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REGIONAL STRATIGRAPHIC CONTROL OF THE SEARCH FOR PENNSYLVANIAN PETROLEUM SOUTHERN MONUMENT UPWARP SOUTHEASTERN UTAH *

by
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REGIONAL FRAMEWORK

The Four Corners segment of the original greater Paradox basin is about 325 miles long in a northwesterly trend and as much as 170 miles wide in its widest northeasterly dimension. It is separated from the Eagle-Gypsum basin of northwestern Colorado by the Late Pennsylvanian Uncompahgre uplift. Pre-Pennsylvanian sediments floor most of this ancient eastern shelf of the Cordilleran geosyncline. Across this pre-Pennsylvanian and earliest Pennsylvanian westerly sloping Cordilleran shelf, the Middle Pennsylvanian greater Paradox basin subsided, separated from the Cordilleran geosyncline on the west by the broad arcuate Aneth platform. A non-marine basin filled with coarse-grained red beds, derived from the rising Uncompahgre uplift, formed to the northeast in latest Pennsylvanian to Permian time.

The region of the Monument upwarp lies southwest of the thickest Pennsylvanian evaporite sedimentation. Along this southwest shelf of the Paradox basin, maximum normal marine, euxinic and evaporite facies gradations developed. Within and directly above these lithologic complexities lie the Pennsylvanian petroleum production and added potential of the region. Petroleum exploration requires analysis of ancient subsurface tectonic features as well as present surface tectonic patterns due principally to later folding, faulting and tilting. The tectonic features obvious on the surface today are of Laramide folding and Tertiary tilting origin and are segments of Late Paleozoic tectonic elements. Many undrilled stratigraphic prospects with several divergent regional tilts important to migration and accumulation of petroleum in porous beds lie on this southwest shelf of the Paradox basin both southwest and northwest of the highest anticlines on the crest of the Monument upwarp.

Southeastern Utah is in the northwestern part of the Colorado Plateau physiographic province of the Four Corners region. The Dirty Devil, Colorado, Green and San Juan rivers and tributaries drain the region, with only the major rivers being perennial streams. The region is accessible via paved U.S. and Utah highways and graded Utah highways. County roads make the internal parts of the several prospective areas on the plateaus accessible for exploration and drilling with a minimum of road building.

*This article is experimental in format and is purposely arranged so that captions are explanatory without text reference to figures or the voluminous literature involving the Paradox basin. Most of the figures, previously published elsewhere, have been updated. References listed are sources of complete bibliographic coverage.

REGIONAL STRUCTURAL HISTORY

The Early Pennsylvanian sedimentary shelf on the east side of the Cordilleran geosyncline was uplifted during Atokan time, when the Ancestral Rocky Mountains emerged above sea level on the east. The greater Aneth shelf, an arcuate barrier flanked by broad shallow platforms, extended across western Colorado and Utah and had a major clinoform that trended northwest-southeast through Arizona and central Utah as the rim of the subsiding Paradox basin. East of this rim, the broad Aneth shelf sloping eastward into the subsiding Paradox basin, developed several shallow sags, open to the deeper marine waters of the Cordilleran miogeosyncline on the west. This gentle shelf slope was probably bordered on the west by low islands which helped control high-shelf sedimentation for barrier carbonate growth, which extended northeastward and eastward into the subsiding Paradox basin during Desmoinesian Cherokee and Marmaton time.

The Paradox basin was loaded by terrigenous sediments from the east and evaporitic deposits nearer the basin center, resulting in lateral expansion of the basin. Along the southwest shelf of the basin, sags developed, flanked by structural terraces and spurs. A series of concentric, down-to-basin flexes and normal faults began to form, creating sediment-controlling alignments. The oldest flexes and faults were basin-centered, bending and cutting the oldest Pennsylvanian formations. Later flexes and faults affected progressively younger formations southwestward on the shelf.

