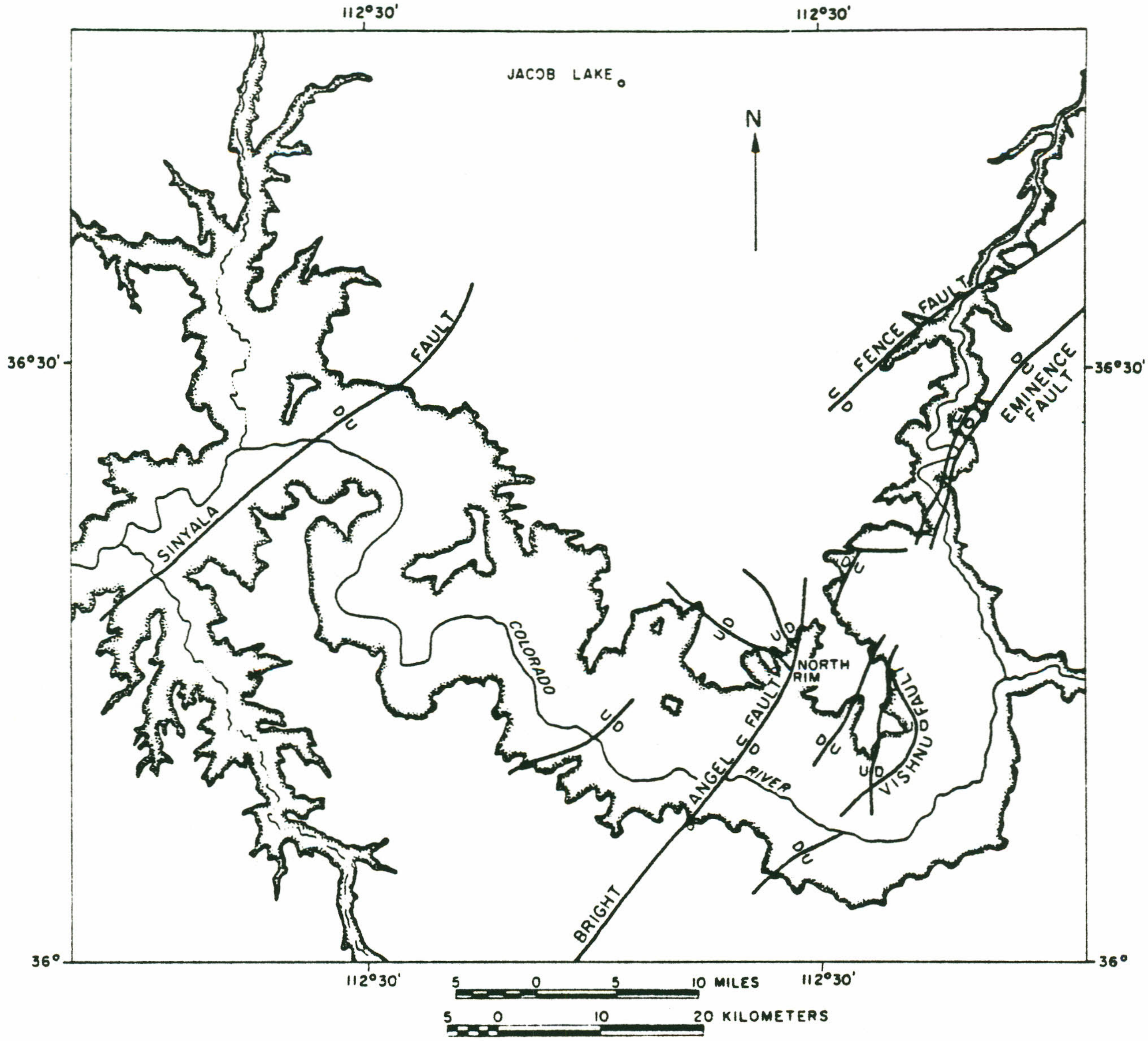


Figure 11. Principal northeast-trending normal faults in the eastern Grand Canyon region (from Huntoon, 1972).

Upwarp. Displacements along this fault zone have provided about one-half of the total structural relief (3,000 feet total) between the adjoining Kanab Plateau (on the west) and the crest of the upwarp. The remaining displacement is due to flexing of the strata along the monocline.

The Echo Cliffs Uplift is located at the extreme eastern margin of the Strip Country. It is a long, north-trending, arcuate anticline which is asymmetrically steeper to the east (Kelley and Clinton, 1960). This structure is about 80 miles long and 20 miles wide. Near the southern end of the structure the crestal axis is topographically offset to the west. Structural relief may be nearly 3,000 feet in the northern part but less than 1,000 feet near the southern end. The west flank of the uplift contains a very long gentle fold (Vermillion Anticline) generally parallel to the main axis.

STRATIGRAPHIC OVERVIEW

General

This section of the report provides a stratigraphic synthesis of northwestern Arizona, a relatively large and unexplored region, and the adjacent area of southwestern Utah where limited exploration activity has encountered modest petroleum resources. Due to the broad scope of this paper, descriptions of the numerous units are generalized but many references are cited to provide an investigator with access to local details.

The sedimentary strata of the area comprise a nearly complete section of Phanerozoic rocks. The regional stratigraphic setting has been directly influenced by the existence of the Transcontinental Arch and the Cordilleran miogeosyncline whose eastern boundary is demarcated by the Wasatch Line (fig. 12). The Transcontinental Arch, a broad band of Precambrian rock extending from the Great Lakes area to the Mohave Desert, was a dominant structural feature during the Cambrian Period. Throughout the remaining Paleozoic Era the arch persisted as a subdued positive belt. This arch influenced sedimentation patterns by forming a low barrier between multiple marine transgressions encroaching from the southeast and northwest. Numerous unconformities or depositional gaps are found in the subsurface overlying this feature (Stokes and Heylmun, 1963) due to failure of onlapping sediments to top the arch or due to erosion of the attenuated sections on its summit (King, 1959).

The Wasatch Line represents the location of a relatively narrow hinge zone dividing the thick section of geosynclinal sediments to the west from the stable shelf facies to the east. In southwestern Utah and northwestern Arizona the Wasatch Line is subparallel and relatively close to the northwestern flank of the Transcontinental Arch. The rate of subsidence along the hinge line, as well as its location, has not been locally consistent. Location of the hinge line is less evident in strata of the late Paleozoic Era. Tectonic activity associated with the ancestral Rocky Mountain system is manifest in the subsurface as an apparent uplift known as the Kaibab Positive area. Pennsylvanian beds were either not deposited or were removed by pre-Permian erosion along the crest of the uplift. A distinct basal Permian unconformity has been reported by Heylmun (1958, 1961) along with additional information. These regional tectonic features are indicated in figure 12.

Distribution of Outcrops

The generalized distribution of outcrops is shown on the Geologic Map of Arizona (Wilson and others, 1969), the Geologic Map of Mohave County, Arizona (Wilson and Moore, 1959), and the Geologic Map of Coconino County, Arizona (Moore and others, 1960). Additional geologic maps of greater scale but smaller areal extent are referenced in the Index of Maps (Conley and others, 1976).

Nearly all exposed rock units east of the Grand Wash Fault consist of Paleozoic and Mesozoic formations. The outcrop pattern has resulted from

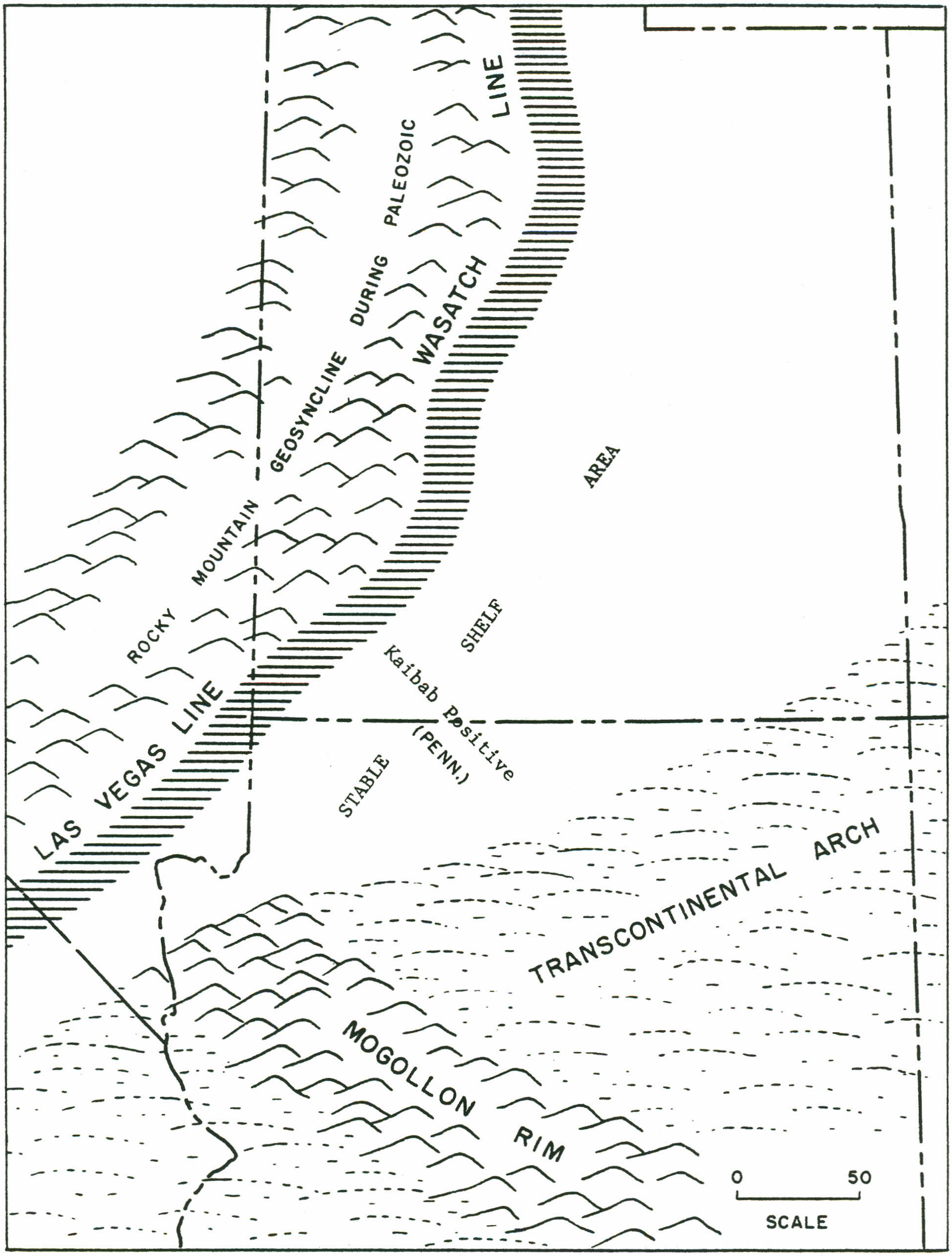


Figure 12. Some major pre-Tertiary tectonic features affecting sedimentation patterns of Arizona and Utah (modified from Stokes and Heylmun, 1963).

differential erosion of nearly horizontal strata locally modified by minor structural warping. Cenozoic volcanic flows, ranging from small isolated remnants to moderately extensive flows, cap portions of the west half of the area. The Permian Kaibab Formation comprises most of the surficial Paleozoic outcrops. Outcrops of all remaining Paleozoic periods except Silurian are invariably limited to exposures found in incised canyons. Several large lobes within the northern portions of the area, as well as a narrow strip extending southeast along the Hurricane Cliffs, expose Triassic or Jurassic rocks. Mesozoic strata are typically lacking a complete section in the Strip Country. Jurassic beds are essentially limited to subaerial monadnocks, and Cretaceous strata are practically nonexistent.

West of the Grand Wash Fault, outcrop patterns are somewhat complex due to development of typical Basin and Range structures and the Virgin Mountain Anticline. Rock units span geologic time from Precambrian to Recent but a complete section of Cenozoic beds is not exposed. Tertiary beds in the Virgin River Valley form extensive outcrops and exceed a depth of 2,000 feet.

The Paleozoic section represents the largest suite of potentially petroliferous rocks. Thickness of the Paleozoic section ranges from 7,500 feet near the Nevada border to approximately 4,000 feet near the southeast margin of the area. The following text includes a brief summary of the lithology and stratigraphic setting of the Paleozoic and Lower Triassic rocks which characterize northwestern Arizona. A typical columnar section is illustrated in figure 13.

Cambrian Tonto Group

Cambrian sediments were deposited by a marine transgression, resulting in progressive eastward onlap across northern Arizona from the Cordilleran geosyncline toward the Defiance Positive landmass. Reference to lithofacies maps of Cambrian series rocks (Mallory and others, 1972) clearly illustrates the time-transgressive nature of the Cambrian formations. Fossil assemblages indicate an early Cambrian age associated with the beginning of the transgression in the western Grand Canyon region, with marine conditions reaching the eastern margin of the area in Middle Cambrian time (McKee, 1974). Examination of the Cambrian section reveals a series of gray limestone tongues projecting eastward into green shaly mudstone units, indicating a number of minor retreats occurring prior to the major regression which terminated Cambrian deposition.

Lowermost Cambrian rocks are represented by the Tapeats Sandstone. This unit is brown, coarse to medium-grained, cross-bedded sandstone ranging in thickness from 100 to 300 feet. The Tapeats sandstones grade upward through a zone of alternating coarse sandstone and green shaly mudstone into the Bright Angel Shale.

The Bright Angel Shale is predominantly shaly green mudstone but also contains fine-grained sandstone of various colors and gray platy siltstone. This formation grades upward into the Muav Limestone.

Strata of the Muav Limestone (uppermost Tonto Group) consist of mottled gray limestone which is thin bedded in the eastern Grand Canyon area and becomes progressively thicker toward the west. Shaly mudstone,

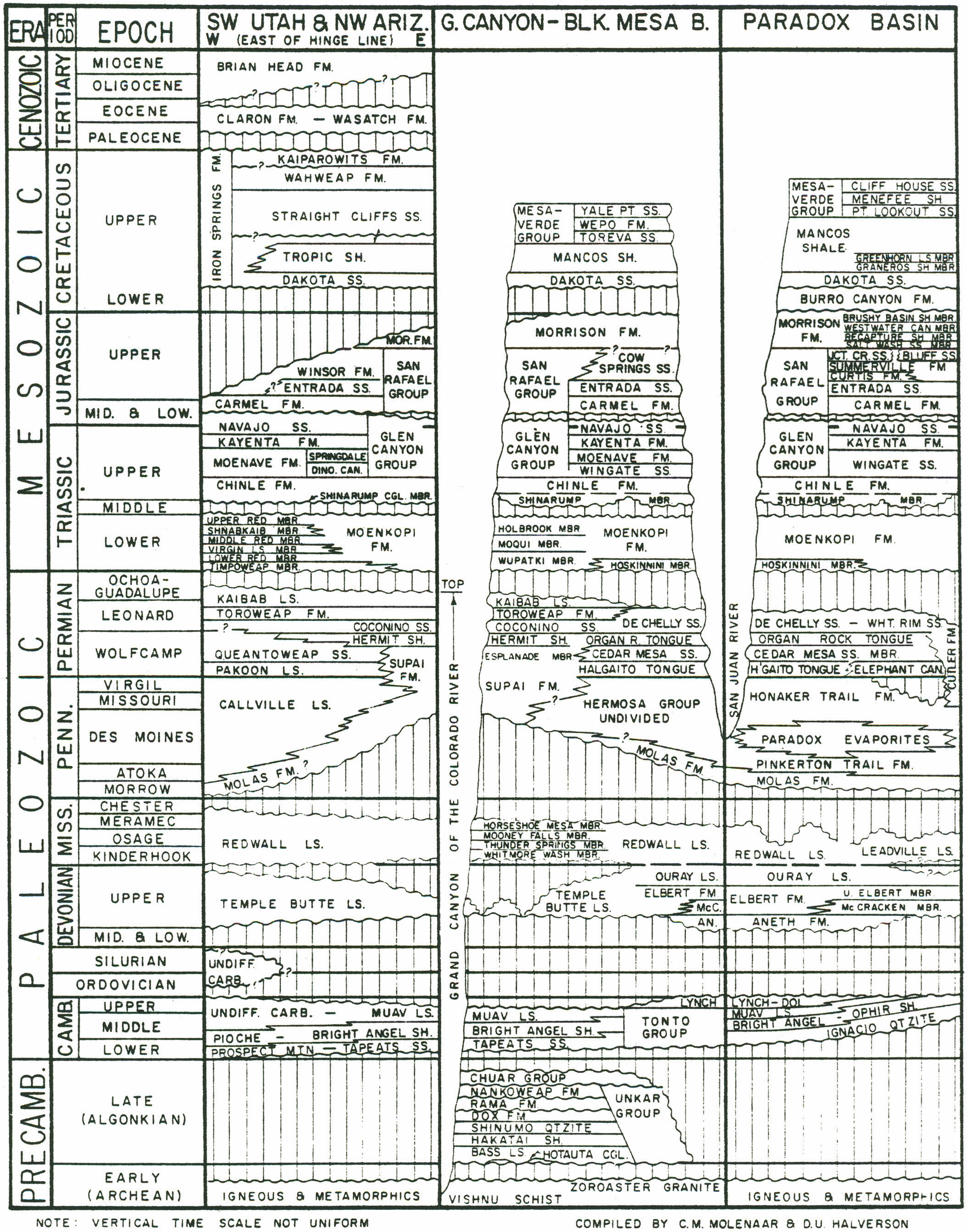


Figure 13. Nomenclature chart of the Grand Canyon and adjacent areas (from Molenaar and Halverson, 1969).

micaceous siltstone, or flat-pebble conglomerate beds are found between the massive limestone beds in the western Grand Canyon area (McKee, 1974).

Several relatively thin but distinctive wide-spread marker beds form persistent units which are representative of approximate time planes within the Cambrian deposits. The lithology and fauna of these key units are described by McKee and Resser (1945). Cambrian outcrops located in the Virgin Mountains, at the extreme northwestern corner of the area, have been mapped by Moore (1972). He recognized about 250 feet of Tapeats sandstone and quartzite overlain by approximately 500 feet of Bright Angel green and red shale.

Representative Cambrian sections of southwestern Utah and a section from the Grand Canyon are shown in figure 14. Nomenclature of the shelf deposits of Utah remain unchanged in sections 5, 6, and 7 of this figure. Brief descriptions of Cambrian strata located in the hinge line zone of southwestern Utah are given by Hintze (1963).

Isopachs of the Tonto Group are indicated on figure 15. On a regional scale Cambrian rocks thicken uniformly toward the northwest where they are in excess of 1,600 feet. At the east margin of the Strip Country, Cambrian rocks range between 900 and 1,000 feet thick. Although the generalized isopachs reflect a uniform rate of thickening, abrupt attenuation of lower Paleozoic strata may be encountered locally due to low to moderate structural/erosional relief developed on the basement complex.

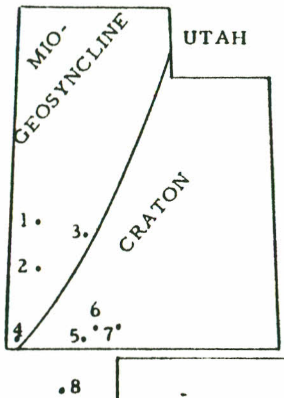
Precambrian monadnocks of granite, schist, and quartzite formed isolated islands in the Cambrian seas, with the size and abundance of these hills related to the distance from the Transcontinental Arch. Relief on the Precambrian surface decreases oceanward toward the Cordilleran geosyncline. Many stratigraphic details regarding this unconformity have been examined along numerous exposures in the Grand Canyon and are described in reports by Hinds (1935), Sharp (1940), and McKee and Resser (1945).

Ordovician-Silurian

Ordovician strata are not indicated by isopach maps due to their limited thickness and areal distribution (McKee, 1951). Similarly, Ordovician shelf deposits of southwestern Utah are not recognized (fig. 14) but Ordovician-Silurian rocks west of the Wasatch Line form significant units. Silurian strata have not been recognized in Arizona.