During Desmoinesian time, the deepest part of the Paradox basin became an axis of uplift, along lines controlled by an earlier major flex alignment system which, still later in Missourian time, became the Uncompahgre front. As uplift of the Uncompahgre progressed, stresses developed against the down-flexed blocks of the Paradox low-shelf slope. Salt was squeezed by the pinching action and responded to this vertical compression by flowing in the direction of least resistance where it encountered the flex and fault faces and was diverted upward to create salt welts and domes. Thus salt doming was tectonically related to the initial movements along the Uncompahgre front, and the present trends of salt anticlines trace, approximately, the trends of major down-to-basin flexes and

faults which controlled carbonate barrier growth and distribution of porous sediments along the higher shelf alignments.

This deformation resulted in movements which had an important bearing on petroleum accumulations. Some ancient structural trends in the Paradox fault-fold belt have been altered in a complicated fashion by Late Pennsylvanian and Permian salt intrusion, Late Cretaceous folding and Tertiary tilting. Fracture patterns on the Paradox shelf, southwest of the Paradox salt anticlines, coincide with ancient structure and subsurface carbonate barrier trends.

Local paleogeological study indicates that normal marine water moved through sags along the western sill into the Paradox basin. During Paradox evaporite deposition, especially toward the end of evaporite deposition, lineal carbonate barriers grew on the east and northeast-facing paleoslope of the Aneth platform during Desmoinesian time. Wind-driven waves produced strong across-sill currents important to the growth of these porous carbonate barriers and associated porous reef-produced debris along the inner spur-and-sag frilled edge of the Paradox basin shelf. As down-flexing occurred, these porous carbonate barriers could grow upward along the anticlinal bends associated with the northwest-trending alignments. Penecontemporaneous sedimentation is known to have been greatly affected by early structural growth along alignments, their associated flexes, and cross flexes between alignments. Detailed stratigraphic studies thus provide the most important guides to petroleum discovery and are the key to appraisal of the history of each sedimentary unit.

PENNSYLVANIAN ROCKS

These strata are described from oldest to youngest, and have the major oil potential of the Paradox region. Because the Pennsylvanian terminology is once again in a state of flux, all references to group, formation, zone and cycle are deleted from this informal summary.

Molas—On the Monument upwarp, the Lime ,Ridge (Lim) and the Molas comprise a highly variable facies. The Lime Ridge contains lentils of Molas-type silty marine shales derived by the erosion of the underlying Molas from the ancient Emery uplift and other areas. Limcar is the carbonate facies present in most areas at the top of the Molas and above the Molas paleosoils that lie on the eroded Mississippian carbonates. Molas is predominantly a elastic red-bed sequence comprising reddish-brown to variegated siltstone, red silty shale, calcareous sandstone (Mol), grading upward into gray to reddish buff limestone lentils, reefoid in some trends, which comprise (Lim) at the top. The basal part of the Molas contains boulders and cobbles of Leadville limestone and dolomite both in situ and transported. In some places, where the Lime Ridge limestones (Limcar) are missing, the dark gray *Chaetetes* limestone and shale of the Pinkerton Trail (Pin) lie directly on top of the Molas. In some shelf localities there are *Chaetetes* reef facies of the Lime Ridge separating the Pinkerton Trail above from the Molas shale below. In this area, the Des Moines Cherokee-Atoka time interface lies between the Pinkerton Trail and Lime Ridge.

The Molas, lowermost of the Pennsylvanian strata in the Four Corners region, ranges in thickness from wedge-edges in the Shick Spur-Big Flat-San Rafael area of Emery County to over 150 feet on the Monument upwarp. I t is widespread in its distribution throughout the Four Corners region. The entire Molas-Lime Ridge in this region is generally lacking in porosity and permeability.

Paradox—The Paradox is divisible into six time units which may eventually be considered to be mappable formations: (Unk), (Par), (Des) make up the upper third; (Aka), (Bar), the middle third; and (Pin) the lower third. Division of the group into a triad refers to facies and time rather than thickness, which is highly variable.