Devonian

The Temple Butte Limestone unconformably overlies Cambrian strata throughout the area. The hiatus spans the late Cambrian, Ordovician, and Silurian, and extends into middle Devonian time in the eastern portion. The time interval represented by this erosion surface may be progressively shorter toward the west. The surface below Devonian beds is irregular and is characterized by many channels with relief as much as 100 feet. The existence of these channels throughout the entire Grand Canyon has been noted by McKee (1974). In the eastern portion of the area, the Temple Butte Limestone is limited to isolated outcrops which fill channels and depressions within the Muav Limestone. Typically, the eastern Devonian outcrops exhibit a maximum lateral extent of a few hundred feet and are



	← MIOGEOSYNCLINE →		← HINGE LINE →		← CRATON →			
	1	2	3	4	5	6	7	8
	HOUSE & CONFUSION RANGES (Hintze, notes)	SOUTHERN WAHWAH RANGE (Miller, 1959)	PAVANT RANGE (Crosby, 1959)	BEAVER DAM MOUNTAINS (Reber, 1951) (Hintze, notes)	McDermott #1 State 2 - 43S - 8W	Superior Oil Kanab Cr. #1 16 - 42S - 7W	Tidewater # 1 Unit 34 - 42S - 2W	GRAND CANYON (McKee 1945)
DEVONIAN	Pilot Sh 800' Guilmette Fm 2650' Simonson Dolo 600' Sevy Dolo 1500'	Simonson Dolo 80-550 Sevy 150-300	Cove Ft Qtz 80' Guilmette Fm 570' Simonson Dolo 240' Sevy Dolo 670'	Sevy ? 800'	Devonian ls, dolo ss, sh 371'	Devonian ls, dolo ss, sh 392' *	Unclassified ls, dolo ss, sh 297'	Temple Butte Ls 0-100'
SILURIAN	Laketown Dolo 900'	Laketown Dolo 1200'	undifferentiated Silurian-Upper Ordovician dolomite 1000'	cherty dolomite Ordovician Silurian ? 200'	not recognized	not recognized	not recognized	absent
ORDOVICIAN	Fish Haven Dolo 600' Eureka Qtz 875' Pogonip Ls 3000'	Fish Haven Dolo 400' Eureka Qtz 150' Pogonip Ls 700'	Eureka Qtz 180' Pogonip Ls 1110'					
CAMBRIAN carbonate units	Many named units, mostly ls, some sh & dolo 6850'	Ls, some sh & dolo 6800'	Ls, dolo 1680'	dolomite 1100'	C - ? ls & dolo 527' Muav Ls 507'	Muav Ls 987'	Muav Ls 1122'	Muav Ls 136-827'
CAMBRIAN lower shale unit	Pioche Sh 238-314'	Pioche Sh 800'	Ophir Fm 418'	Pioche Sh 215'	Bright Angel Shale 345'	Bright Angel Shale 327'	Bright Angel Shale 301'	Bright Angel Sh 270-450'
CAMBRIAN basal quartzite	Prospect Mtn. Qtzt 2200'+	Prospect Mtn. Qtzt 7500'	Tintic Qtzt 1300'	Prospect Mtn. Qtzt 533'	Tapeats Ss 265'	Tapeats Ss	Tapeats Ss 393'	Tapeats Ss 178-360'
underlying	not exposed	metasediments	not exposed	schist, granite	metasediments		metasediments	metasediments

*Probable Devonian conodonts in upper 20'

Figure 14. Correlation of lower Paleozoic units in southwestern Utah and adjacent areas (from Hintze, 1963).

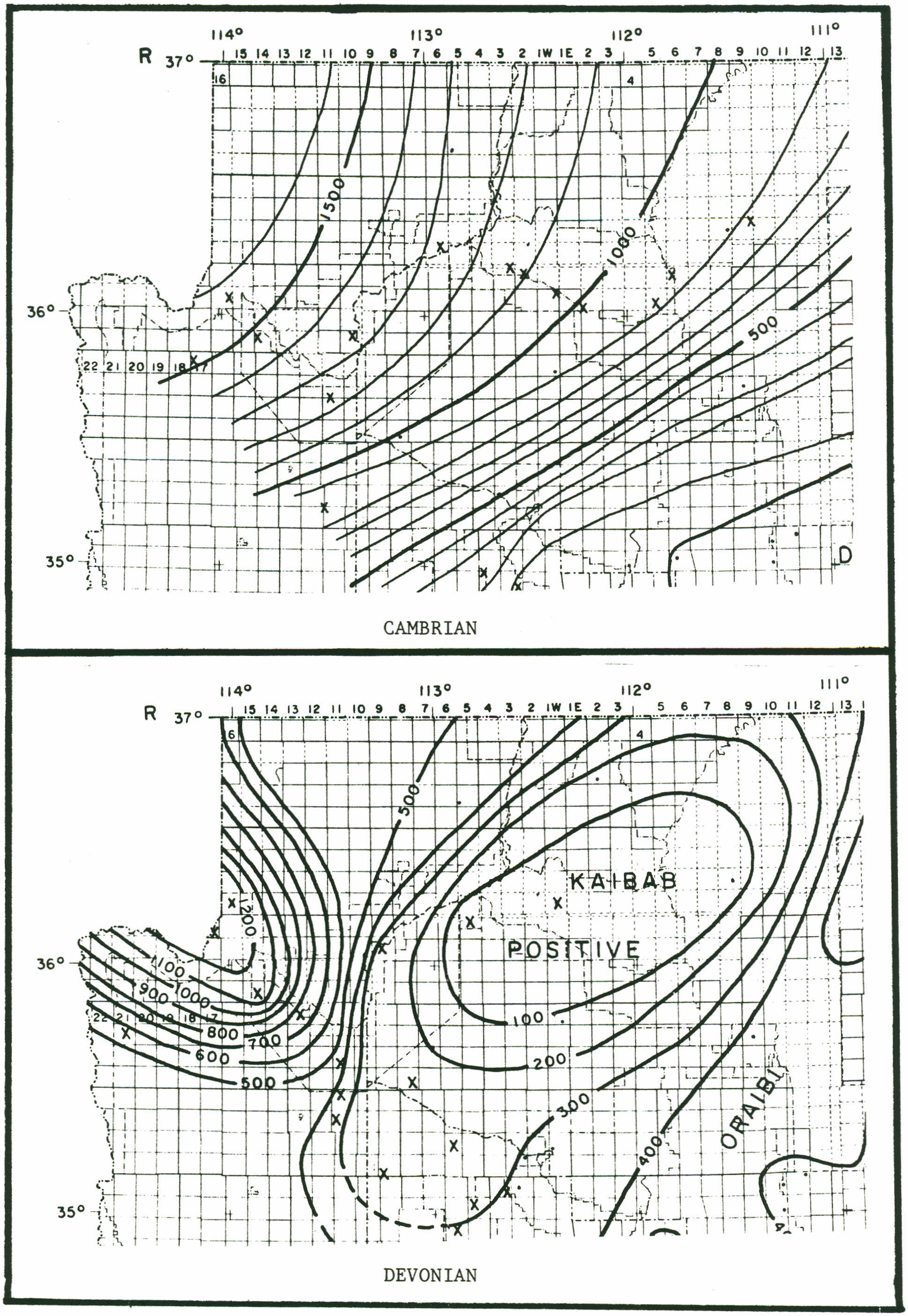


Figure 15. Isopachs (from Peirce and others, 1970).

less than 100 feet thick (McKee, 1974). The Temple Butte Formation becomes progressively thicker and laterally continuous toward the west.

In the Grand Canyon, basal channel-fill deposits consist of irregular, wavy, or crenulated purplish beds with thin continuous strata above the depressions. The latter consists of tan to white, fine-textured, thin-bedded dolomite of probable algal origin and steel gray, fine-grained, medium to thick dolomite beds. The age of the Temple Butte Limestone is presently assigned to the lower part of the Upper Devonian Series, Frasnian Stage (Poole and others, 1967).

In the Virgin Mountain area, Moore (1972) has mapped a thick series of marine limestones and dolomites (±2,200 feet) between the Cambrian Bright Angel Shale and Redwall Limestone. McNair (1951) describes correlations of this interval with Cambrian, Ordovician, and Devonian rocks. Similarly, a sequence of dolomite (2,100 feet) occupies the same interval in the Beaverdam Mountains of southwestern Utah (fig. 14). However, a lack of definitive fossils has precluded detailed age assignments (Hintze, 1963). Hintze suggests that the lower half is lithologically similar to known Cambrian beds located near the Wasatch Line at other Utah localities. Likewise, a 200-foot interval above the Cambrian(?) beds appears similar to Ordovician and Silurian cherty dolomites of western Utah and eastern Nevada. The remaining 800 feet of section consists of light gray dolomite "which clearly resembles the Devonian Sevy Dolomite of the eastern Great Basin" (Hintze, 1963). Correlations of these formations is shown in figure 14.

Devonian strata thin rapidly against the west flank of the Kaibab Positive (fig. 15). Near the Arizona-Nevada boundary Devonian strata fill a deep north to northwest oriented trough where the section thickens rapidly to 1,200 feet. Devonian rocks of southwestern Utah generally range from about 200 to 700 feet thick (Mallory and others, 1972).

Mississippian

Early Mississippian strata unconformably overlie late Devonian rocks in the area common to Arizona, Nevada, and Utah. Locally, Mississippian rocks were deposited on late Cambrian sediments on the summit of the Kaibab Uplift. In the Grand Canyon the Redwall Limestone is generally 500 feet thick and has been divided into four distinct persistent members by McKee and Gutschick (1969).

The Whitmore Wash Member is the lowermost unit, consisting of about 100 feet of fine-grained dolomite in the eastern Grand Canyon and fine-grained limestone in the western Grand Canyon.

The Thunder Springs Member consists of about 80 feet of thin dolomite beds in the eastern Grand Canyon and limestone in the western Grand Canyon. These carbonate beds also contain thin beds and elongate lenses of white opaque chert.

The thickest member, Mooney Falls, ranges from 200 to 350 feet thick with beds from 3 to 20 feet thick. This unit is essentially pure limestone, practically free of detritus and only locally dolomitic.

The Horseshoe Mesa Member is the upper unit of the Redwall and ranges from 35 to 125 feet thick. It is generally thin-bedded aphanitic limestone.

Except for bedded chert, the Redwall Limestone is essentially a total carbonate formation. Some limestone units exhibit granular textures and are comprised of extensive peloidal and bioclastic beds. The aphanitic beds probably originated as lime muds (McKee, 1974). Abrupt thickening of the Redwall and introduction of detrital rocks occurs well beyond the area in the miogeosyncline facies to the west and northwest (fig. 16).

In the Virgin Mountains, Mississippian rocks consist of cherty marine limestones about 600 feet thick. Moore (1958) has traced the Redwall Limestone from its type section in eastern Grand Canyon to within 20 miles of the Virgin Mountains. Apparently Moore was able to distinguish all four members, with the Thunder Springs and Mooney Falls particularly distinctive in the Virgin Mountains.

An excellent summary of Mississippian stratigraphic correlations in adjacent southwestern Utah and eastern Nevada is given by Langenheim (1963). Columnar sections from his report, which illustrate regional correlations, are shown in figure 16.

The Mississippian system of northwestern Arizona is part of the greater Mississippian carbonate shelf margin developed along the eastern flank of the Cordilleran miogeosyncline. This shelf facies is similar to well documented geologic counterparts such as the Guadalupian reef of the West Texas Permian basin and the Lower Cretaceous Edwards shelf margin of the Gulf Coast (Rose, 1976). The Redwall Limestone within most of northwestern Arizona represents two major transgressions. Fossils indicate that the first transgression began in Kinderhook time and the second in Osage time, followed by regression in Meramec time. These rocks, therefore, are representative of the lower depositional complex delineated by Rose and illustrated in figure 17. Evidence of a third transgression is restricted to isolated outcrops of Chester age rocks found in the Grand Canyon area along Bright Angel Trail. Although Mississippian strata of the Upper Meramec and Chester Series (upper complex of Rose) may have covered the Strip Country, it appears that nearly all of these rocks were removed by pre-Supai erosion.

Isopachs of the Redwall Limestone (fig. 18) depict a relatively uniform thickening. The formation is about 500 feet thick, increasing northwestward to 800+ feet. Isopach contours generally continue to strike northeast in adjacent Utah and indicate about 1,000 feet of section near St. George.

Early Pennsylvanian-Early Permian Strata

Rocks of early Pennsylvanian-early Permian age are represented by the Supai Group. In the Grand Canyon region, the Supai Group has been divided into the following formations: Esplanade Sandstone, Wescogame, Manakacha, and Watahomigi (McKee, 1975). In the eastern portion of the Grand Canyon, Supai rocks consist of shaly siltstone red beds and fine-grained buff sandstone (McKee, 1974). Thickness of the Supai Group is somewhat uniform but is characterized by lateral lithologic changes resulting in the existence of distinct time-correlative strata west of Havasu Canyon (fig. 19).

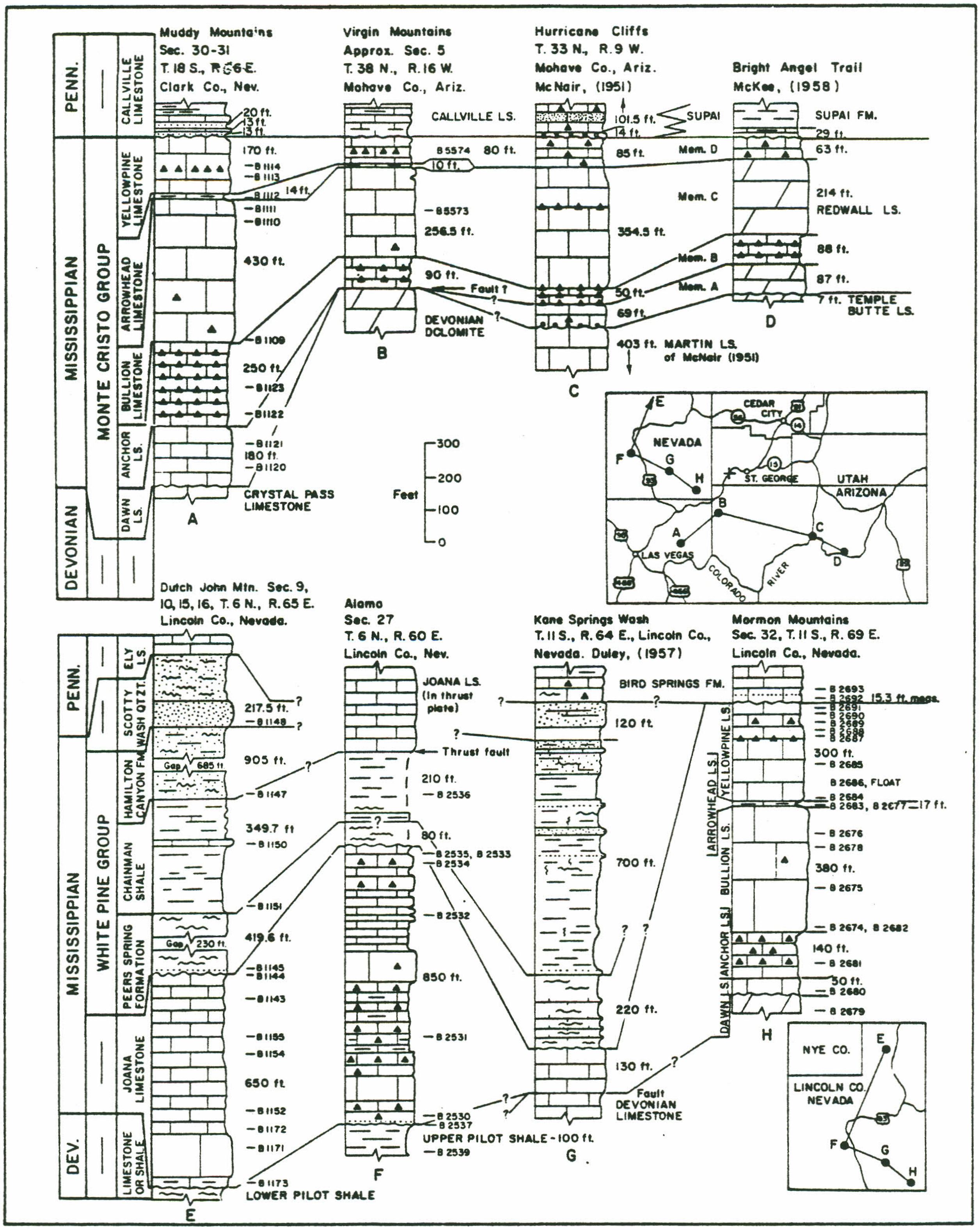


Figure 16. Columnar sections of Mississippian rocks in Nevada and Arizona adjacent to southwestern Utah. Numbers preceded by "B" refer to collections in the Museum of Paleontology, University of California, Berkeley (from Langenheim, 1963).

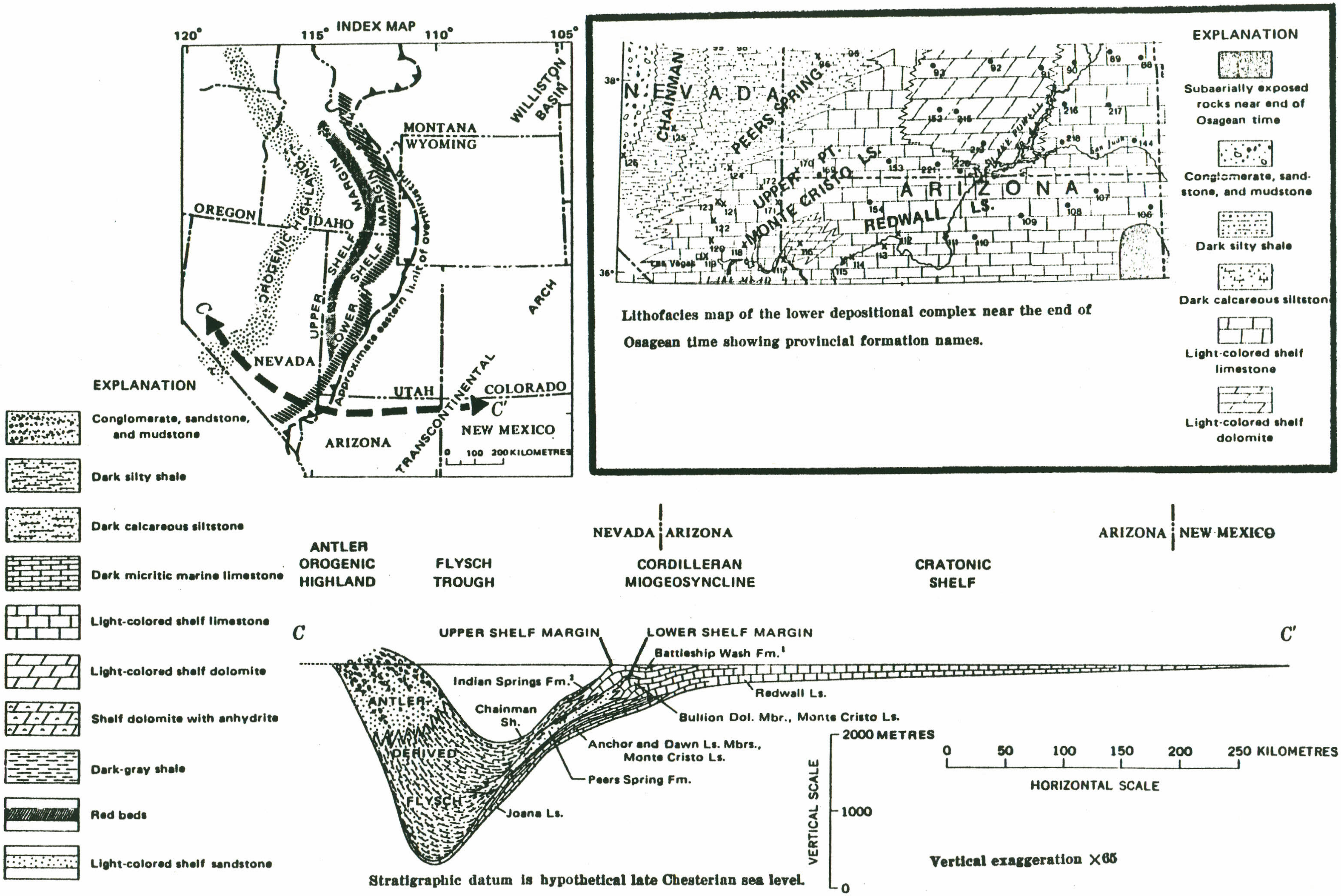
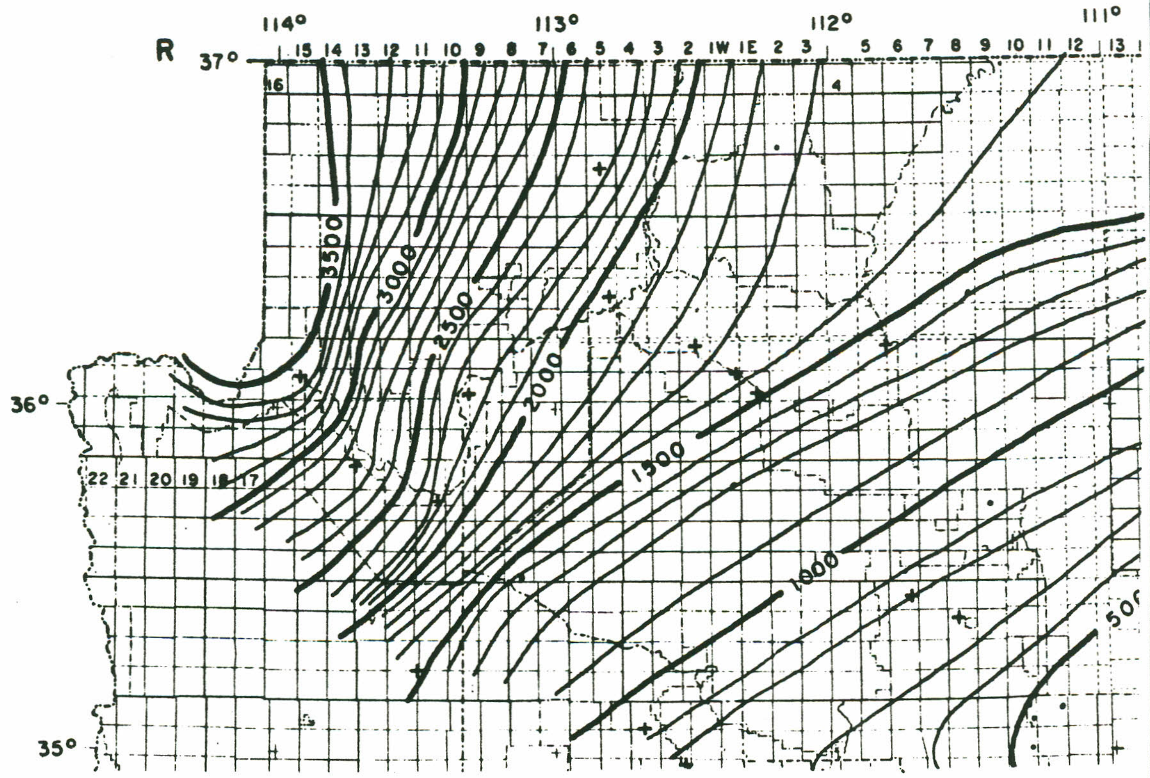
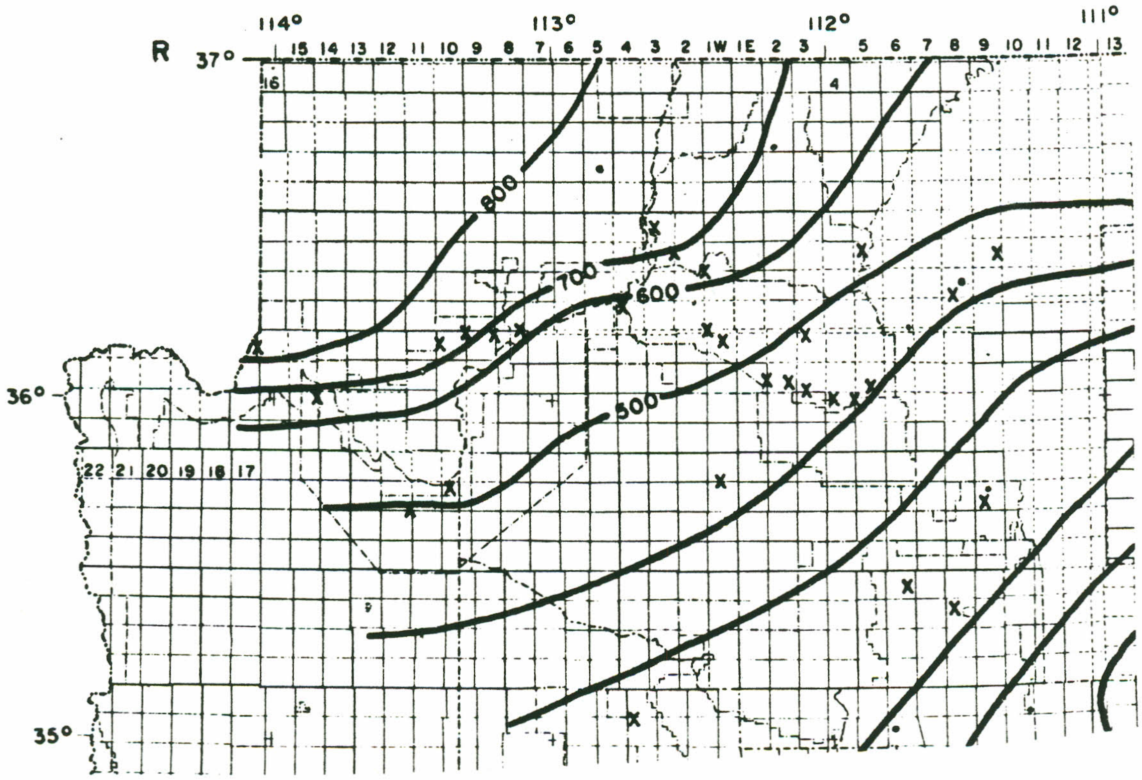


Figure 17. Generalized regional Mississippian stratigraphic cross sections showing local names of units and relative thicknesses (modified from Rose, 1976).

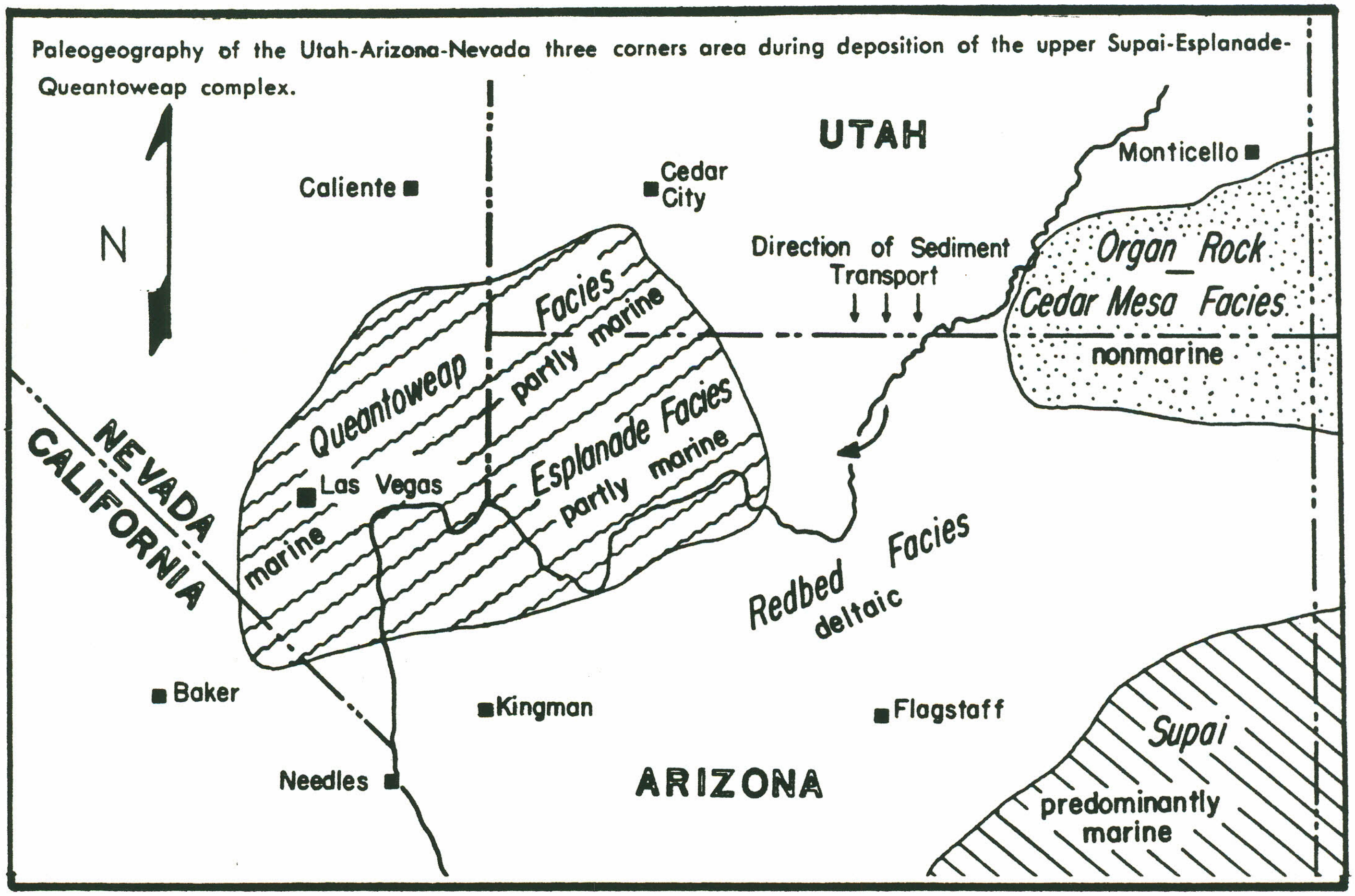


CAMBRIAN-DEVONIAN



MISSISSIPPIAN

Figure 18. Isopachs (from Peirce and others, 1970).



Paleogeography of the Utah-Arizona-Nevada three corners area during deposition of the upper Supai-Esplanade-Queantoweap complex.

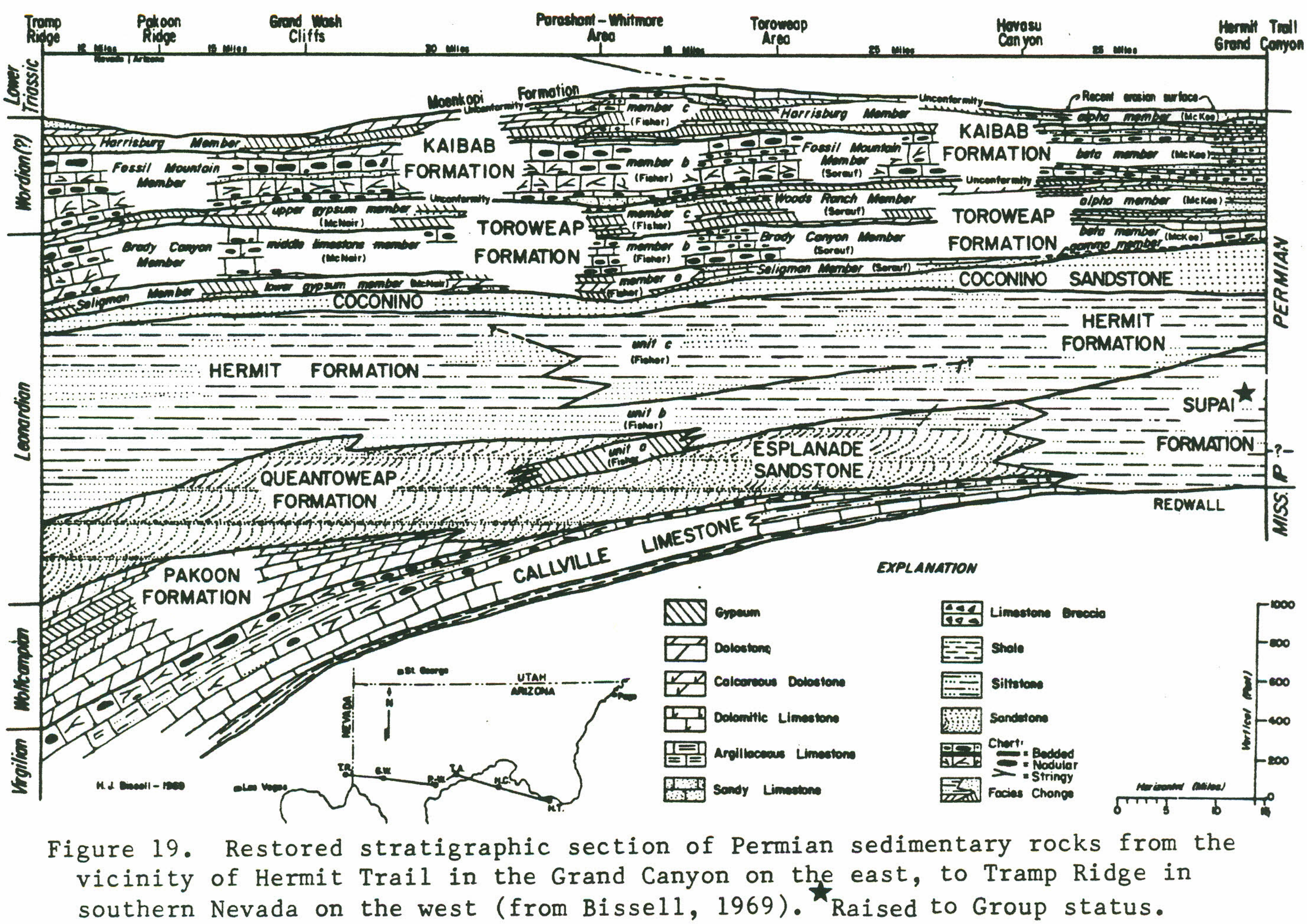


Figure 19. Restored stratigraphic section of Permian sedimentary rocks from the vicinity of Hermit Trail in the Grand Canyon on the east, to Tramp Ridge in southern Nevada on the west (from Bissell, 1969). ★Raised to Group status.

Supai beds increase upsection in sandstone content, resulting in the development of massive cliff-forming beds which have been designated as the Esplanade Sandstone. In the far west portion of the area, rocks representing a lateral equivalent of the Esplanade Sandstone are described by McNair (1951) who named these strata the Queantoweap Formation. This formation consists of about 400 feet of pink and light gray cross-bedded sandstone at Pakoon Ridge, increasing to 645 feet in the north Grand Wash Cliffs. The spatial distribution of the upper Supai red beds, the Esplanade Sandstone, and Queantoweap Formation is indicated in figure 19. This figure also illustrates the westward lateral transition of the lower clastic and limestone beds of the Supai Group into the Callville Formation. The lower Supai beds were considered an eastern extension of the Callville Formation by Fisher (1961).

The Pakoon Formation of Wolfcamp age forms a distinct wedge between the Callville and Queantoweap Formations throughout the western portion of the Strip Country. At Pakoon Ridge in Mohave County this formation is 688 feet of dolomitic limestone. The Pakoon Formation becomes more dolomitic toward the west in eastern Nevada and includes interbedded gypsum.

Red-brown sandstone and shaly siltstone of the Hermit Shale overlies the Esplanade-Queantoweap Formations. Thickness of Hermit rocks increases rapidly from east to west (±100 to >1,000 feet). Hermit strata have been assigned a Permian age based on fossils of seed ferns (McKee, 1974).

In the Virgin Mountain region the Redwall Limestone is overlain by about 1,400 feet of undifferentiated Pennsylvanian-Permian strata of the Callville Formation. Moore (1972) did not recognize a mappable contact between the Pakoon and Callville Formations of this area. He described this interval as thin to thick-bedded marine limestone and dolomitic limestone containing localized lenses of pink to tan chert and cross-bedded pink sandstone. About 200 feet of gypsum, assigned to the Callville Formation and assumed to represent residual evaporites of a retreating Callville sea, crop out in sections 3 and 10, T. 41 N., R. 14 W. About three-fourths square mile of gypsum outcrops are exposed but their subsurface extent is unknown. Permian Supai and Hermit clastic rocks overlie the Callville Formation, marking a distinct change in lithology. The Supai (Queantoweap in this area) consists of massive, flat-bedded to cross-bedded, buff-yellow to dull-red sandstone (800 to 1,250 feet thick). The Hermit Shale consists of thin-bedded, dark-red, fine-grained sandstone interbedded with medium-bedded, lighter colored sandstone. This unit is about 400 feet thick at Bunkerville Mountain but thins rapidly to the north. Moore (1972) could not recognize Hermit strata above Supai in Sullivans Canyon.

In southwestern Utah, rocks assigned to the Callville Formation are restricted to those of Pennsylvanian age with an interval of overlying Permian beds called the Pakoon Formation. In the Beaverdam Mountains of southwestern Utah, the Callville consists of about 1,000 feet of interbedded limestone, sandstone, and dolomite in thin to thick beds overlain by about 300 to 500 feet of Pakoon dolomitic limestone of Permian age (Bissell, 1963). Apparently the Pakoon-Callville contact and associated lithologies are not clearly defined in this area, resulting in considerable differences in the thickness of reported sections. Both the Pakoon Limestone and overlying Queantoweap Sandstone have been described by McNair (1951) at their type localities in northwestern Arizona. Thickness of these units and brief descriptions at various localities of southwestern Utah and northwestern Arizona are given by Bissell (1963). About 1,000 feet of Hermit Shale was measured by Bissell at Tramp Ridge in southeastern Nevada (fig. 19). In the vicinity of the Beaverdam Mountains, Hermit lithology becomes difficult to differentiate between Queantoweap Sandstone and overlying Coconino beds. At this locality Hermit Shale consists of tan, gray, and yellow sandstones.

Middle and Upper Permian Strata

The Coconino Sandstone, a lower Leonardian eolian deposit of well-sorted gray to white sandstone, is about 100 feet thick in the central Grand Canyon area and thins to the north, northwest, and west. This unit is readily identified by its ubiquitous large-scale cross bedding which is characterized by predominantly south-dipping foreset beds, indicating transportation by north winds (Reiche, 1938). The presence of Coconino Sandstone in wells drilled in southwestern Utah is often difficult to identify due to possible pinch out or lithologic similarity to the Queantoweap Formation. A summary of the subsurface occurrence of the Coconino Sandstone in southwestern Utah is given by Bissell (1963).

The Toroweap and Kaibab Formations comprise the uppermost Permian units of northwestern Arizona. In the Grand Canyon area these formations are predominantly carbonate rocks deposited during two major west to east transgressions of the Permian sea. Both formations are characterized by three members which represent the marine transgression, maximum advance and regression phases of deposition (McKee, 1963). A fence diagram of the Toroweap Formation is shown in figure 20. The lower Seligman Member of the Toroweap Formation was deposited upon Coconino sand dunes. The Seligman Member generally consists of gypsum and fine-grained calcareous sandstone. The sandstones are horizontally bedded, interfinger with Coconino beds in the eastern portion of the area, and are less than 50 feet thick where exposed in the Grand Canyon (Rawson and Turner, 1974). Bissell (1969) states that this unit contains thin-bedded, porous dolostone and gypsum at Tramp Ridge near the Arizona-Nevada border.

Marine carbonates overlie the supratidal and continental deposits and are represented by the Brady Canyon Member. The lithology of this unit grades from sandy dolomite to skeletal limestone from east to west as shown on the facies map of figure 21. The Brady Canyon Member totals 350 feet at Pakoon Ridge and thins to less than 50 feet along the eastern margin of the area. A detailed description of the petrology and facies of this member is provided by Rawson and Turner (1974).

Strata of the Woods Ranch Member were deposited during the westward regression of the Middle Permian sea. The unit consists of massive gypsum, anhydrite, red and white fine-grained sandstone, and minor carbonate beds. Petroliferous dolomite occurs in the type section in Hack Canyon (Rawson and Turner, 1974).

The Kaibab-Toroweap contact represents a regional unconformity which exhibits slight but widespread deformation and locally severe erosion. The Kaibab Formation is a distinct areally extensive unit, recognized by Bissell (1969) as extending as far north as the Gold Hill district, Utah.