The lower third is the Pinkerton Trail and comprises a penesaline to saline complex of gypseous siltstone, interbedded black shale, dark gray siltstone, gypsum and salt and dolomite in the central part and along the low southwest shelves of the Paradox basin, with dark gray shales, gray porous dolomite, locally developed carbonate barrier biostromes and gray cherty limestone on the west and southwest Paradox sedimentational shelf. This mappable lower third includes the Alkali Gulch as used by some workers in the region of the Aneth fields, but in this study it encompasses the time zone of Pinkerton Trail (Pin) and often mistakenly includes evaporitic lentils of (Lim) found only in the deepest part of the Paradox basin.

The Pinkerton Trail on the southwest Paradox shelf comprises gray, fine to medium crystalline, calcarenaceous, fossiliferous limestone interbedded with and underlain by light to dark gray silty shale. Limestone conglomerates and evidence of disconformity are present locally. The mappable Pinkerton Trail, as a time zone (Pin), reaches thicknesses of several hundred feet and contains evaporites deeper in the Paradox basin. It wedges out southwestward and thickens into barrier-type carbonates along some parts of the Aneth and Boundary Butte alignments, and to the northeast it grades into thick salt. In this analysis, (Pin) is clearly of early post-Atoka (early Cherokee) age.

The middle third of the Paradox, the major salt sequence, contains the thick prisms of interbedded salt, euxinic black shale, black calcareous siltstone, evaporitic gypsum, anhydrite, dolomite, and high on the shelf southeast of evaporite deposition, biohermal-biostromal dolomitic limestone with several marine disconformities. It embraces the Akah (Aka) and the Barker Creek (Bar) which range from early to middle Cherokee age.

The upper and lower parts of the Paradox represent penesaline transitional phases in the history of the Paradox geosyncline. The upper part (Unk-Par-Des) grades from penesaline strata shelfward into biostromal-biohermal dolomitic limestone, gray shale and dolomite. The (Unk) member is an evaporite section present only in the deeper parts of the basin. Major oil production of the region has been discovered in algal and oolite banks of the Desert Creek Formation (Des). Age of (Unk-Par-Des) is late Cherokee.

Depositional thickness of the Paradox along the axis of the Paradox basin is greater than 4,200 feet, and is of Cherokee (early to middle Des Moines) age. The equivalent Paradox section ranges from 400 to 800 feet in thickness in the southern Monument upwarp area.

Honaker Trail—The Honaker Trail is a mega-time zone of Desmoinesian Marmaton, Missourian and Virgilian age. This section comprises gray to reddish-gray to buff-gray shale, sandstone, limestone and calcareous sandy siltstone, a lithologic association typical of a marine shallow-water environment. Southward, westward, and northwestward high on the shelf, the Honaker Trail contains many disconformities and grades into dolomite, whereas basinward it grades into sandier arkosic

facies. This section ranges from an erosional wedge-edge high on the shelf on the southwest to 1,750 feet in thickness on the lower shelf in a northeasterly direction toward the Uncompahgre uplift.

The Honaker Trail formerly included the lower part of (Wol) (now the Permian Elephant Canyon carbonates), (Ric), (Her), (Tra) and (Ism) of this more detailed analysis. Now included are only the Hermosa (Her), Transition (Tra) and the Ismay (Ism) as separate mappable time-stratigraphic formations. The Ismay is of Marmaton and uppermost Cherokee age and is a major oil and gas producer out of algal matte barriers and banks in the Aneth fields. The Honaker Trail in the southern Monument upwarp area ranges irregularly from 650 to 950 feet in thickness, and clearly represents deposits made under open marine conditions subsequent to the barred, evaporite conditions which resulted in deposition of the Paradox.

REGIONAL UNCONFORMITIES

Three major unconformities of regional to subregional extent are presently recognized as of great importance in genesis of Pennsylvanian strata in this region. These unconformities are variable in time length in large areas of the Paradox shelf and have had great effect on the distribution of sediments critical to the oil and gas potential. The region underwent gentle subaerial erosion without orogeny, through part of Meramecian, all of Chesterian, all of Springeran, most of Morrowan, and parts of Atokan time. Over the Circle Cliffs-Emery uplifts and the root zone of the Nequoia Arch northwest of Monument upwarp area, Wolfcamp strata lie directly on the Mississippian Leadville carbonates, with Pennsylvanian strata missing.