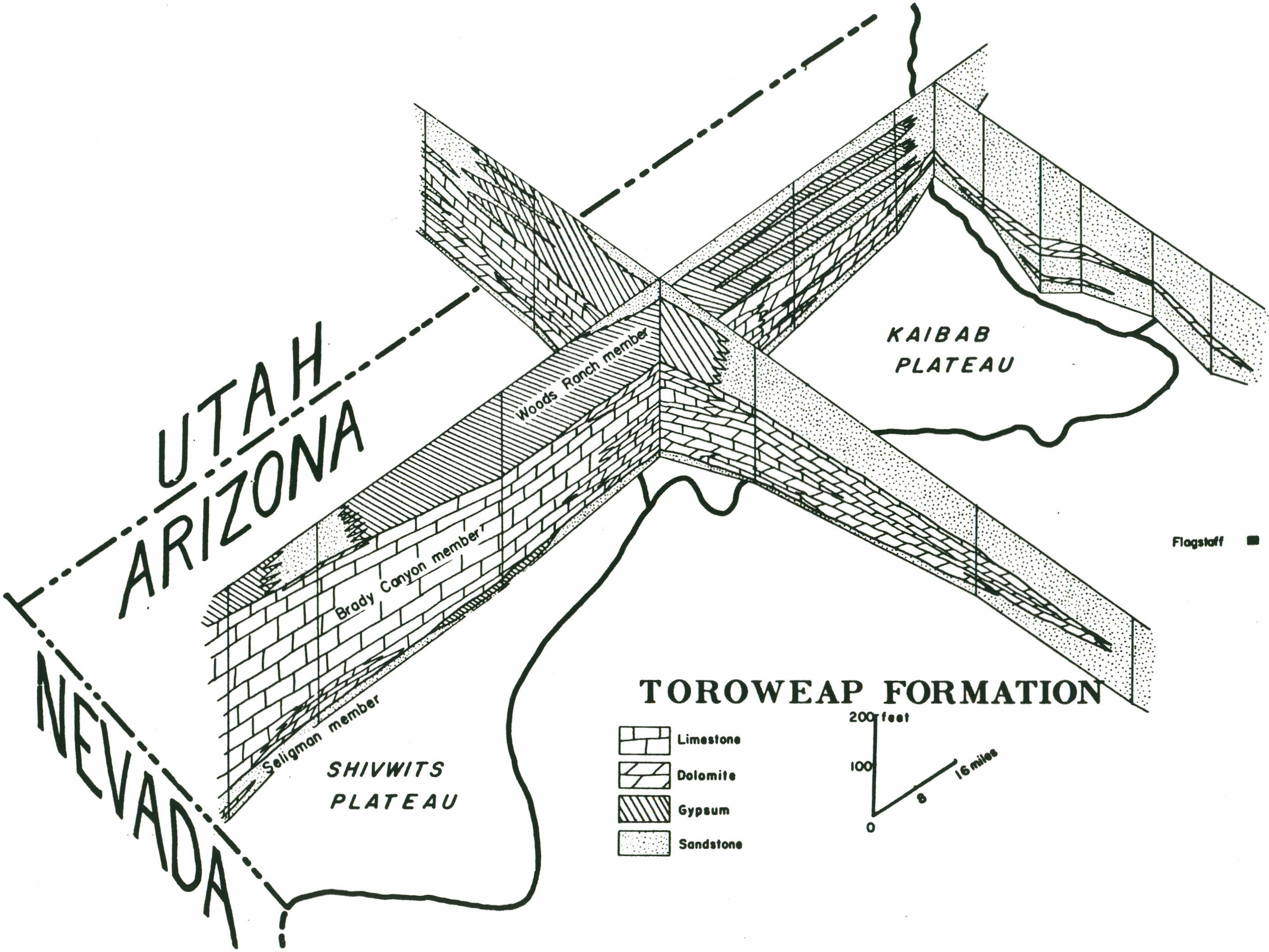


Figure 20. Panel diagram, Toroweap Formation, northern Arizona (from Rawson and Turner, 1974).

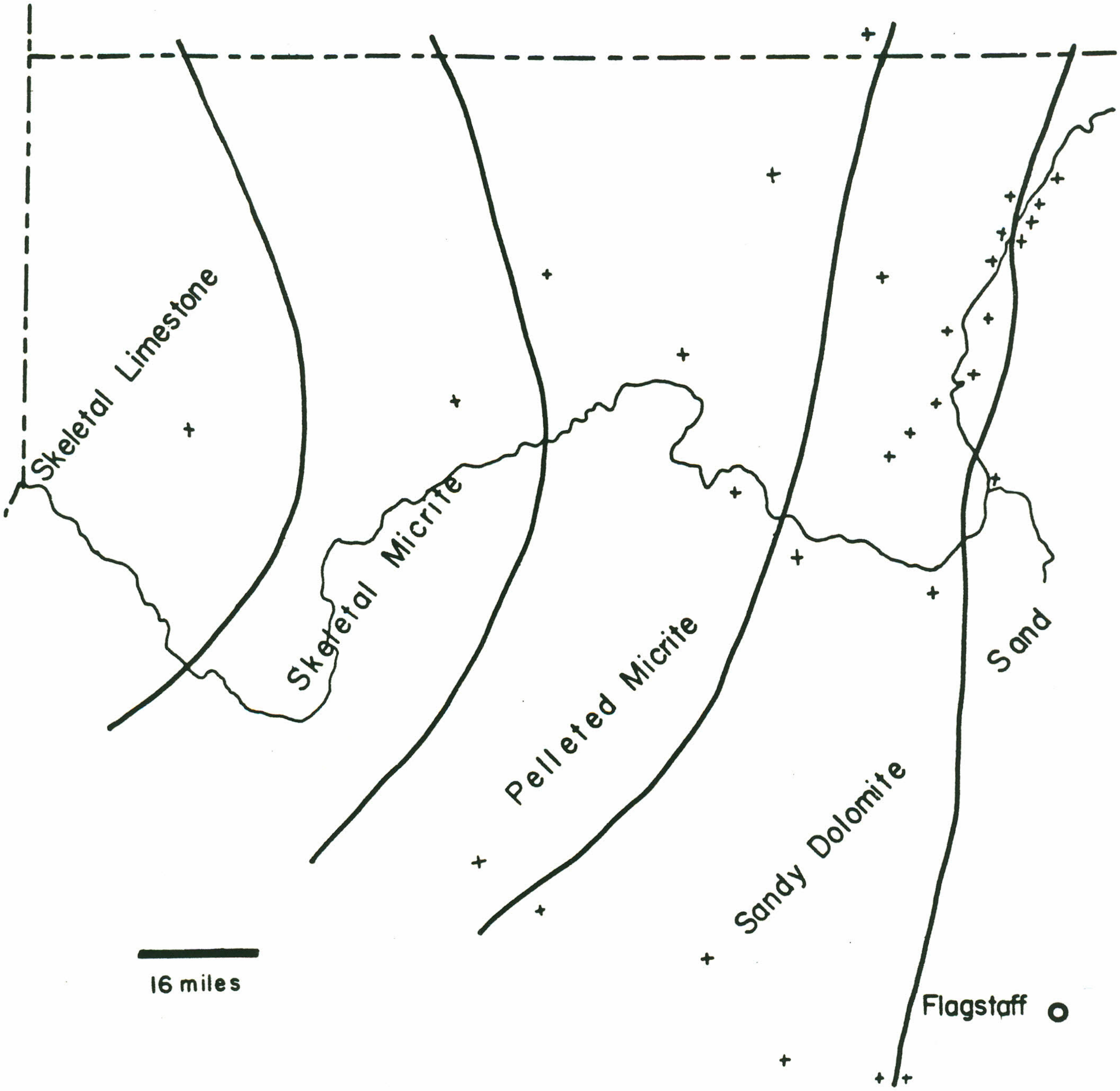


Figure 21. Facies map, Brady Canyon Member, northwestern Arizona (from Rawson and Turner, 1974).

McKee's Beta Member of the Kaibab Formation corresponds to the basal Fossil Mountain Member of Sorauf (1962). At its type locality in Grand Canyon National Park, this unit consists of 211 feet of gray to yellow cherty and noncherty limestone with intercalated chert beds (Bissell, 1969). Data relating to details of this unit have been provided by McKee (1938), Fisher (1961), and Sorauf (1962). A facies map of the Fossil Mountain Member is shown in figure 22. The distinct uppermost member of the Kaibab Formation is called the Harrisburg Member. At Hells Hole, Grand Canyon, this member is 300 feet thick and consists primarily of gypsum, tan limestone, and dolostone. These sediments accumulated during a regressive phase of the Kaibab sea in late Permian time. The lithofacies of this unit, interpreted by Bissell (1969), is shown in figure 23.

In the Virgin Mountain region, Moore (1972) reports a total thickness of 750 feet for the undifferentiated Toroweap-Kaibab section. Outcrops in these mountains were described as consisting of "two thick-bedded to massive, cliff-forming, dark-gray limestone units separated from each other and from overlying and underlying formations by soft, slope-forming gypsiferous, and in some places, marly, red-bed units."

The thickness of the Pennsylvanian-Permian rocks exceed that of the combined lower Paleozoic rocks. Figure 24 illustrates the general isopachs of the upper Paleozoic strata across the Strip Country. The thickness of these strata decrease on the Kaibab Positive area where the section is about 2,000 feet thick. Northwestward toward the geosyncline, these rocks are found in excess of 4,000 feet.

Mesozoic

Triassic rocks form extensive outcrops along the northern border of the area and minor local outliers elsewhere. Scattered remnants of early Triassic rocks have been identified at many localities in the southern and central portions of the area, indicating denudation of a preexisting extensive cover. Jurassic rocks are essentially limited to beds of the Navajo Sandstone (Triassic-Jurassic age?). The sparce distribution of Upper Triassic, Jurassic, and younger strata in northwestern Arizona limits their petroleum potential.

The spatial distribution of Triassic outcrops, as well as isopachs of the Lower and Middle Triassic Moenkopi Formation, is shown in figure 25. Detailed restoration of isopachs has been encumbered by lack of measured sections and absence of complete sections.

The Moenkopi Formation is the oldest Mesozoic unit in the Strip Country. It unconformably overlies the Kaibab Formation. Although six members of the Moenkopi Formation have been locally recognized in the area common to southeastern Nevada, southwestern Utah, and northwestern Arizona, the spatial distribution of these members has not been clearly delineated. The six members recognized in northwestern Arizona and adjacent areas of Utah are, in ascending order, Timpoweap, Lower Red, Virgin Limestone, Middle Red, Shnabkaib, and Upper Red. The Timpoweap Member generally consists of red siltstone, gray limestone, and chert pebble conglomerate. The Virgin Limestone Member consists of limestone and siltstone. The Shnabkaib consists of red siltstone, gypsum, and limestone. The Lower,

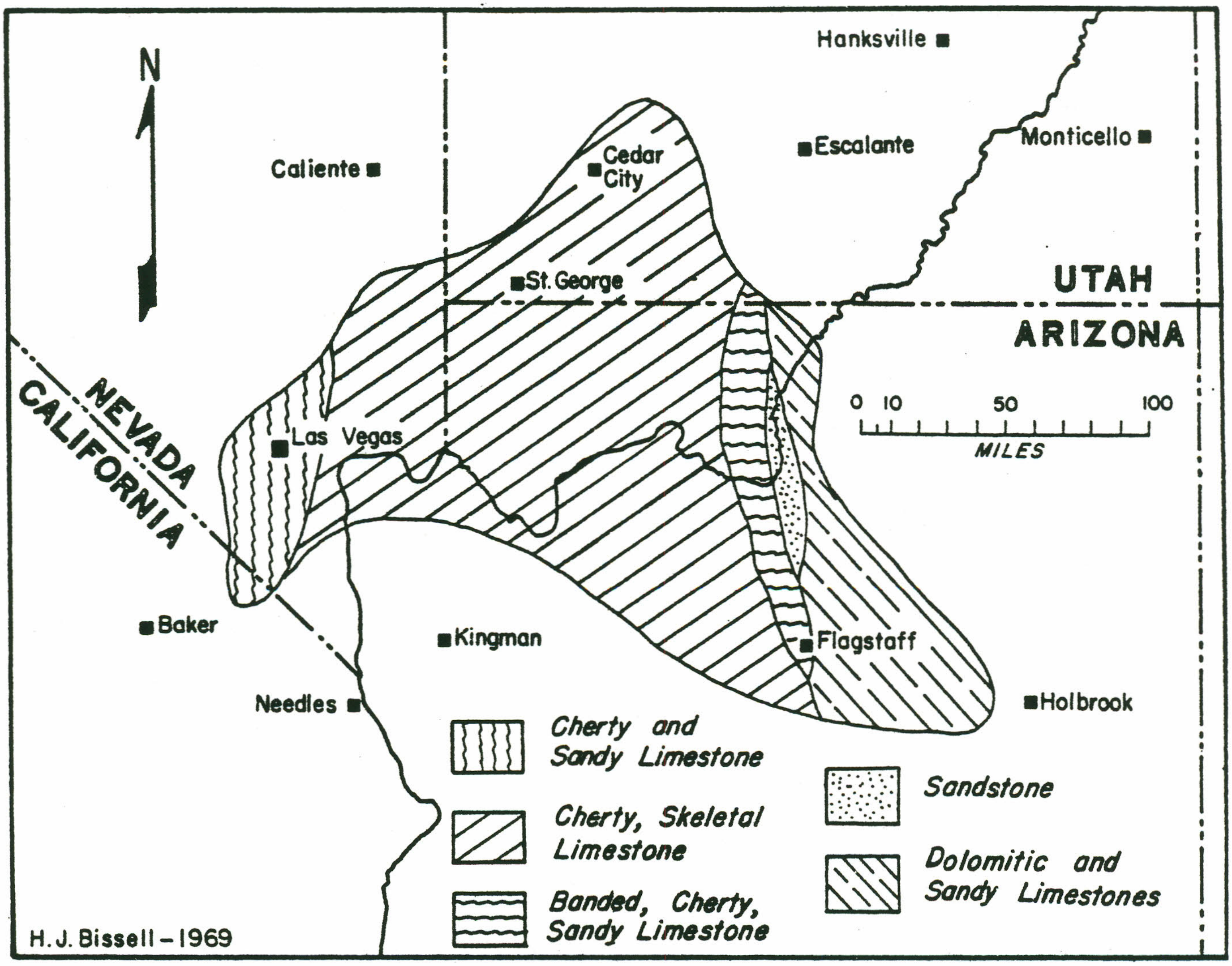


Figure 22. Facies map of the Fossil Mountain Member of the Kaibab Formation from the eastern Grand Canyon region of Arizona to the Lovell Wash area in the Spring Mountains, west of Las Vegas, Nevada (from Bissell, 1969).

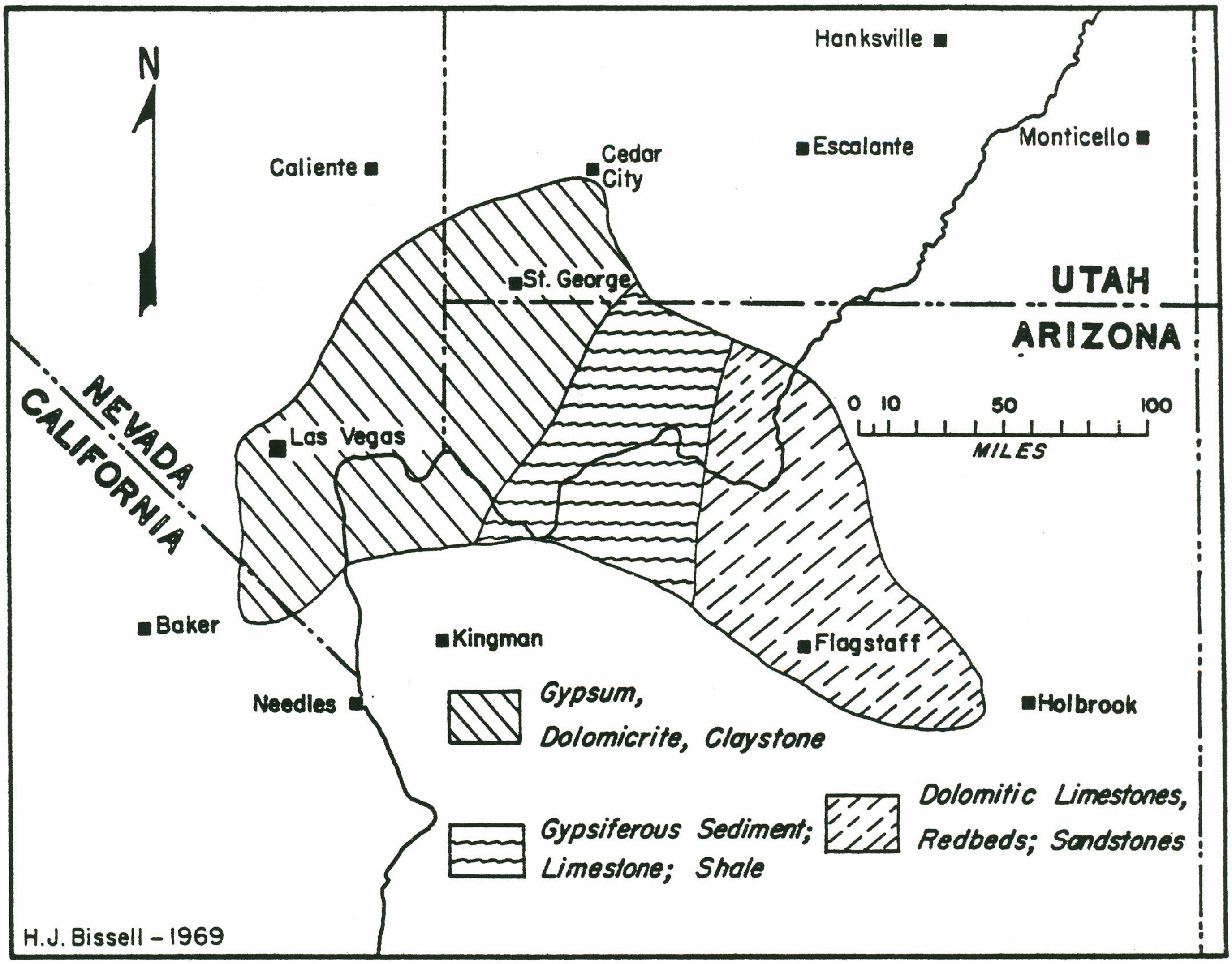
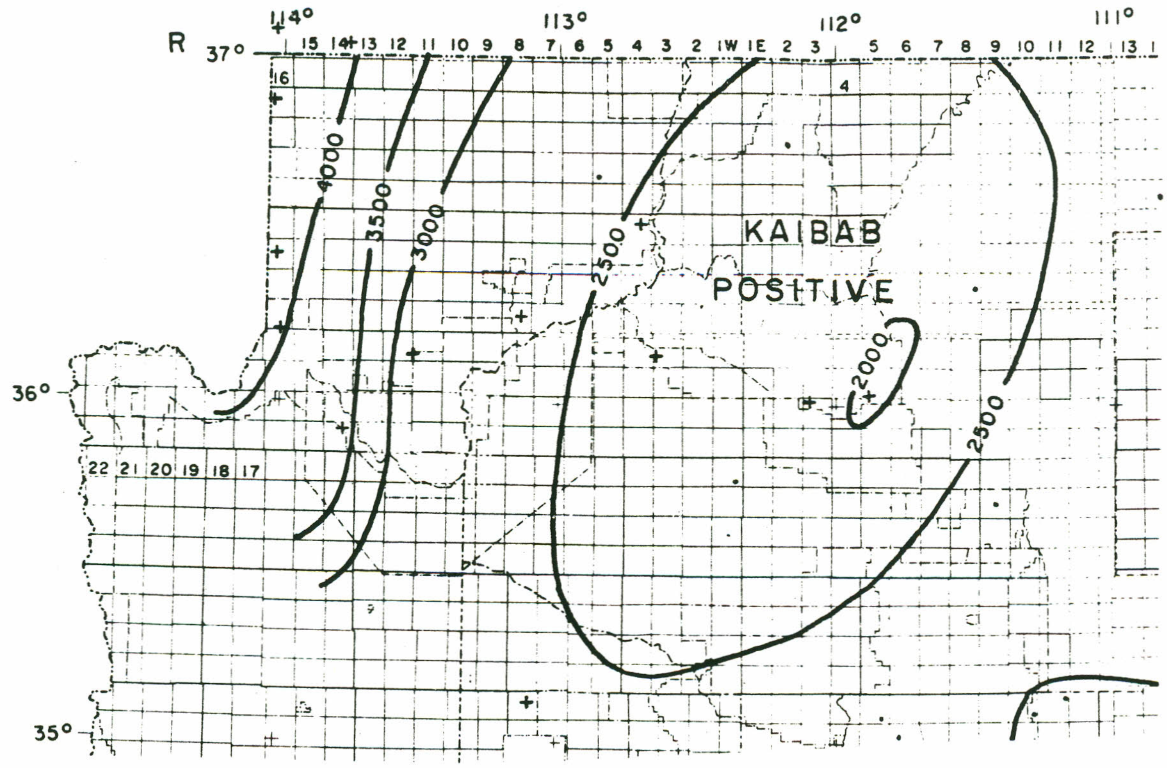
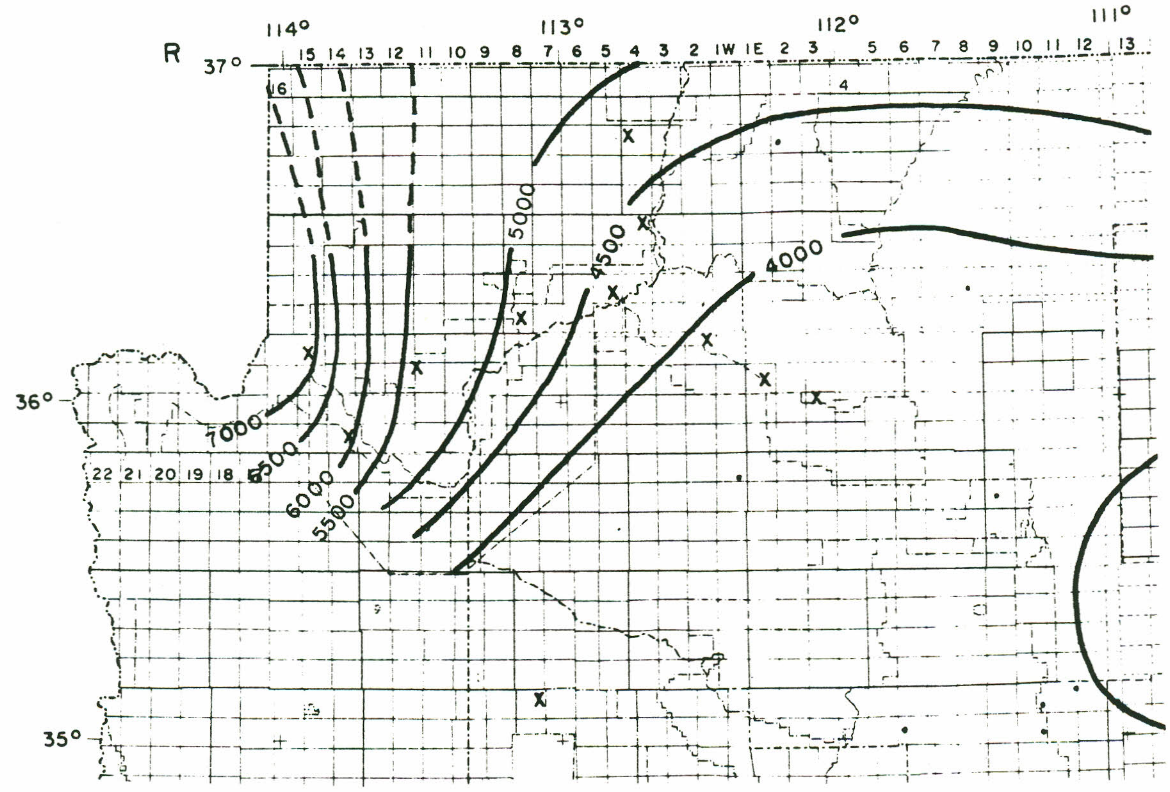


Figure 23. Facies map of the Harrisburg Member of the Kaibab Formation from east of the Grand Canyon region of Arizona to the Blue Diamond Hill-Bird Spring Range area west of Las Vegas, Nevada (from Bissell, 1969).



PENNSYLVANIAN-PERMIAN



TOTAL PALEOZOICS

Figure 24. Isopachs (from Peirce and others, 1970).

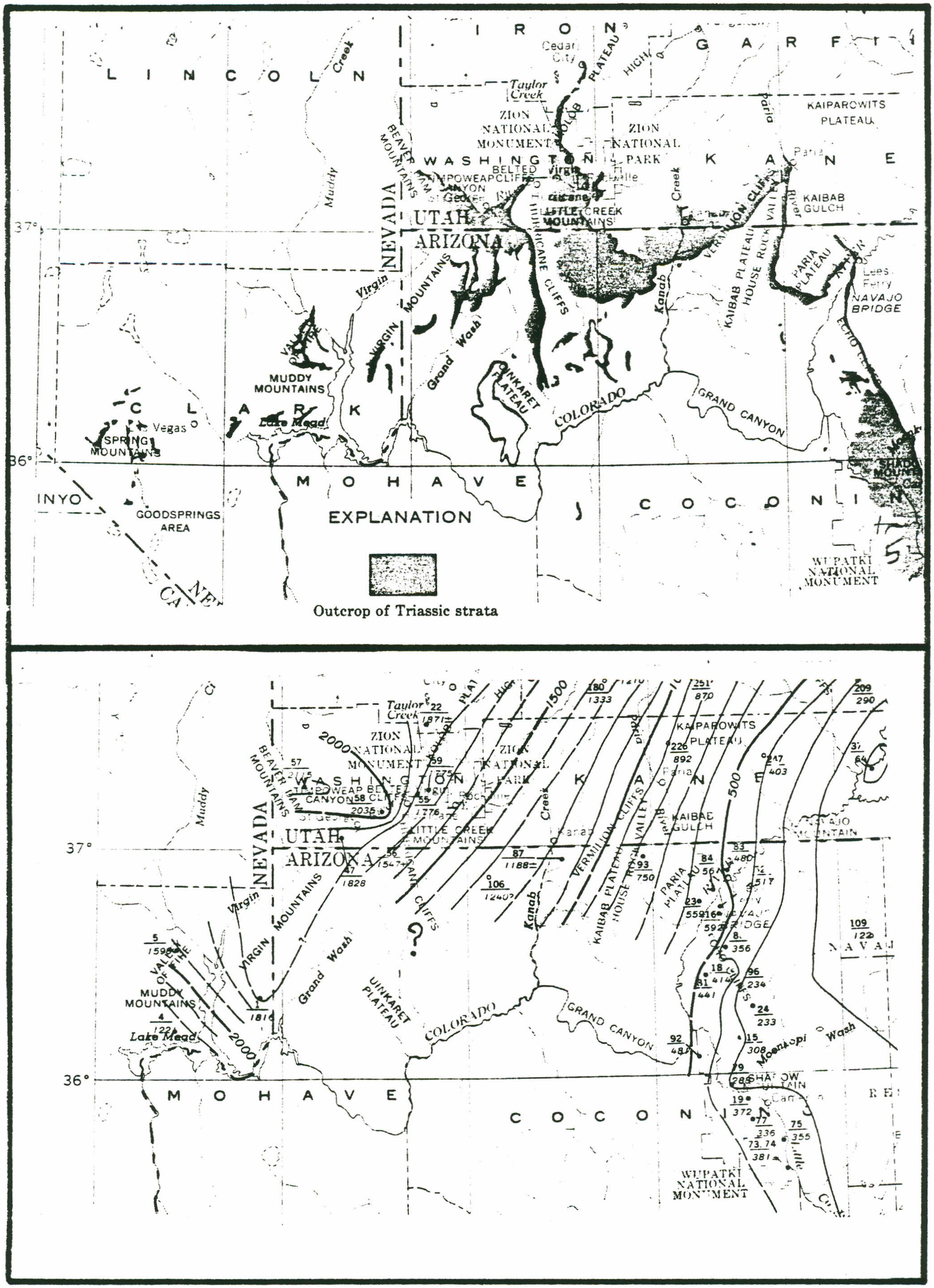


Figure 25. Isopachs of Moenkopi Formation (from Stewart and others, 1972).

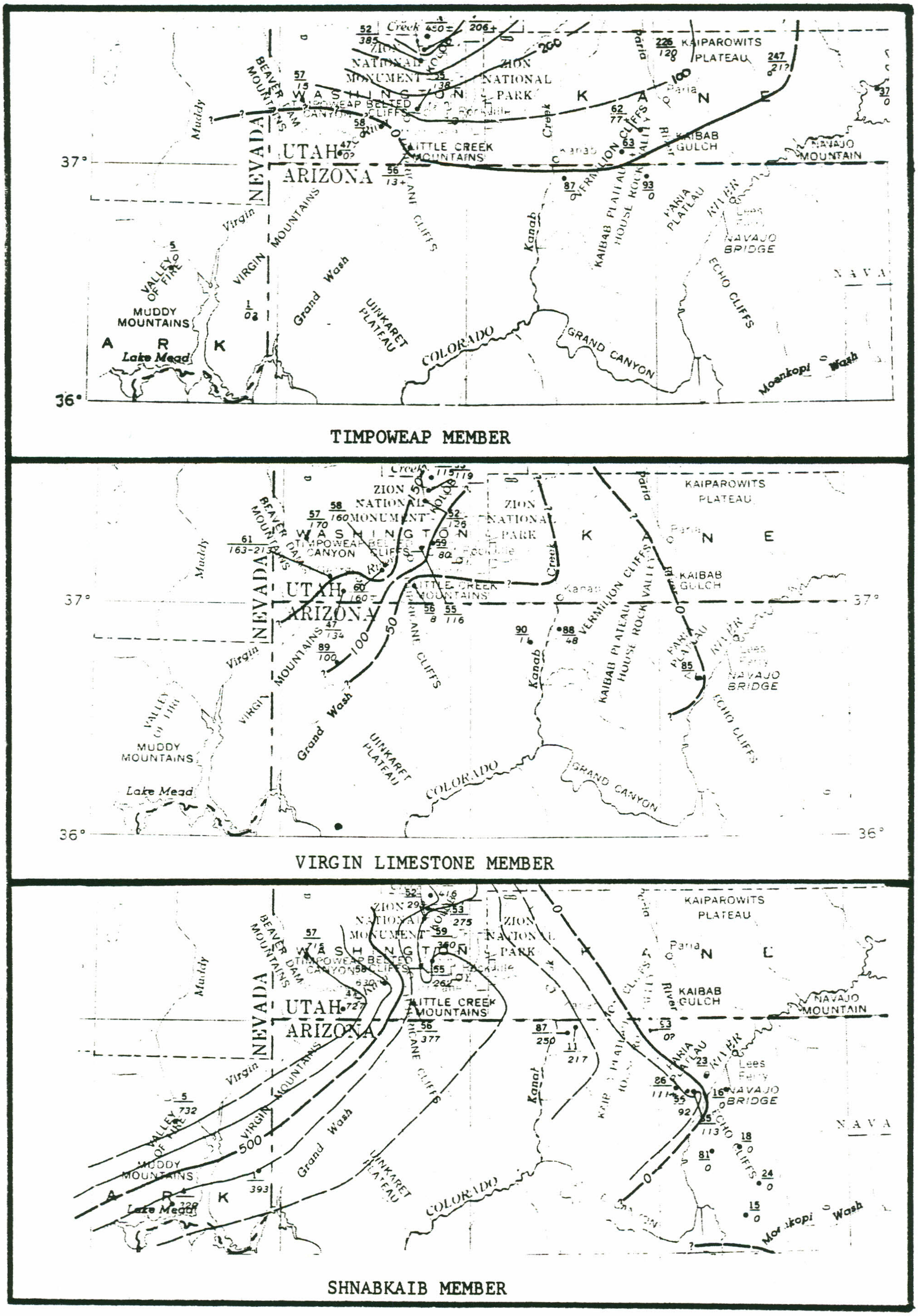


Figure 26. Isopachs of Moenkopi Formation (from Stewart and others, 1972).

Middle, and Upper Red Members consist predominantly of red siltstone (Stewart and others, 1972). It appears from a few widely separated reported sections near the Arizona-Utah border that the basal Timpoweap Member is restricted to an area near the extreme northern border of Arizona. Generalized isopachs of the Timpoweap, Virgin Limestone, and Shnabkaib Members are indicated in figure 26.

HISTORICAL PETROLEUM EXPLORATION

General

Nineteen wells have been drilled for oil or gas in the Strip Country (table 1). The Oil and Gas Conservation Commission records indicate that the earliest known attempt to find oil in this region was conducted in 1909 by drilling a well 900 feet deep. Of the 19 wells only a few were located on prospects defined by either geological or geophysical information. Some of the borings were spudded on known surface structures, others on weak geological information; but most were strictly "promotional" ventures (Conley, 1974). The locations of these wells are shown in figure 27.

Historical exploration drilling east of the Toroweap Fault is limited to one well, spudded in the Kaibab Formation near the northern crest of the Kaibab Uplift. One well penetrated the Shivwits Plateau, three wells were located in the Basin and Range province, and the remaining 14 wells have been concentrated in the northern Uinkaret Plateau. Of the 19 wells, 13 have reported oil shows (table 2), one had no show, and the incomplete records of five early wells lack pertinent data.

Shows of oil have been reported in all formations ranging from the Triassic Moenkopi to the Cambrian Muav with the exception of the Permian Supai and Cambrian Bright Angel and Tapeats. These data are illustrated in figure 28, together with reported shows in northeastern Arizona.

Antelope Springs Structures, Arizona

The Antelope Springs structures (fig. 29) are located in the Uinkaret Plateau about 40 miles west of Fredonia, Arizona. The structures form a series of plunging anticlines (20 miles in length) which are generally parallel to and about 6 to 10 miles east of the Hurricane Fault. The stratigraphic section encountered in wells which penetrated these anticlines is typical of the intercalated carbonate-clastic beds which characterize the transgressive-regressive phases of the Cordilleran shelf deposits.

The earliest known exploration activity on these structures was a well spudded on the north Antelope Springs Anticline in 1932 (Antelope Petroleum 1 Morris). Total depth of this well was 1,522 feet. However, no other information is available in the Commission files.

In 1956 the Falcon-Seaboard-Valen Antelope 1 was drilled to a depth of 3,753 feet. This well represents the deepest penetration of the structures and was abandoned in the Redwall Limestone due to lost circulation. At least eight distinct zones contained significant shows of live or dead oil. The most important show, located between 1,105 and 1,180 feet, exhibited good fluorescence which would readily cut with carbon tetrachloride (Swapp, 1956). Swapp interpreted this interval as a transition zone between the Coconino Sandstone and Toroweap Formations. In his report to the operator, Swapp suggested that additional testing be conducted in this interval and that further drilling be extended into the lower Paleozoic section.

Table 1. Wells drilled for oil and natural gas in northwestern Arizona

			WELL DATA				
O&GCC IDENTIFICATION NUMBER	LOCATION	OPERATOR, NUMBER, AND LEASE	ELEVATION (FEET)	ORIGINAL COMPLETION DATE	STATUS 11-30-79	TOTAL DEPTH (FEET)	STRATIGRAPHIC UNIT OR SYSTEM AT TOTAL DEPTH
COCONINO COUNTY							
275	39N- 2E-32 NE NE	Underwood 1-32 Jacob Lake Unit-Fed	7680 KB	5/64	D	3868	Cambrian Bright Angel
MOHAVE COUNTY							
43	38N- 5W-31 NW SE	Western Drlg-Valen O&G 1 Federal	5052 DF	5/58	D	4666	Cambrian Bright Angel
41	38N- 7W-17 SW SW	Roger A Fields 1 Federal	4976±KB	6/57	D	460	Permian Toroweap?
53	-17 SW SW	Roger A Fields 1-X Federal	4972±DF	4/58	D	1780	Permian
502	-29 NW NE	James J Harris 1 Federal	4985±GL	7/70	D	1115	Permian Hermit
42	39N- 6W-14 SW NW	Paul Poteet & Tony Lyons 1 Federal	5310±GL	8/57	D	2303	Permian Coconino
56	-35 NE SW	Tony Lyons 1 Federal	5260±GL	9/58	D	1820	Permian Toroweap
347	39N- 7W- 2 NE SE	Skelly Oil 1 Federal-A	5118 KB	5/66	D	4031	Mississippian Mooney Falls
114	39N-13W-35 SE SW	Tennessee Gas Transmission 1 Schreiber-Federal	5416 KB	5/60	D	4015	Mississippian
40	40N- 6W-12 NW SW	T W George 1 Federal	5250±GL	6/57	D	2202	Permian Kaibab
33	40N- 8W-28 SE SW	Falcon Seaboard Drlg & Valen Oil & Minerals 1 Antelope-Federal	4718±DF	8/56	D	3753	Mississippian
677	40N- 9W-18 NE SW	Pyramid Oil 2 Federal	4958 KB	11/77	D	4509	Devonian
8-19	41N- 6W-16 SE	Cane Bed 1 State	5030±GL	/31	D	542	
8-20	41N- 8W-18 NE NW	Antelope Petroleum 1 Morris-Fed	4515±GL	/32	D	1522	
676	41N- 9W-28 NW SE	Pyramid Oil 1 Federal	4743 KB	12/77	TA	4150	Mississippian
8-21	41N-15W-29 SW SE	Virgin Oil 4 State	1960±GL	/18	D	2600	
8-22	42N- 8W-31 SW SW	Arizona & Utah Consol Oil 1 State	4410±GL	/09	D	936	
8-23	42N-15W-32	Virgin Oil & Mines 1 State		/31	D	1405	
8-24	-32	Virgin Oil & Mines 6 State		/31	D	545	

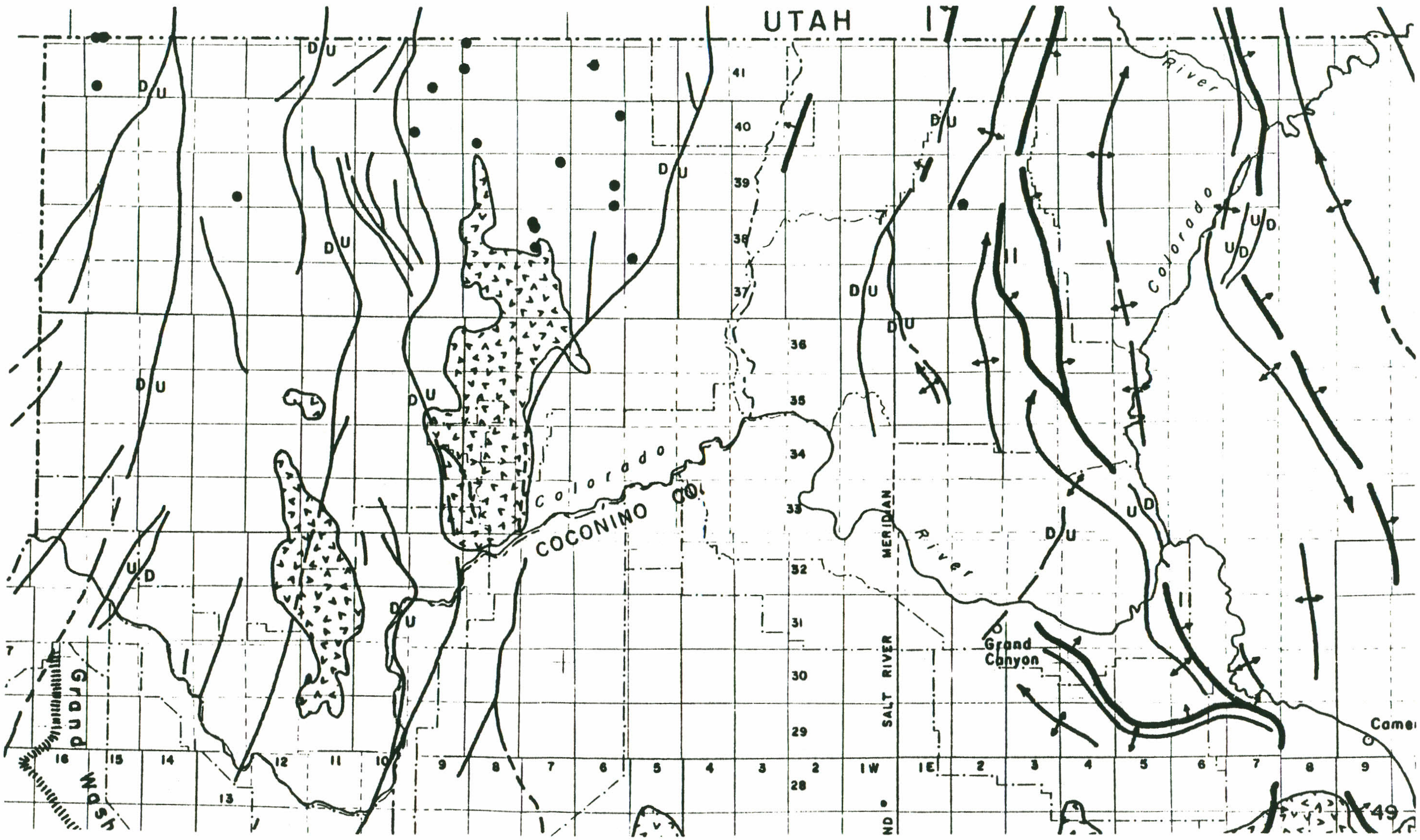


Figure 27. Generalized tectonic map showing location of test wells in northwestern Arizona (modified from Peirce and others, 1970). Black dot indicates test well.