The second disconformity of subregional extent lies between upper Lime Ridge strata (Lim) of the Molas section and the lowermost Pinkerton Trail (Pin) of the Paradox section. After deposition of Lime Ridge marine carbonates, the Desmoinesian seas regressed partially, allowing the development of a widespread, mild, erosion surface which cuts as deep as the top of the Molas in places. The upper Molas to Pinkerton Trail strata (Mol-Lim) to (Pin) thus encompass a clear record of a transgressive-regressive marine hemi-cycle of Atokan-early Desmoinesian age. In some places on the Monument upwarp, a pre-Desmoinesian (Atokan) conglomerate records one surface of this disconformity. This physical break in sedimentation is a record of a "rocking" regional tilt which preceded the major subsidence of the Paradox geosyncline.

The third and economically most important disconformity-angular unconformity in the Paradox shelf region was developed at the top of the Paradox (base of (Ism)) after the completion of the major part of Paradox penesaline deposition and prior to the complete normal marine ventilation of the basin. Gentle warping and subsidence initiated differential deposition of normal high-shelf marine carbonates interbedded with sandstones from the surrounding but distant positive areas and along erosional cuestas related to flexes, and possibly faults, parallel to and between alignments. This widespread combination submarine-subaerial disconformity in the middle to low shelf region does not represent a stand high above sea level to suffer deep subaerial erosion for a protracted time; however, owing to a post-Paradox easterly regional tilt, the Ismay lies on progressively older formations to the west and south across the westernmost and southernmost parts of the Paradox high shelf.

The base of the Ismay, an easily mapped discontinuity of profound importance in finding new oil fields, lies progressively deeper in the section also to the southwestward, at the top of (Par), top of (Des), or top of (Aka); and in tectonically localized areas southwest of the Aneth alignment the Ismay lies on the Barker Creek. This is the most widespread and economically important intra-Pennsylvanian time surface involved in the discovery of Pennsylvanian oil and gas on the Paradox shelf.

In summary, most marine evaporite basins whose shelves suffer normal marine water interchange with warmer, shallower penesaline to hypersaline waters have transgressive and regressive calcareous sandstones, bedded calcarenites and barrier carbonates along the gently shelving flexes or breaks-in-submarine slopes. The southwest and west shelf of the Paradox basin shows this association, from (Lim) to (Tra) time, with its accompanying rapid facies changes basinward from high-shelf disconformities to dolomitized disconformity breccias, barrier-reef lagoonal facies, biohermal barriers and barrier-front talus-type biostromes, generally correlative with but initiated before and persisting for some time subsequent to the deposition of saline beds in the rapidly subsiding Paradox evaporite basin.

REGIONAL FACTORS IN PETROLEUM EXPLORATION

Regional Tilts

The Paradox shelf region is a logical place to drill for oil and gas owing to its stratigraphic section, tectonic history and location astraddle a zone of diverse marine regional tilts throughout geologic time. A succeeding table records known ages, directions and inferred amounts of regional tilt important to the localization of oil and gas pools during first and second phase petroleum migration.

The amounts of paleoslope and regional tilt are based on projection of known strata! thicknesses both in and surrounding the region and are complicated by submarine erosional removal of sediments. Local sedimentational dips related to

Age	*Direction*	*Inferred amounts of paleoslope in feet per mile**
Cambrian to earliest Pennsylvanian	westerly	10 to 60
Mid-Pennsylvanian	northeasterly	20 to 120
Late Pennsylvanian	southeasterly	40 to 180
Early Permian	northerly to southwesterly	10 to 90
Middle Permian	westerly	20 to 70
Triassic	westerly	10 to 50
Jurassic	northerly	10 to 50
Cretaceous	northeasterly	20 to 90
Eocene	southwesterly**	10 to 50
Miocene	westerly***	0 to 180

*locally there existed tectonic divergences from these regional paleoslopes.