Table 2. Records of wells in northwestern Arizona

O&GCC ID	DEPTH (Feet)	FORMATION	REPORTED SHOWS
COCONINO COUNTY			
275	Underwood 1-32 Jacob Lake-Federal, 39N-2E-32		
	2750-2770	Redwall	Dead oil stain
MOHAVE COUNTY			
43	Western Drlg-Valen Oil & Gas 1 Federal, 38N-5W-31		
	555	Toroweap	Questionable oil stain
	905- 945	Basal Toroweap	Spotted staining, fluoresces in solvent
	1275	Hermit	Dead oil stain
	3450-3460	Mississippian	Questionable oil stain
	4365	Mauv	Do.
	4440-4490	Do.	Dead oil stains
	4535	Do.	Questionable oil stain
	4585	Do.	Dead oil stain
41	Roger A. Fields 1 Federal, 38N-7W-17		
	150	Top of Timpoweap	
	150- 190	Timpoweap	Show of oil
	230- 240	Do.	Good yellow fluorescence and good yellow cut with ether or pentane
	260- 270	Do.	Black asphaltic soft shaly lime, kerosene odor, no cut, white fluorescence
	380- 400	Do.	Slight yellow cut
	445- 460		White fluorescence, faint to good yellow cut with ether
	460	Top of Kaibab	
53	Roger A. Fields 1-X Federal, 38N-7W-17		
	460	Top of Kaibab	
	600	Top of Toroweap	
	600- 612	Toroweap	Staining and white fluorescence, ether cut dark brown to yellow, slight odor of kerosene
	1111-1116	Basal Toroweap?	Oil and gas show, good odor, good yellow cut, solid orange fluorescence
	1116-1121	Top of Coconino	Same as above with odor of kerosene
	1136-1139	Coconino	Good white fluorescence, good odor, good yellow cut with ether
502	James J. Harris 1 Federal, 38N-7W-29		
	290- 300	Moenkopi red beds	Small fluorescence
	312	Top of Timpoweap	
	380- 385	Timpoweap	Fluorescent oil shows
	448	Top of Kaibab	
	585	Top of Toroweap	
	610- 750	Toroweap	Good fluorescent oil shows
	840- 868	Do.	Best oil show, good cuts and fluorescence
	1080	Top of Coconino	
	1107	Coconino	Small fluorescence

Note: Very little gas encountered, some smell in oil show zones, but no pressure.

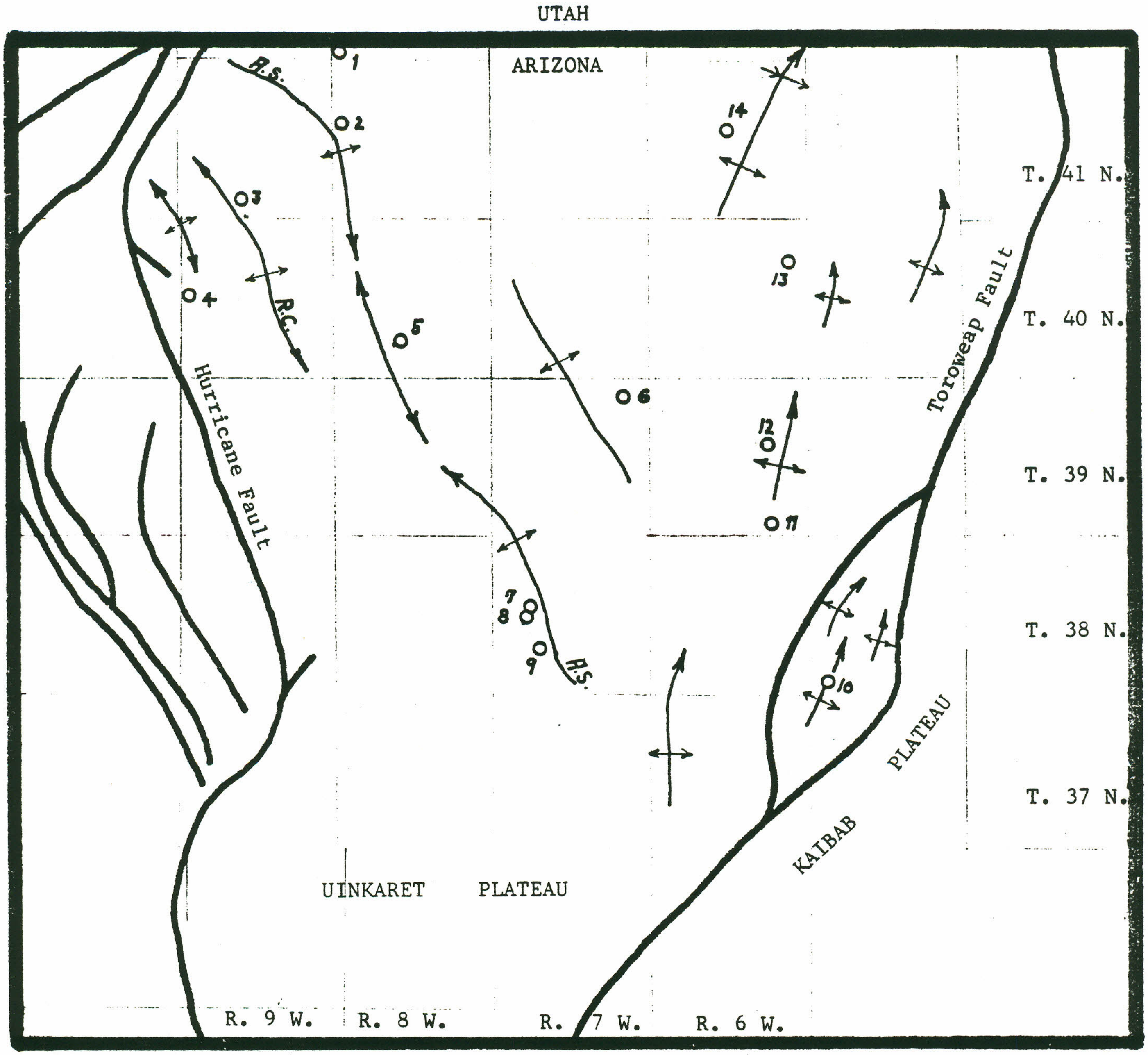
O&GCC ID	DEPTH (Feet)	FORMATION	REPORTED SHOWS
42	Paul Poteet & Tony Lyons 1 Federal, 39N-6W-14		
	420- 655	Moenkopi (Schnabkaib)	Approx. 100' in this interval contained some live oil fluorescence
	1990-2008	Toroweap	Little oil stain with some dead oil
	2222-2235	Do.	Light show of live oil
56	Tony Lyons 1 Federal, 39N-6W-35		
			From AMSTRAT log:
	1340-1400	Kaibab-Toroweap	Spotted staining, fluoresces in solvent
	1540-1580	Toroweap	Dead oil stain
	1730-1740	Do.	Questionable oil stains
347	Skelly Oil 1 Federal-A, 39N-7W-2		
	85	Moenkopi	Medium to poor oil stains
	135- 150	Do.	Medium and light oil stains
	190- 220	Do.	Do.
	855- 885	Timpoweap-Kaibab	Do.
	1170-1190	Kaibab	Light oil stains
	1530	Toroweap	Dead oil stains
	1560	Do.	Do.
	1570	Do.	Do.
	1610	Do.	Do.
	1640	Do.	Do.
	1660	Do.	Do.
	1720-1750	Do.	Do.
	3930	Redwall	Medium to poor oil stain
114	Tennessee Gas Transmission 1 Schreiber-Federal, 39N-13W-35		
	760- 790	Toroweap	Questionable dead oil stain
	940- 950	Do.	Slight dead oil stain
	2690-2700	Queantoweap	Slight dead oil stain, no fluorescence, no cut
	2730-2740	Do.	Slight black to brown dead oil stain, no fluorescence, no cut
	3140-3150	Callville	Heavy dead oil stain in few vugs
	3150-3160	Do.	Poor to fair dead oil stain, slight fluorescence, no cut
	3570-3650	Do.	Some black dead oil stain on fractures, no fluorescence or cut
	3700-3710	Do.	Do.
40	T. W. George 1 Federal, 40N-6W-12		
			No shows recorded
33	Falcon Seaboard Drlg. & Valen Oil & Minerals 1 Antelope-Federal, 40N-8W-28		
			From AMSTRAT log:
	1125-1155	Basal Toroweap	Medium, poor, or spotted oil stain
	1190-1210	Coconino	Do.
	1330-1350	Hermit	Dead oil
	1660-1680	Do.	Do.
	1690-1985	Do.	Do.
	1985-2020	Queantoweap	Do.
	2500-2520	Do.	Medium, poor, or spotted oil stain
	2550-2565	Do.	Do.
	2580-2600	Pakoon	Dead oil
	2610-2630	Do.	Light, questionable oil stain
	2690-2710	Do.	Do.
	3160-3180	Callville	Do.
	3330-3350	Redwall	Dead oil (Swapp)
	3360-3370	Do.	Live oil (Swapp)

O&GCC ID	DEPTH (Feet)	FORMATION	REPORTED SHOWS
677	Pyramid Oil 2 Federal, 40N-9W-18		
	3385-3390	Redwall	Minor gas show
	3540-3550	Do.	Tar-like dead oil stain
	4155-4165	Cambrian (Supra-Mauv)	Minor dead oil stain with 25 units hydrocarbon gas
8-19	Cane Bed 1 State, 41N-6W-16		
	246	Chinle?	Sand showing oil
	461	Chinle or Moenkopi	Gray shale and sand showing oil
8-20	Antelope Petroleum 1 Morris-Federal, 41N-8W-18		
			No data in files
676	Pyramid Oil 1 Federal, 41N-9W-28		
	1100	Coconino	Slight oil show
	2100	Queantoweap	Reported gas odor
	2322	Pakoon	Do.
	2400	Do.	Gas logger installed
	2405-2425	Do.	Gas on mud logger: 50 units
	2480-2495	Do.	Gas on mud logger: 25 units, minor shows & gilsonite
	2480-2510	Do.	Brownish-black oil stain, dull yellow fluorescence
8-21	Virgin Oil 4 State, 41N-15W-29		
			No data in files
8-22	Arizona & Utah Consolidated Oil 1 State, 42N-8W-31		
			No data in files
8-23	Virgin Oil & Mines 1 State, 42N-15W-32		
			No data in files
8-24	Virgin Oil & Mines 6 State, 42N-15W-32		
			No data in files

ERA Period	STRATIGRAPHIC UNIT	
	Northwest Arizona	Northeast Arizona
MESOZOIC Cretaceous		Dakota
Jurassic		
Triassic		Shinarump
	Moenkopi	Moenkopi
PALEOZOIC Permian	Kaibab Toroweap Coconino Hermit Queantoweap Pakoon	Supai
Pennsylvanian	Callville	Naco-Hermosa
Mississippian	Redwall	Redwall
Devonian	Temple Butte	Ouray Elbert McCracken Aneth Martin
Silurian		
Ordovician		
Cambrian	Muav	Tapeats
PRECAMBRIAN		

Note: "Reported show" has been considered to be any indication of naturally occurring hydrocarbons in the records of the Oil and Gas Conservation Commission or in published literature. The quality of shows noted varied from questionable light staining on drill-bit cuttings to measured quantities of oil or gas recorded on drill-stem tests or geophysical loggers.

Figure 28. Reported shows of oil and gas



Legend:

A.S. Antelope Springs Anticlines

R.C. Rock Creek Anticline

Numbers	O&GCC ID	Numbers	O&GCC ID	Numbers	O&GCC ID	Numbers	O&GCC ID
1	8-22	5	33	9	502	13	40
2	8-20	6	347	10	43	14	8-19
3	676	7	41	11	56		
4	677	8	53	12	42		

For well names and locations see Table 1

Figure 29. Generalized structure map of Uinkaret Plateau showing location of petroleum exploration wells.

Examination of the Commission records does not indicate any further tests were conducted. A report of the oil shows encountered in this well is shown in table 2.

In 1957 the Roger A. Fields 1 Federal and 1-X Federal were drilled to depths of 460 and 1,780 feet, respectively. These wells were located on the south Antelope Springs Anticline. Several shows of oil in the shallow well (1) were reported in the Timpoweap Limestone in the depth intervals shown in table 2. This well was abandoned in the Moenkopi Formation due to development of a crooked hole.

A deeper hole (1-X) was spudded close to the abandoned well and was terminated in the Hermit Shale. The report of testing for this well is fragmentary but apparently excellent oil shows were encountered in the basal Toroweap(?) and uppermost beds of the Coconino Sandstone at a depth of about 1,110 feet. The Commission records indicate the following tests were conducted:

> ...Well was bailed and plugged back to 1,139 feet, to top of Hermit Shale. Well was swabbed several days and approximately one barrel of 39.1 gravity oil per day was recovered. Well was fractured by Halliburton, and no increase of oil was noted. Well was then shot with 112 quarts of nitroglycerine, and no increase was noted. The Sun Oil Company shot across the well with seismograph instruments and shot 100 pounds of nitronon gelatin dynamite, and the well bailed no increase of oil over approximately one barrel per day.
>
> A pump unit was installed and left for a few months on the well in the hope that it would break in and the oil would increase. After many checks on this, no further increase was noted...
>
> Porosity was at a minimum throughout all the well, otherwise we would have made a good well at this location.

Additional shows reported in the 1-X Federal well are indicated in table 2.

The last well to probe the Antelope Springs structures was the Harris 1 Federal. This well was spudded in May 1969 about one mile south of the Roger Fields wells. Like previous tests of these anticlines, the Harris 1 was unable to obtain commercial production and also failed to explore the lower Paleozoic section. The well was abandoned at 1,110 feet in the Hermit Shale. Shows from this well are listed in table 2.

Rock Creek Structure, Arizona

The Rock Creek structure is located in the northwestern corner of the Uinkaret Plateau. The structure is a double plunging anticline about nine miles long and subparallel to the northwest-trending segment of the Hurricane Fault (fig. 29). The Pyramid Oil 1 Federal was spudded on the northern end of this anticline in October 1977. Currently, this well is temporarily abandoned due to loss of drill pipe in the hole.

The completion report of the well geologist (Lauth, 1978) states that the Pakoon Formation warrants further testing especially in light of the presence of high porosity zone (16 to 26%) associated with hydrocarbon shows. Table 2 lists the reported shows from this well.

Unnamed Structures, Arizona

Two wells were drilled in an anticlinal structure located in T. 39 N., R. 6 W. (fig. 29). No information was readily available regarding the characteristics of this structure. The Poteet-Lyons 1 Federal was started in June 1957 in the Moenkopi Formation and terminated at a depth of 2,303 feet in the Coconino Sandstone. Several oil shows were reported in this well. Cloyd Swapp (1957) summarized the completion report as follows:

> It is felt that this test well has furnished considerable favorable information regarding the oil and gas possibilities of this general region. It has shown that there are adequate source and reservoir beds present in the section. It will now require more work to determine the locations of the most favorable structural conditions to combine with these features which should greatly increase the possibilities of finding oil and gas in commercial quantities.

A second well, Tony Lyons 1 Federal, was drilled at the south end of this anticline in August 1958. It was spudded in the Moenkopi Formation and terminated in the Toroweap at a depth of 1,820 feet. Reported oil shows from both wells penetrating this anticline are listed in table 2.

An unnamed anticline, located in T. 38 N., R. 5 W., was explored by Western Drilling-Valen 1 Federal in July 1957. This well was spudded in the Timpoweap and bottomed in the Cambrian Bright Angel Shale at a depth of 4,650 feet. The only record obtained for this test is from an American Stratigraphic Co. log which reported shows as indicated in table 2.

The Skelly Oil 1 Federal-A was drilled on the flank of an unnamed anticline (Tps. 39 and 40 N., R. 7 W.). The well was spudded in April 1966 in the Moenkopi Formation and reached a total depth of 4,031 feet, bottoming in the Redwall Limestone. Shows from this well are limited to those recorded by an American Stratigraphic Co. log and are indicated in table 2.

In the adjacent region of southern Washington and Kane Counties, Utah, exploration drilling has been somewhat more active. Because documentation of these historical plays is relevant to the similar geologic setting of the Strip Country, a summary of these ventures is presented herein.

Virgin Oil Field, Utah (Bahr, 1963)

The closest productive area to northwestern Arizona is approximately 15 miles north of the Arizona border in Washington County, Utah (T. 41 S., R. 12 W.). The Virgin oil field is Utah's oldest producing area with the first well drilled in 1907. Initially, drilling was started due to the presence of several oil seeps and outcrops of oil sand. As of 1963, 140 wells have been drilled, of which 53 achieved significant production. The wells were drilled with cable tools, utilizing only a short string of surface casing, and completed as open holes. Productive depths are relatively shallow, 475 to 800 feet. Total field production is estimated at about 200,000 barrels. The initial average production rate of successful wells ranges from one to five barrels of oil per day (BOPD), characterized by good refining qualities. The productive capacity of the Diamond Oil 3 was increased to 35 BOPD by utilizing a thermite-like heat treatment to reduce paraffin wax accumulation on the borehole face of the producing section. Oil production is from the Rock Canyon (Timpoweap) basal member of the Moenkopi Formation. Bahr states that the Virgin field exhibits no structural closure and the petroleum accumulation is stratigraphic in nature. Production is obtained from discontinuous porous limestone intervals within the central platform facies which is characterized by algal, algal bioclastic, pelletal, and oolitic limestone, including small bioherms and dark, finely laminated, fetid black shale. According to Bahr:

> The lithologic similarity of the Rock Canyon "Central" facies to oil producing facies of similar age in other areas suggests a similar reason for the accumulation of oil in the Virgin field. The areal extent and total thickness of the Rock Canyon facies is less than that of similar facies in other oil producing areas. More importantly, individual reservoir-type carbonate units are relatively thin and scattered. However, continued exploration may reveal areas of thicker reservoir development which could contain accumulations of oil more sizeable than the Virgin oil field.

Anderson Junction Field, Utah (Peterson, 1974)

The Anderson Junction oil field (T. 40 S., R. 13 W.) is located in the transition area between the Basin and Range and Colorado Plateau provinces. The field produces from the Callville Limestone within a faulted east flank of the Kanarra asymmetric anticline. It has not been determined whether the oil accumulation is trapped by an anticlinal closure or a fault wedge.

The initial well (Pease 1 Govt.) was drilled in February 1968 and recovered a small amount of oil with a high water ratio. This well was subsequently shut in. A second well (Buttes 36-C1 State) was spudded in January 1969 and was drilled to a total depth of 4,124 feet. Oil from this well is obtained from an open hole interval between 3,855 and 3,992 feet and accounts for nearly all of the field's limited cumulative production. The cumulative production through 1977 reported by the Utah Geological and Mineral Survey is 1,690 barrels.