**northernmost part of Paradox region suffered a north tilt into the Uinta Tertiary basin during Eocene time.

***present regional dip into the regional Henry Mountain syncline off the west flank of the Monument upwarp.

barrier growth, reef-front deposition, or local tectonic folding can be ascertained only by drilling for the stratigraphic traps almost certain to be present along the Boundary Butte, Aneth and Dirty Devil alignments.

Regional Reservoir Characteristics

Based on many published and confidential studies of the Aneth-Ismay complex of oil fields, and the drill-stem tests and other data from wildcat wells already drilled on the Paradox shelf, as well as the author's subsurface analysis, a succeeding table shows logical criteria concerning porosity zones in Pennsylvanian strata ranging in age from the Honaker Trail above through the Pinkerton Trail below.

Although many of these data are from the Aneth fields and thus are highly inferential for wildcat areas, it is entirely possible that the reservoirs of strata of undrilled prospects on the Paradox shelf region northwest and southeast of the Monument upwarp as well as around its south plunge, south of San Juan Canyon, may have active saline water drive on sweet paraffin-base oil of 40° gravity in Pinkerton Trail reservoirs; sour gas with sour condensate in Barker Creek barrier bioherms, disconformities and dolomite reservoirs; dissolved gas drive to active saline water drive with sweet paraffin-base 38° to 42° gravity oil in Akah, Desert Creek, Ismay and Transition reservoirs. Substantial oil and gas shows have been encountered in the Honaker Trail section in many Paradox basin tests, as well as in the Mexican Hat field.

Reservoir types: algal, oolitic, oomoldic, intercrystalline, coralgal, quartz and fossil "hash" intergranular and calcarenitic.

Strata/ lithology: limestone, dolomitic limestone, limy dolomite, quartz sandstone.

Range of reservoir thickness (effective porosity): 10 to 150 feet.

Producible permeability range: 10 to 900 millidarcies.

Porosity range: 6 to 24 percent.

Oil saturation: 20 to 80 percent.

Total water saturation: 10 to 50 percent.

Barrels per acre foot: 200 to 800.

Recoverable primary oil: 20 to 60 percent.

Range of gas-oil ratios: highly variable.

Reservoir drive: active saline water, dissolved gas, gas cap.

CONCLUSIONS

The Raplee, Lime Ridge, Cedar Mesa, Johns Canyon and Slickhorn anticlines where transected by San Juan Canyon in the Mexican Hat area of the southern Monument upwarp and are classic localities for the study of outcropping Pennsylvanian strata. Discovery of oil in the Mexican Hat area in 1908, followed by Shell's oil discovery on the Desert Creek anticline in 1952 and Texaco's discovery at Aneth in 1954, have led to detailed stratigraphic studies resulting in the naming of Pennsylvanian units after oil field localities in the Blanding basin east of the Monument upwarp.

The lithologic-stratigraphic cross section from Raplee anticline on the east, via Honaker Trail, to Slickhorn anticline on the west has been recorrelated to show the presently known lithology with formal cycles in the subsurface. These correlations are a combination of studies made by Don Baars, Dennis Irwin, John Welsh, John Strickland, Marvin Matheny, Ernest Szabo and the author between 1951 and 1973. Many other geologists have measured and studied these sections since the above initial measurements in 1951; however, the early works by Woodruff in 1911 and Miser in 1924 were excellent guides to the recognition of oil potential in the region.

The southern Monument upwarp area has been sparsely drilled, excepting on the anticlines. An exposed fossil oil field was discovered in Ismay and Desert Creek bioherms in San Juan Canyon along the eastern flank of Raplee anticline by Peterson and Ohlen of Shell Oil Company about 1960. An earlier discovery was made by the author in 1950 of at least three biohermal barrier trends in Akah and Barker Creek strata, shelfward, in the Goosenecks sector of San Juan Canyon. These Pennsylvanian zones or cycles are all correlative with oil and gas fields discovered in southeastern Utah and northeastern Arizona since 1952.