Upper Valley Oil Field, Utah (Campbell, 1969)

The Upper Valley field is located in the Kaiparowits Basin, Utah, approximately 50 miles northwest of Page, Arizona (fig. 30). Locally the plateau encompassing the field is dissected by many canyons tributory to the Colorado River. The Upper Valley Anticline was initially drilled to 8,857 feet in 1947 by the California Co. Of 22 formation tests in Permian rocks, seven contained oil shows with the completed well producing 60,000 barrels of fluid containing about 20 percent low gravity oil before abandonment in 1949. A second test near the axis of the structure was drilled

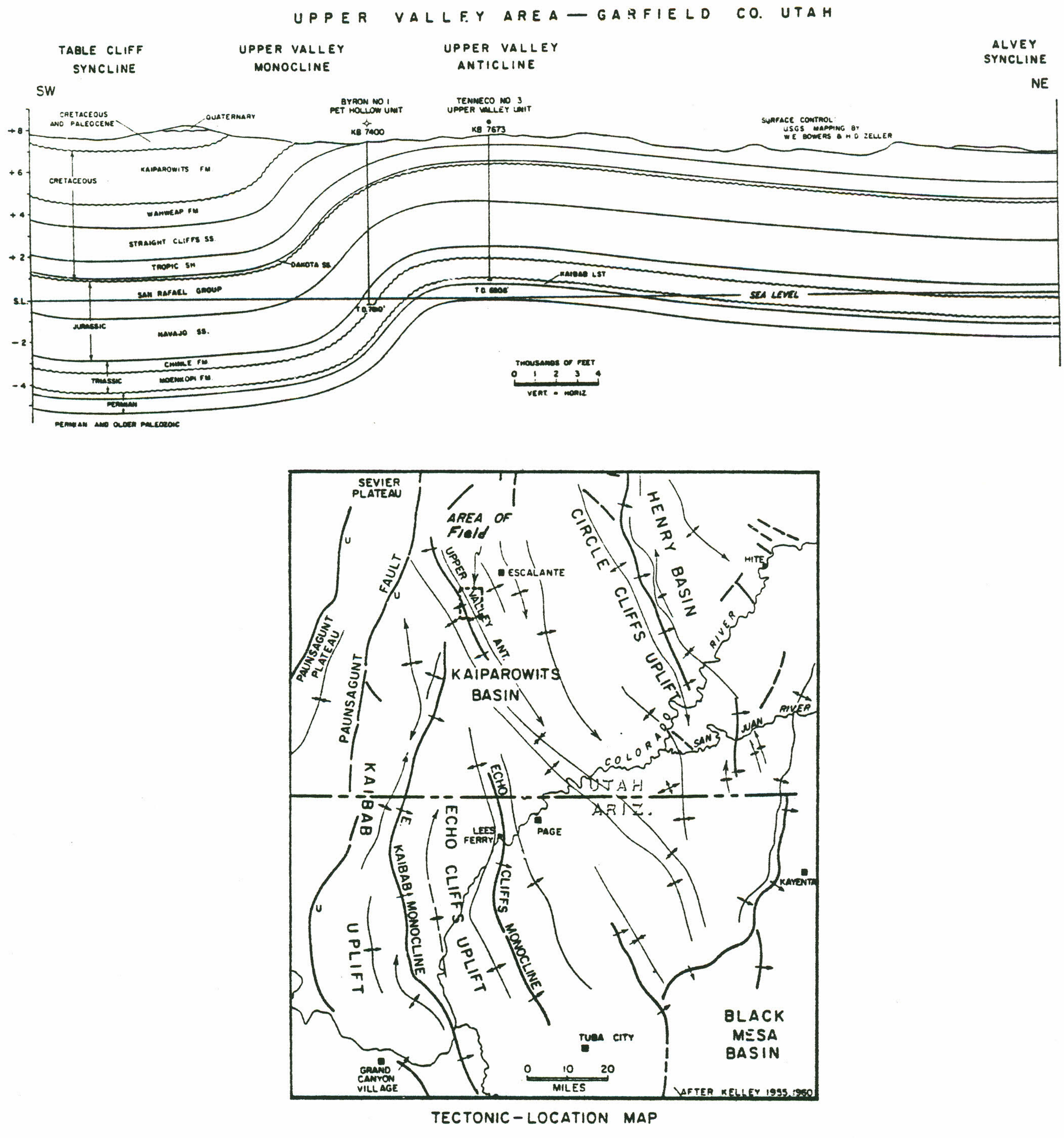


Figure 30. Upper Valley oil field, Garfield County, Utah (from Campbell, 1969).

to 7,114 feet, encountering oil staining and recovering gas cut mud from the Kaibab Formation. In 1962 Tenneco Oil Co. drilled a third well without success. However, the Tenneco 2 well eventually recovered about 60 feet of oil saturated core from the Timpoweap and Kaibab. This well was completed at an initial production of 300 BOPD without water. At present, the Upper Valley field is still active. The Utah Geological and Mineral Survey reports an all-time accumulation of 16,897,000 barrels with 932,400 barrels produced in 1977 from 25 wells.

The Upper Valley Anticline is a prominent northwest-trending structure among similar structures which extend into the Strip Country, east of the Sevier-Toroweap Fault (fig. 20). The anticline is a relatively narrow structure with a sinuous axis which can be traced for about 50 miles. The flexure originated as a Laramide event which corresponds to the age of the major uplifts of the Circle and Echo Cliffs that flank the anticline. In the area of the field, the structure is strongly asymmetric (fig. 30) with 5,000 feet of structural relief on the southwest flank and about 2,000 feet on the northeast flank.

Production from the Upper Valley oil field is obtained from strata which is adjacent to the Permian-Triassic unconformity. The limestone of both formations is dolomitized, with the productive intervals characterized by crystalline texture and fine vugs. Permeability is locally enhanced by the existence of fractures. Principal production is obtained from two persistent porous zones below the unconformity within the Beta Member of the Kaibab Formation. The major productive zone varies in thickness from about 30 to 65 feet.

The pool's oil-water contact appears to be tilted to the southwest due to hydrodynamic drive which may originate from water infiltration into Permian outcrops located northeast of the Circle Cliffs Uplift, coupled with the southwesterly regional dip of the area. In addition, the reservoir is characterized by subnormal pressure which may have developed as a result of depressed piezometric surfaces near deep canyons.

Kanab Creek Unit Area, Utah (Tapp, 1963)

The Kanab Creek Unit area is located on the Sevier Fault in Utah, approximately 10 miles north of the Strip Country. The geologic cross section and structure contours shown in figures 31 and 32 summarize the subsurface structure and lithologies encountered at the Kanab Creek Unit. Table 3 lists the significant oil shows encountered in this unit.

The McDermott 1 State was drilled in 1959 and penetrated the entire Paleozoic section. Significantly, it encountered over 200 feet of good oil shows but considerable testing indicated that this well probably lacked only the porosity and permeability necessary in the critical areas to make a commercial producer (Swapp, 1961).

Tapp concluded that the most promising reservoir objectives for future drilling include: 1) Timpoweap Member of Moenkopi, 2) Kaibab Formation, and 3) middle carbonate member of Toroweap Formation. In addition he states that the lower Paleozoic sediments may eventually prove to be productive especially in light of sparse but significant shows from isolated tests in Cambrian rocks.

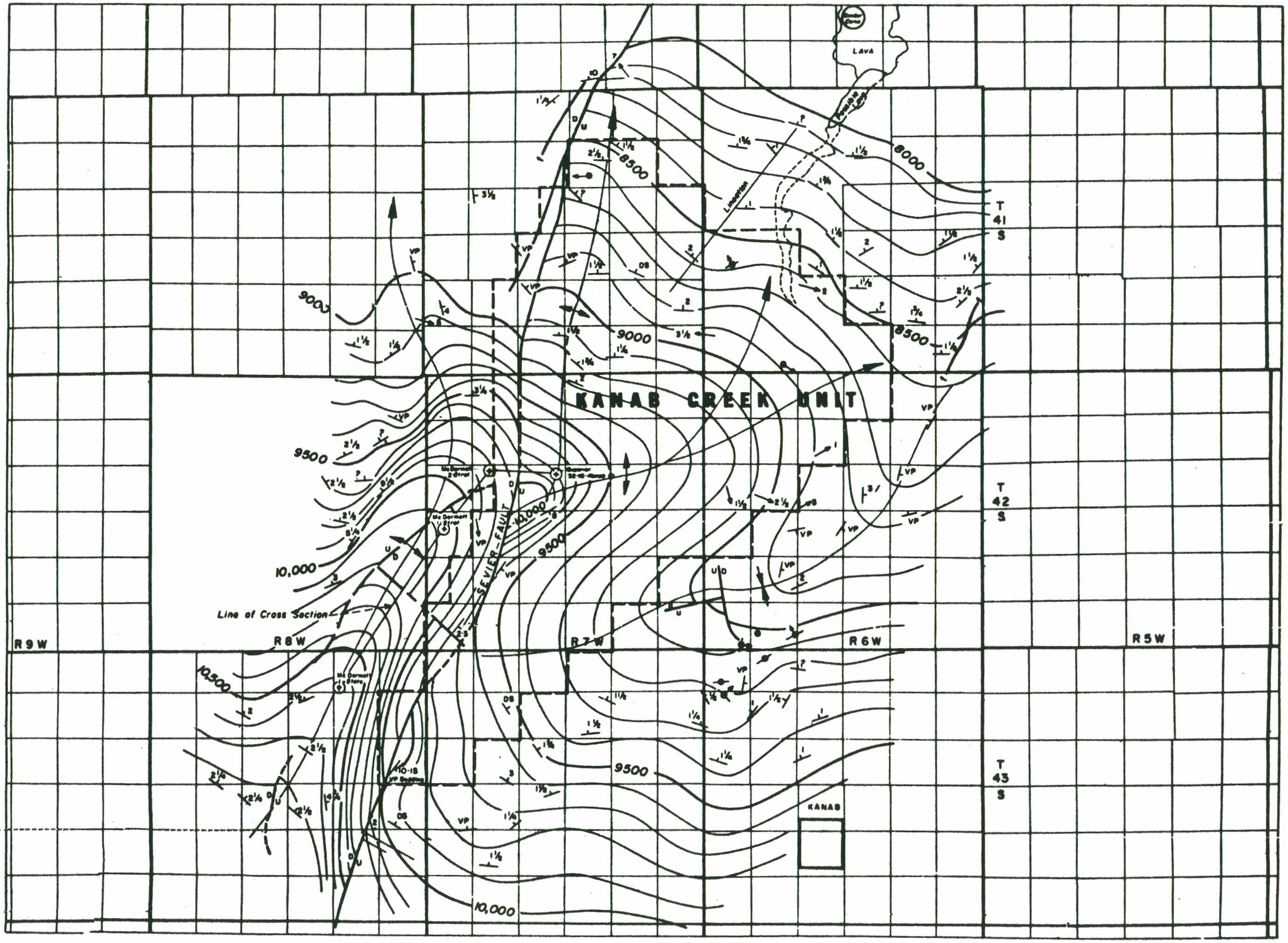
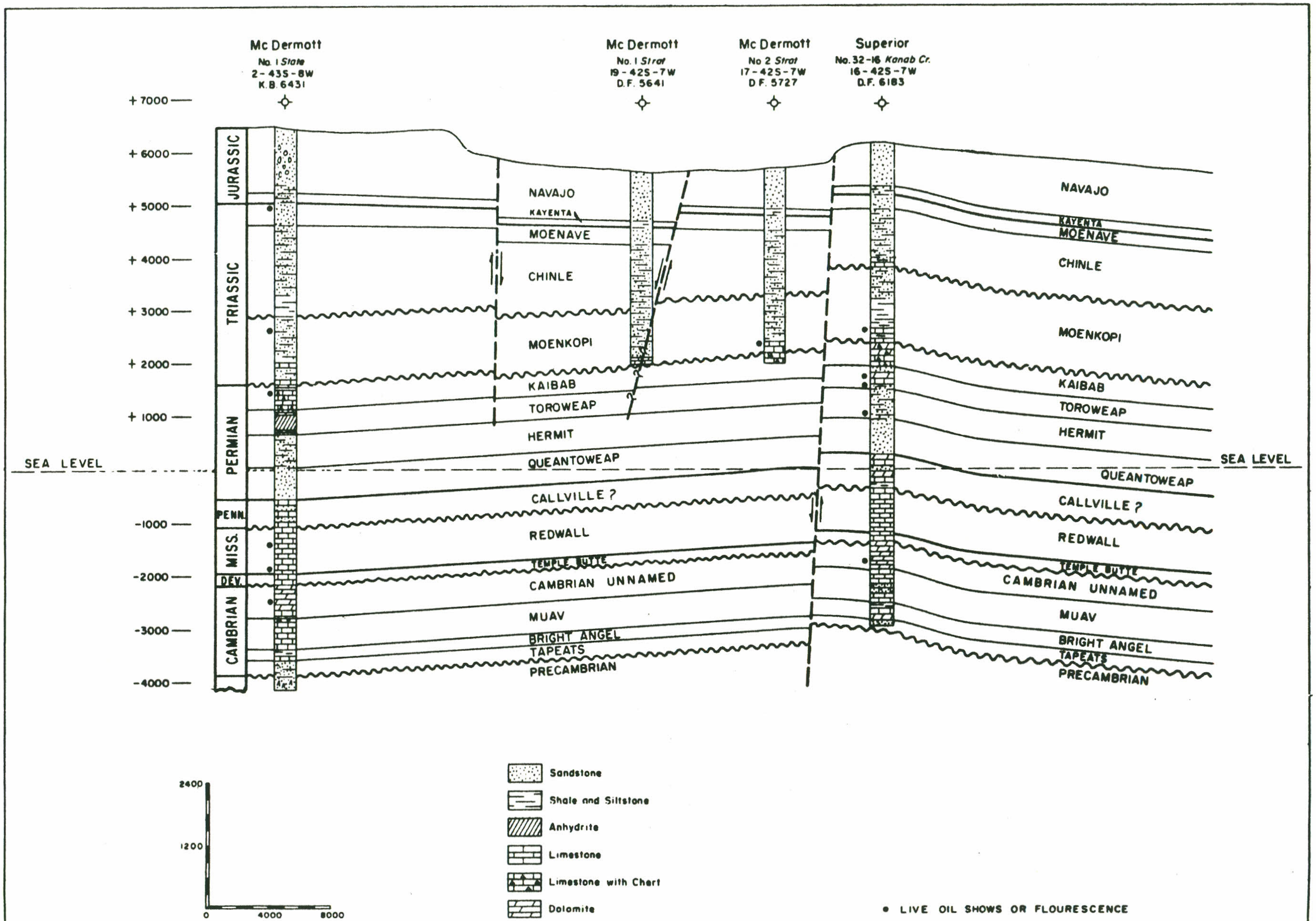


Figure 31. Form-line photogeologic dip contour map of Kanab Creek Unit area, Kane County, Utah (from Tapp, 1963).



(See figure 31 for location of cross section)

Figure 32. Geologic cross section, Kanab Creek Unit (from Tapp, 1963).

Table 3. Significant shows, Utah (from Tapp, 1963)

DEPTH (Feet)	FORMATION	REPORTED SHOWS
Superior Oil Kanab Creek, 42S-7W-16 C SW NE		
3755-3780	Timpoweap Member	Spotty saturation with slight odor
4236-4239	Toroweap	Slight yellow fluorescence
4435-4450	Do.	Do.
4593-4623	Do.	Pale yellow fluorescence
5258-5266	Hermit	Trace live oil stains with fluorescence
8040-8045	Cambrian unnamed	Slight yellow fluorescence
McDermott 2 Strat, 42S-7W-17 C NE NW		
3581-3598	Timpoweap Member	Spotted dark oil stain
McDermott 1 State, 43S-8W-2 C SW SW		
2650-2715	Moenave	Dark brown oil stain with fluorescence
3842-3872	Moenkopi	Spotted light oil stain
5120-5308	Kaibab	Questionable oil stain
7820-7830	Redwall	Slight oil stain with good fluorescence
8340-8345	Do.	Live oil stain
8900-9057	Cambrian unnamed	Spotted stain with slight fluorescence

Johns Valley and Muley Creek Anticlines, Utah (Alexander and Clark, 1954)

The Johns Valley and Muley Creek Anticlines are typical Laramide asymmetric folds controlled by basement block faulting. The locations of these anticlines are shown in figures 33 and 34. The Johns Valley Anticline trends northwest, is approximately eight miles long, 3.5 miles wide, and contains about 900 feet of closure. The crest of the anticline is broad with the east flank dipping about 15 to 20 degrees. The west flank dips about 10 to 15 degrees. The first exploration well was spudded in 1948 on the crest of the structure. After penetrating 146 feet of Redwall Limestone, the well was abandoned at a total depth of 10,335 feet.

Shows of irregular small oil stains were logged from a dolomitic limestone in the basal Moenkopi Formation but were not considered significant. Four drill-stem tests, as well as tests through perforated casing, were conducted in the Timpoweap Member as a result of shows indicating oil in cavities, a zone of pin-point porosity and oil staining in tight fractures. The drill-stem tests recovered fluid cut ten percent oil at an average rate of 15 barrels per hour for 15 hours. Drill-stem tests were also made in the Kaibab Formation, recovering only a few specks of oil within the formation water. In addition, tests in the Redwall Limestone produced only fresh water. Other shows in the Coconino, Hermosa, and Molas apparently did not warrant further testing.

A second well was drilled in order to further evaluate the Timpoweap Member of the Moenkopi Formation. This well, spudded in 1952, recovered cores with good shows of black viscous oil contained in vugs and fractures. However, subsequent tests contained only water and minor quantities of oil.

The Muley Creek Anticline is a symmetrical fold about eight miles long and three miles wide with a minimum of 300 feet of surface closure. Both limbs dip about four degrees. The California Co. drilled one well on the crest of this structure in 1951. Drilling was terminated in Cambrian rocks at a depth of 8,362 feet. Although the Timpoweap Member was an objective, carbonate strata were not encountered in this section of the Timpoweap and shows of oil or gas were not observed. Scattered oil-stained cuttings were obtained from the White Rim Sandstone Member of the Cutler Formation and subsequent sidewall cores indicated fair to good saturation of 33° gravity black oil. Further core tests in the White Rim found locally high oil saturation, therefore encouraging two drill-stem tests to evaluate potential oil production. However, the results of these tests recovered water with no trace of oil or gas. Drill-stem tests in the Hermosa, Redwall, and Devonian rocks failed to recover any trace of oil or gas.

Pintura Anticline, Utah (Cary, 1963)

The crest of the Pintura Anticline is located three miles west of the Hurricane Fault in Washington County, Utah (fig. 35). The anticline lies in the transition zone between the Basin and Range and Colorado Plateau provinces. The structure is nearly symmetrical, trending N. 20° E. with 2,000 feet of closure mapped on top of the Navajo. The south plunge exhibits numerous high angle faults of minor displacement, including a graben of 1,500 feet maximum stratigraphic throw. The Pintura Anticline was penetrated by the Sun Oil 1 in 1951 to a depth of 5,496 feet in the Coconino Sandstone. This well was abandoned without encountering significant shows.

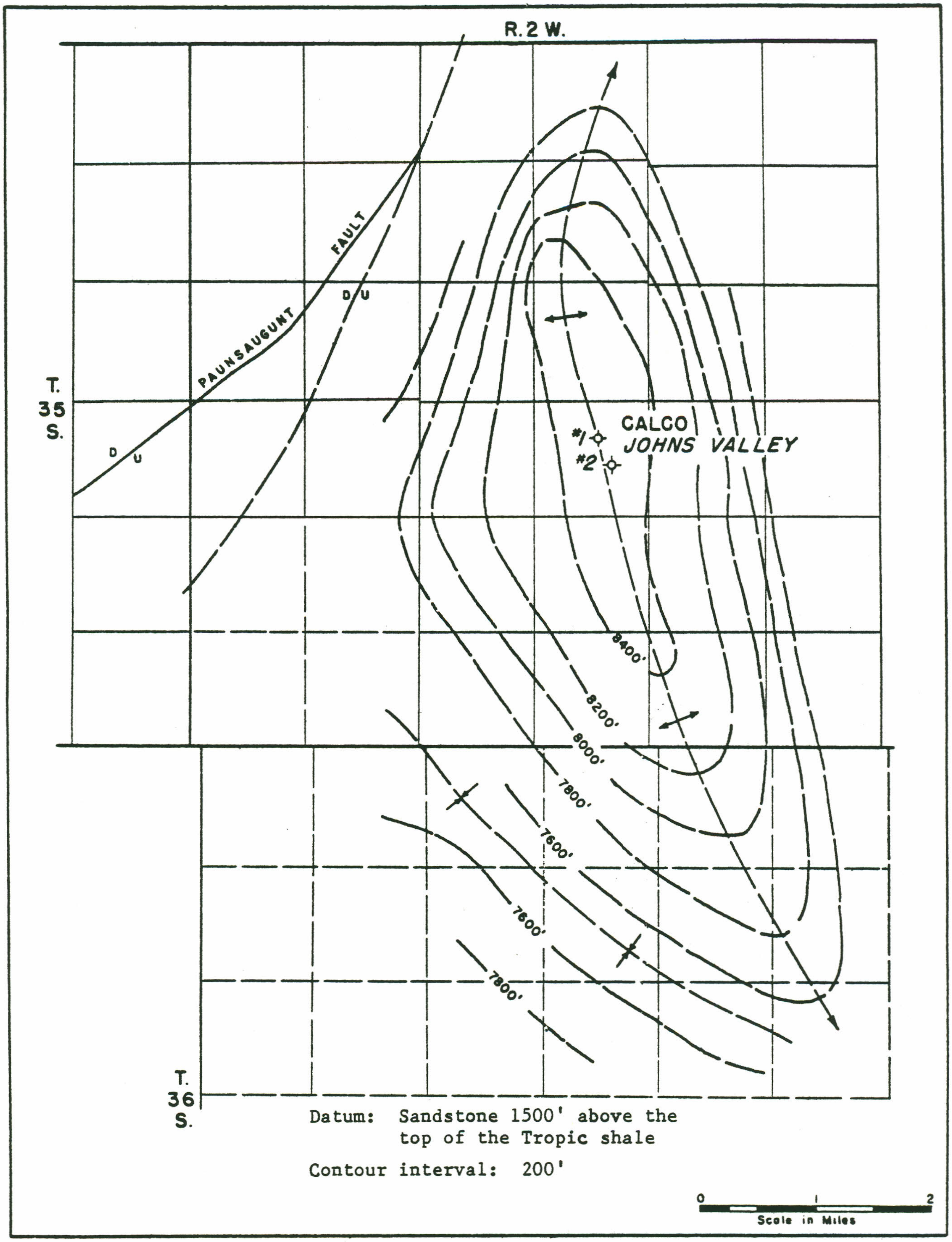


Figure 33. Structure contour map, Johns Valley Anticline, Utah (from Alexander and Clark, 1954).

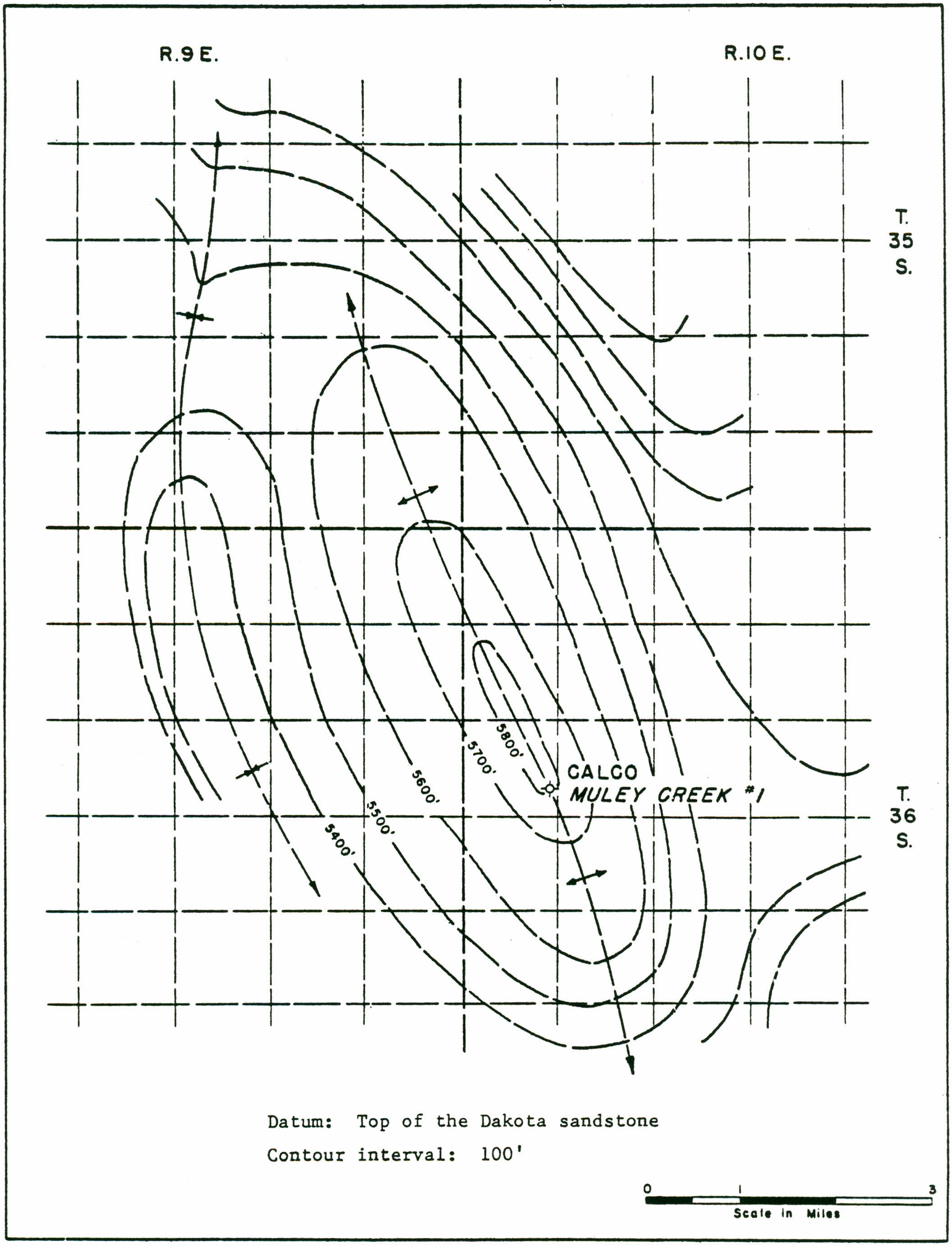


Figure 34. Structure contour map, Muley Creek Anticline, Utah (from Alexander and Clark, 1954).

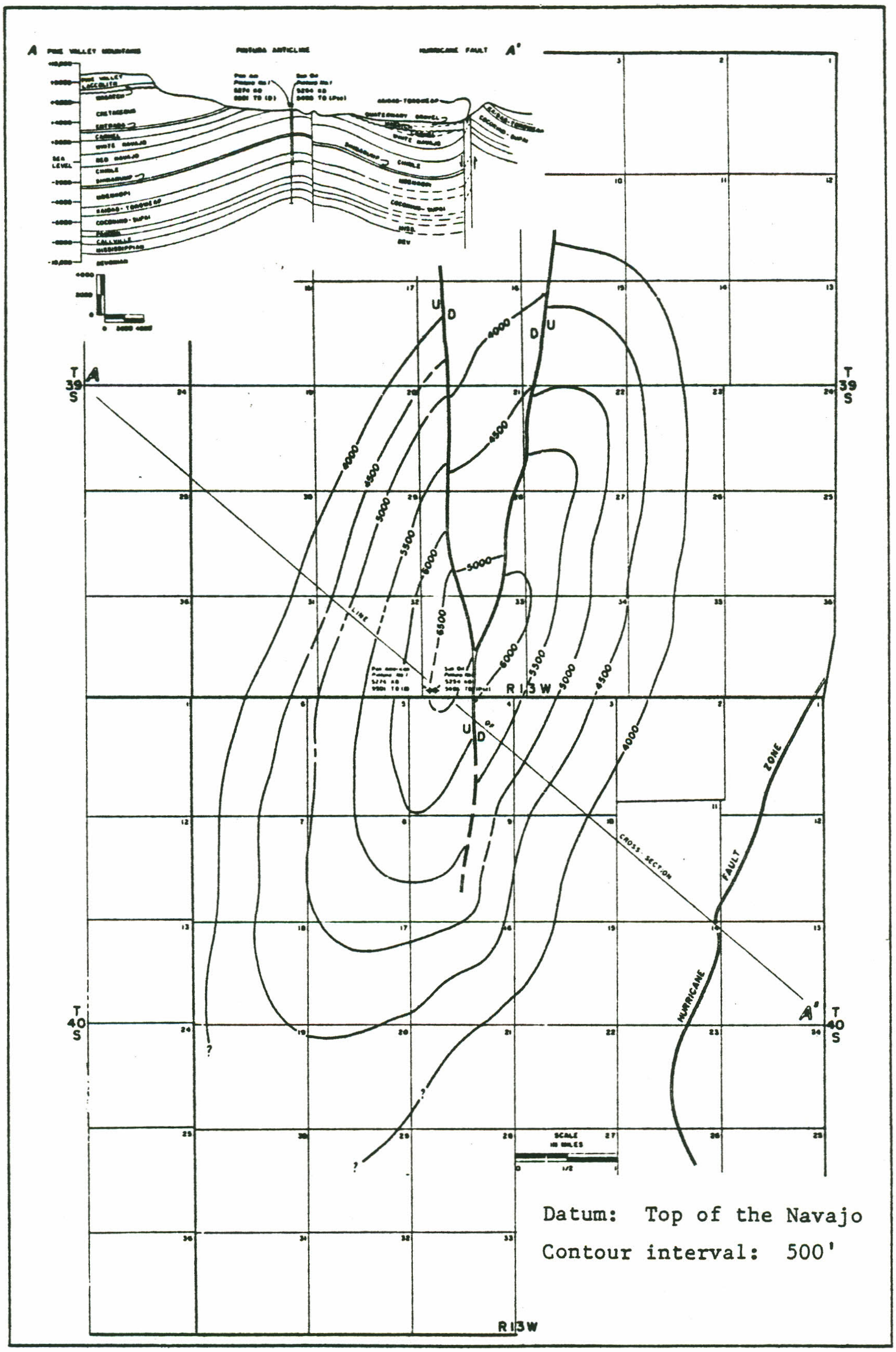


Figure 35. Pintura Anticline, Washington County, Utah (from Cary, 1963).

Table 4. Pan American 1, Pintura Anticline, Washington County, Utah (from Cary, 1963)

Formation	Age	Show Description	Porosity	Formation Fluid
Shnabkaib	Triassic	Dead oil & spotty live	Tight	DST recovered 30' mud
Timpoweap	Triassic	Dead oil & spotty live	Trace	No test
Kaibab	Permian	Black residue & trace live	Tight	No test
Toroweap	Permian	Black residue & trace live	Tight	No test
Coconino Supai	Permian	Trace live	Poor (clay cement)	No test
Pakoon	Permian	Dead oil stain & trace to spotty live	Tight	No test
Callville	Penn.	Dead oil stain & trace live	Tight to fair, fracture	Fresh water flowing into hole
Mississippian		Black residue top 150' No samples remainder	Trace to poor fracture & vuggy	Lost circulation & fresh water flowing
Devonian		No samples Black residue in core 9077-81	Fracture & vuggy	DST recovered 30' mud DST recovered 2,000' mud 3,270' fresh water

In October 1961 the Pan American 1 was spudded 300 feet west of the Sun Oil 1 location to a total depth of 9,501 feet in Devonian rocks. A description of the stratigraphy is given by Cary. Table 4 indicates all shows, related porosity, and formation fluids encountered in this well. Cary states that the presence of oil shows is indicative of source rocks but he believes the proximity of the Hurricane Fault has allowed hydrocarbons to escape.

PETROLEUM POTENTIAL SUMMARIZED

The following section represents a summary of the petroleum potential characterizing the stratigraphic section of northwestern Arizona.

Cambrian

Reported shows in the Cambrian section of McDermott 1 State, Western Drilling-Valen 1 Federal, and Tidewater's Kaibab Gulch test have included these sediments among possible future objectives. Shows in the McDermott 1 State occur in hard siliceous limestone of the supra Muav near the regional Cambrian-Devonian unconformity. "Lack of primary porosity and permeability is undoubtedly a contributing factor in the failure of this well to produce" (Heylmun, 1961).

Cambrian strata may have developed stratigraphic traps due to pinch out from depositional thinning to the east as well as regional post Cambrian erosion. Cambrian strata of the area could have received eastward migrating hydrocarbons which may have originated in hinge-line and (or) miogeosyncline rocks. Regionally, Cambrian rocks were tilted down to the west due to Paleozoic subsidence of the geosyncline, providing the potential for updip migration toward northwestern Arizona. In addition, the Muav Limestone and supra Muav rocks pinch out near the eastern margin of the area. The pinch-out zone is oriented northeast-southwest. McKee (1974) recognized that successively younger members of the Muav extend further eastward in the subsurface, forming a series of limestone tongues projecting eastward into shaly Bright Angel units.

When referring to the Tapeats Sandstone, Lessentine (1965) states, "Potentially productive strand line or offshore bar deposits may exist."

Devonian

Shows of oil have been reported in Devonian beds of the Western Drilling-Valen 1 Federal and the Pyramid 1 Federal wells. Devonian strata pinch out in the eastern half of the area against the Kaibab Positive area, as indicated by regional isopachs and field evidence summarized by McKee (1974). In the southwest corner, Devonian strata thicken abruptly in an apparent intracratonic Devonian basin. It is conceivable that hydrocarbons, originating in thick Devonian sediments of this basin, may have migrated updip toward the east and northeast until stratigraphically trapped in the section. Lessentine (1965) sums up the potential for these rocks as follows:

> Regionally, the petroleum possibilities of Devonian rocks should be good. Gas and oil production is found at the Lisbon field in southeastern Utah, and minor oil production exists in northeastern Arizona. Elsewhere "shows" of oil or gas and (or) substantial fluid testify to the presence of good reservoir rocks. Oil seeps and petroliferous carbonates are reported in the literature. Coral and stromatoporoid bioherms are found

in surface outcrops. Many interesting potential oil and gas stratigraphic traps may be awaiting the diligent and persistent searcher.

Mississippian

The Redwall Limestone has become more important due to its encouraging oil indications in south-central Utah and northeastern Arizona (Swapp, 1961). Oil shows were reported in the Western Drilling-Valen 1 Federal, Skelly Oil 1 Federal, and Pyramid 2 Federal wells and many wells in adjacent Utah. The comments of Lessentine (1965), referring to Mississippian strata of the Kaiparowits and Black Mesa areas, are also relevant to the Strip Country and are quoted herein:

> ...Patterns of distribution of fossiliferous carbonate reveal a thriving biotic assemblage related to ill-defined bathymetric parameters on the shelf. Distribution of these fossiliferous units may prove to be the key to establishing substantial production...
>
> Production has been established from the Mississippian in southeastern Utah, southwestern Colorado, northwestern New Mexico, and northeastern Arizona. These fields include limited production at the Dry Mesa field on the northeastern margin of the Black Mesa basin and non-commercial production on Upper Valley anticline in the Kaiparowits basin. "Shows" of oil and gas have been numerous, organic marine carbonates should provide an indigenous source for hydrocarbons, and porous and permeable dolomites are common in the section. Therefore, the Mississippian should be a prime objective for future oil and gas exploration.

Pennsylvanian

Data relative to the petroleum potential of Pennsylvanian strata are sparse. Reported oil shows are limited to the Antelope Springs 1 Federal and the Tennessee Gas Transmission 1 wells (table 2). The latter well represents the sole known exploration attempt in the Shivwits Plateau. Pennsylvanian strata in northeastern Arizona and southwestern Utah have excellent reservoir characteristics. Several oil shows were reported in the Hermosa Formation in Utah's Kaiparowits region (Heylmun, 1958) with several oil and gas pools in northeastern Arizona currently pumping from production zones within the Hermosa.

Permian

Permian strata exhibit a wide lithologic range which includes evaporites, shale, sandstone, limestone, and dolomite. Much of this section was deposited under large-scale cyclic deposition due to major transgressions and regressions of the Permian sea. Swapp (1961) believes that these units contain numerous zones which could serve as source and reservoir beds and that considerable possibilities for stratigraphic traps exist.

Permian oil shows were reported in the Western Drilling-Valen 1 Federal, Roger Fields 1 Federal, James Harris 1 Federal, Poteet and Lyons 1 Federal, Tony Lyons 1 Federal, Skelly Oil 1 Federal, and Falcon Seaboard & Valen 1 Federal. These reported shows, supplemented by similar shows and limited production from the Permian section of the Upper Valley Anticline in south-central Utah indicate that several Permian units are clearly petroliferous. Due to similar regional lithologic and stratigraphic characteristics of Permian strata with adjacent areas of Utah, it appears that the Permian continues to provide substantial incentive for future exploration. Because the Kaibab Formation is subaerially exposed over much of the region, the petroleum potential of this unit is enhanced in areas where it is capped by Triassic red beds. Long exposure of the Kaibab erosion surface may have resulted in the loss of Permian hydrocarbons. However, many reported shows in basal Triassic rocks suggest that seepage loss may be minimized where Kaibab remains capped by red beds.

Mesozoic

The basal limestone and sandstone members of the Triassic Moenkopi Formation are considered targets for petroleum exploration in southwestern Utah where current oil production is closely associated with the underlying Kaibab Formation. Moenkopi rocks form extensive outcrops in the northern portion of the area. The basal Timpoweap Member was noted in most wells drilled in the Uinkaret Plateau, with a reported section of about 140 feet in most cases. The isopachs of this member, shown in figure 26, therefore can be considered as extending south locally into the northern half of the Uinkaret Plateau.

The basal Triassic strata unconformably overlie the Kaibab Limestone and may prove to be petroliferous where conglomeratic Timpoweap rocks have developed porosity similar to the reworked Kaibab (Timpoweap) found in Utah.

CONCLUSIONS AND RECOMMENDATIONS

Northwest Arizona has not been explored sufficiently to prove or disprove its merit for commercial oil production. Surface geologic and structure maps are generally limited to small-scale regional maps while published geophysical investigations are practically nonexistant. Subsurface stratigraphic control is sparce and irregularly distributed, averaging about one test well per 400 square miles. Some of the major folds have been tested but none adequately. Limited tests of obvious surface structures in the area combined with similar nonproductive attempts in southwestern Utah, however, does invoke uncertainty regarding the efficacy of Laramide structural traps.

A minimum of 16 well-defined surface structures (fig. 27) and many smaller structures (fig. 29), among others, represent a variety of distinct potential structural traps. It is probable that these structures were formed long after hydrocarbons had developed in the Paleozoic source rocks. Migration and subsequent local entrapment of the primary hydrocarbon accumulations may have been initially dominated by stratigraphic entrapment during the tectonically quiescent Paleozoic and most of the Mesozoic Eras. It is conceivable that the development of anticlines during the Laramide orogeny may have locally caused secondary migration into the higher structural closures, but definitive conclusions derived from testing of a number of these structures have been clouded by a) low porosity and (or) subnormal pressures in zones exhibiting good oil shows, b) inadequate followup testing in some structures, and c) general failure to penetrate the deeper portions of the section.

In addition to the development of folds, the role of subsequent Miocene normal faulting has not been established. Whether these fractures have provided a mechanism whereby existing hydrocarbons have escaped or, in fact, have provided additional structural traps remains speculative. In referring to the oil possibilities of southern Utah, Heylmun (1958) states:

> ...Drag along these faults [Sevier-Paunsaugunt] could produce structures favorable to oil and gas accumulation, but no seeps have been reported in their vicinity.

The postulated loss of petroleum through seepage from dissected canyons must also be considered. It should be noted, however, that late Pliocene canyon cutting, although vertically impressive, is essentially an areally localized feature. This influence is likely to be limited to a relatively narrow strip at the southern and eastern margin of the area, coincident with the Grand Canyon and several of its major tributaries.

It is obvious that the development of stratigraphic and structural traps of the region predates the existing fluvial erosion. Therefore, the escape of hydrocarbons from preexisting accumulations within potential traps would intuitively appear to be limited to local areas in close proximity to a dissected section.

It is clear, however, from the numerous reported shows throughout the region that substantial hydrocarbons may have migrated through practically the entire geologic section. Efforts to probe deeper stratigraphic levels appear warranted in the relatively unexplored lower Paleozoic section where possible loss of hydrocarbons through the mechanism of denudation or canyon cutting would be minimized.

The author believes that future exploration should direct greater emphasis to delineation of stratigraphic traps in light of the ubiquitous historical shows, suggesting regional hydrocarbon migration, combined with a conducive updip wedge out of the stratigraphic section. Although shelf sediments deposited in close proximity to the Paleozoic hinge line have classically offered excellent potential for stratigraphic traps, at the present time their location can be inferred only from a broad appraisal of the regional stratigraphic relationships. Identification of specific stratigraphic traps will require careful review of existing petrologic/stratigraphic reports in an area of interest, supplemented by additional subsurface geophysical and downhole data.

In addition, it is suggested that a high priority be given to utilization of state-of-the-art techniques and equipment specifically designed for testing and completion of wells which encounter high viscosity hydrocarbons and (or) subnormal pressures. It is possible that the repeated failures of many early drill-stem tests, conducted in zones otherwise exhibiting good shows, could be attributed to these conditions.

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