It is believed by most geologists familiar with the region that the breaching of the southern Monument upwarp by San Juan Canyon has released pressures and oil in all porous Pennsylvanian strata above San Juan River level. Numerous oil seeps in the San Juan Canyon and lack of pressures in wells drilled on the Monument upwarp anticlines attest to the validity of the concept; however, there are great expanses of the southern Monument upwarp and basinal areas to the southeast, south, southwest and northwest of the Monument upwarp that have not been drilled, and that lie structurally *below* the productive sections exposed in San Juan Canyon. Stratigraphic variation in the Honaker Trail and Paradox sections is great, and one may surmise that commercial oil and gas may be discovered in those areas, as well as along alignments that cross the Monument upwarp where correlative porosity zones lie *above* river level, isolated by facies change from reservoir drainage into San Juan Canyon.

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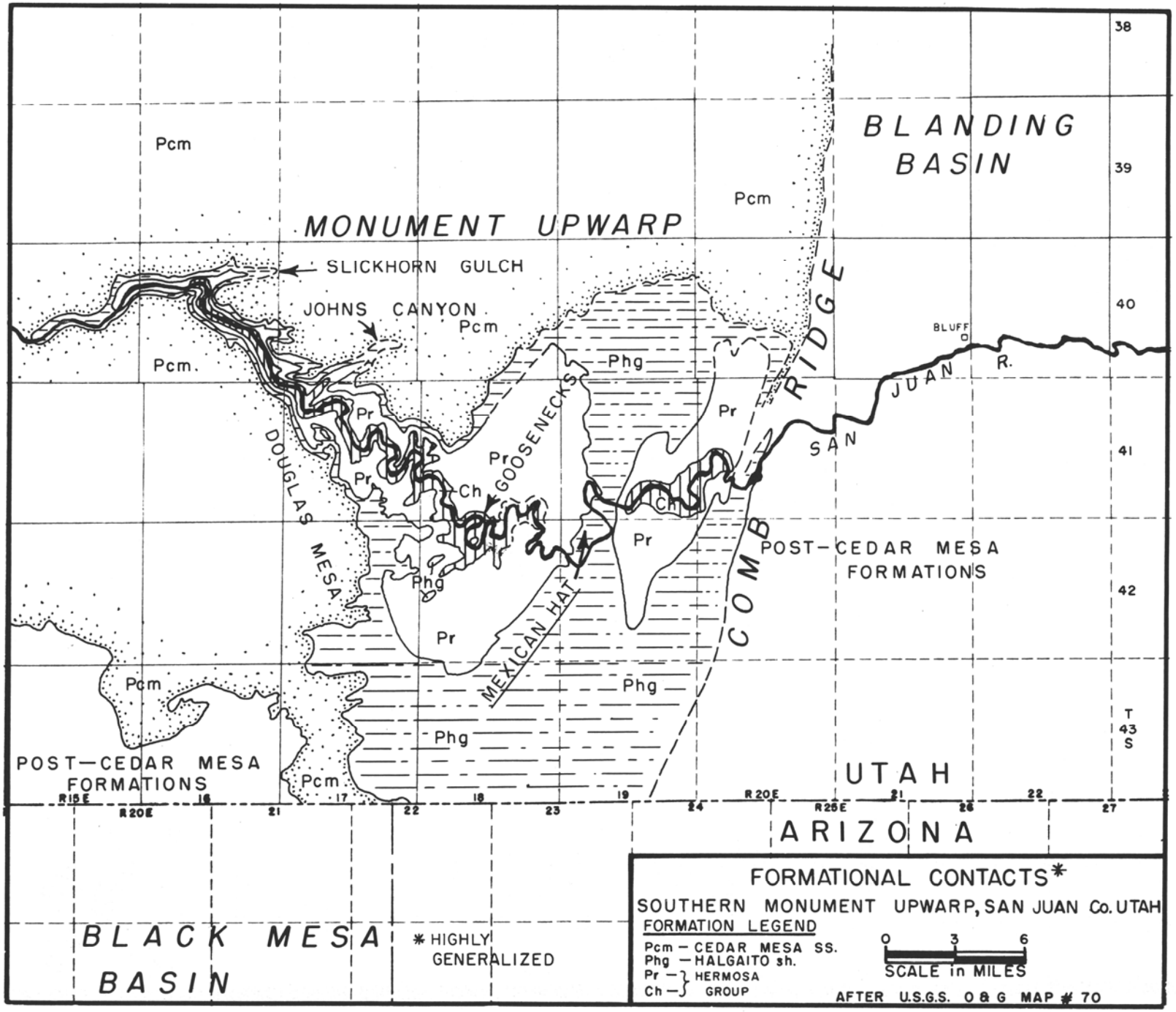
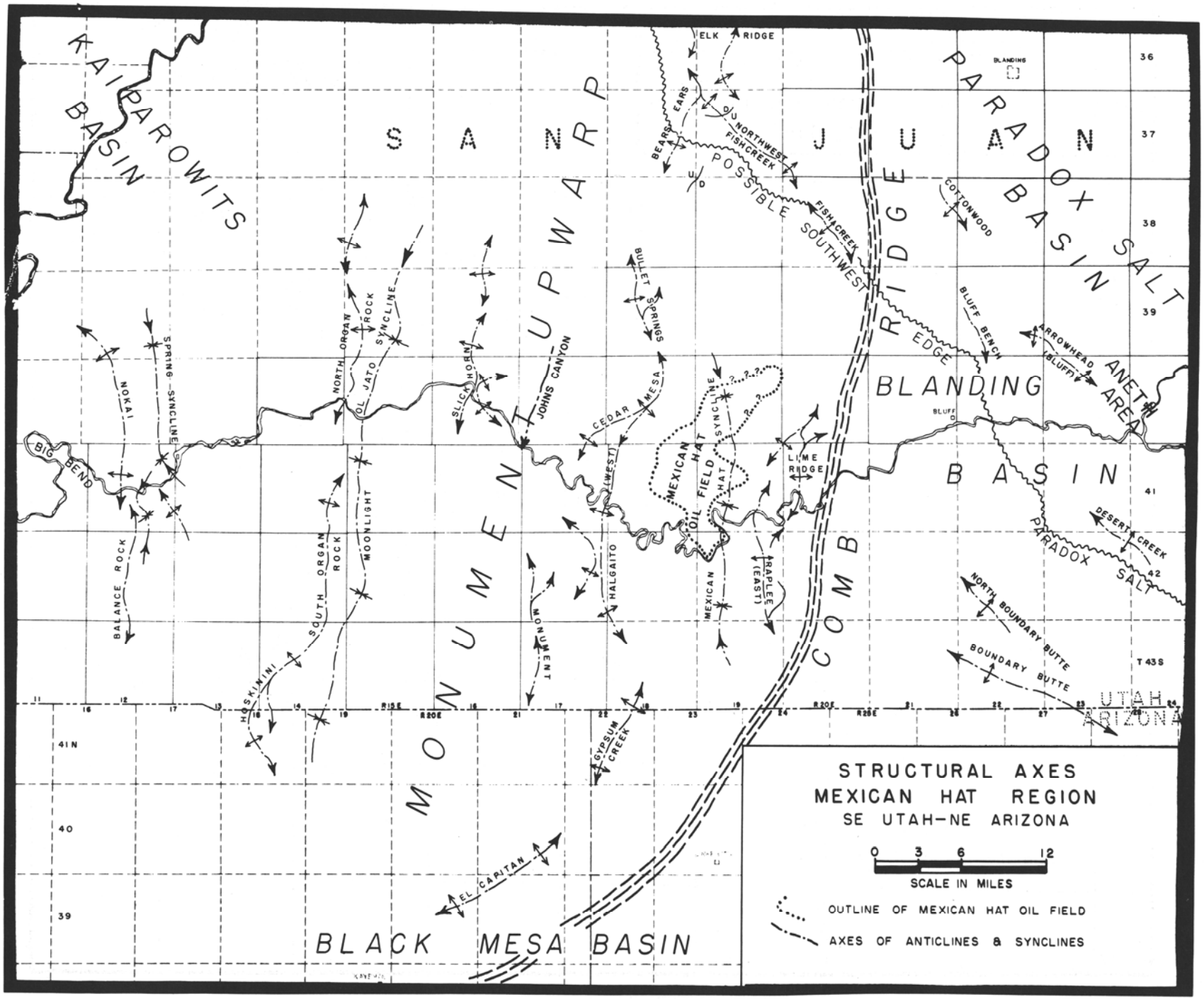
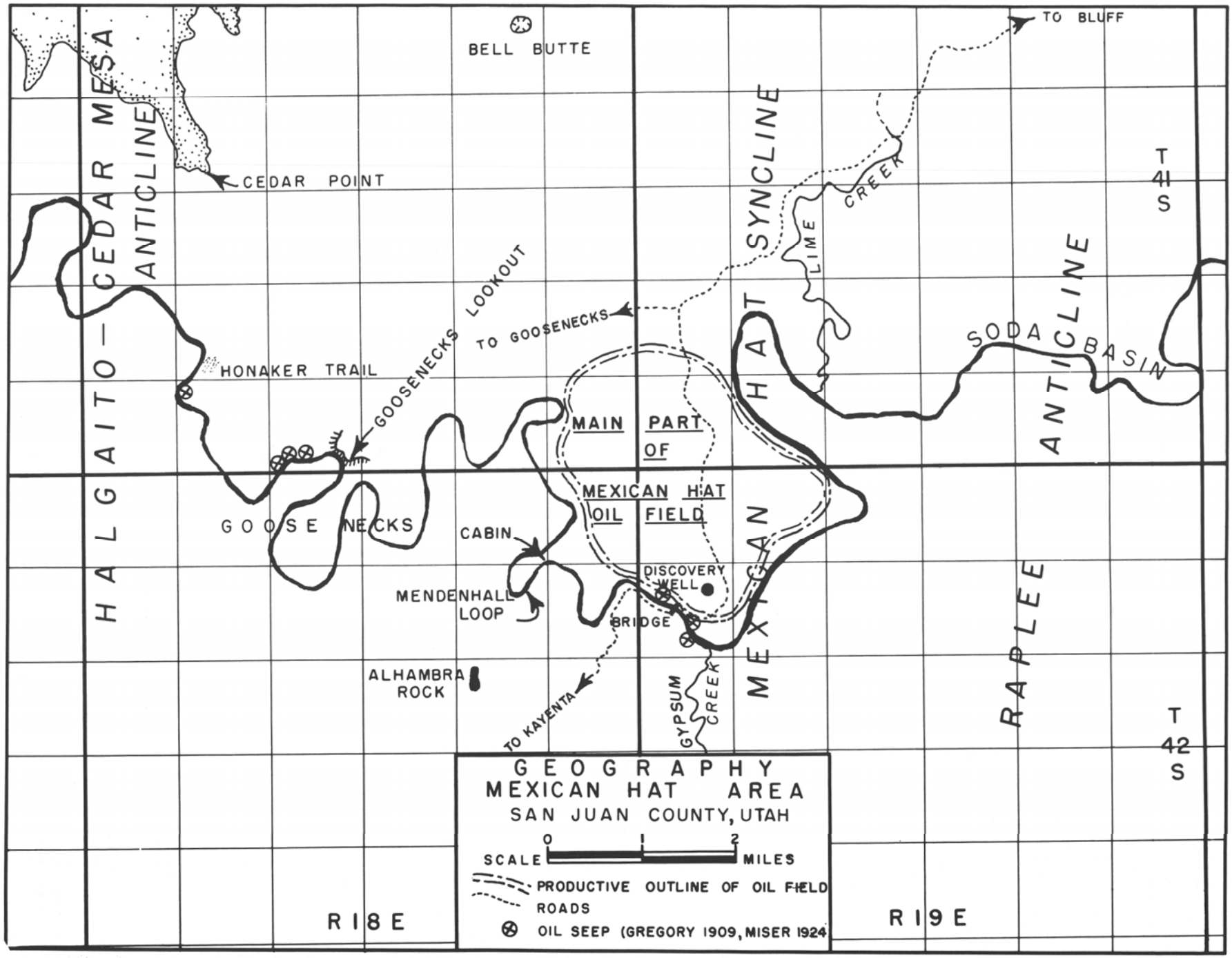
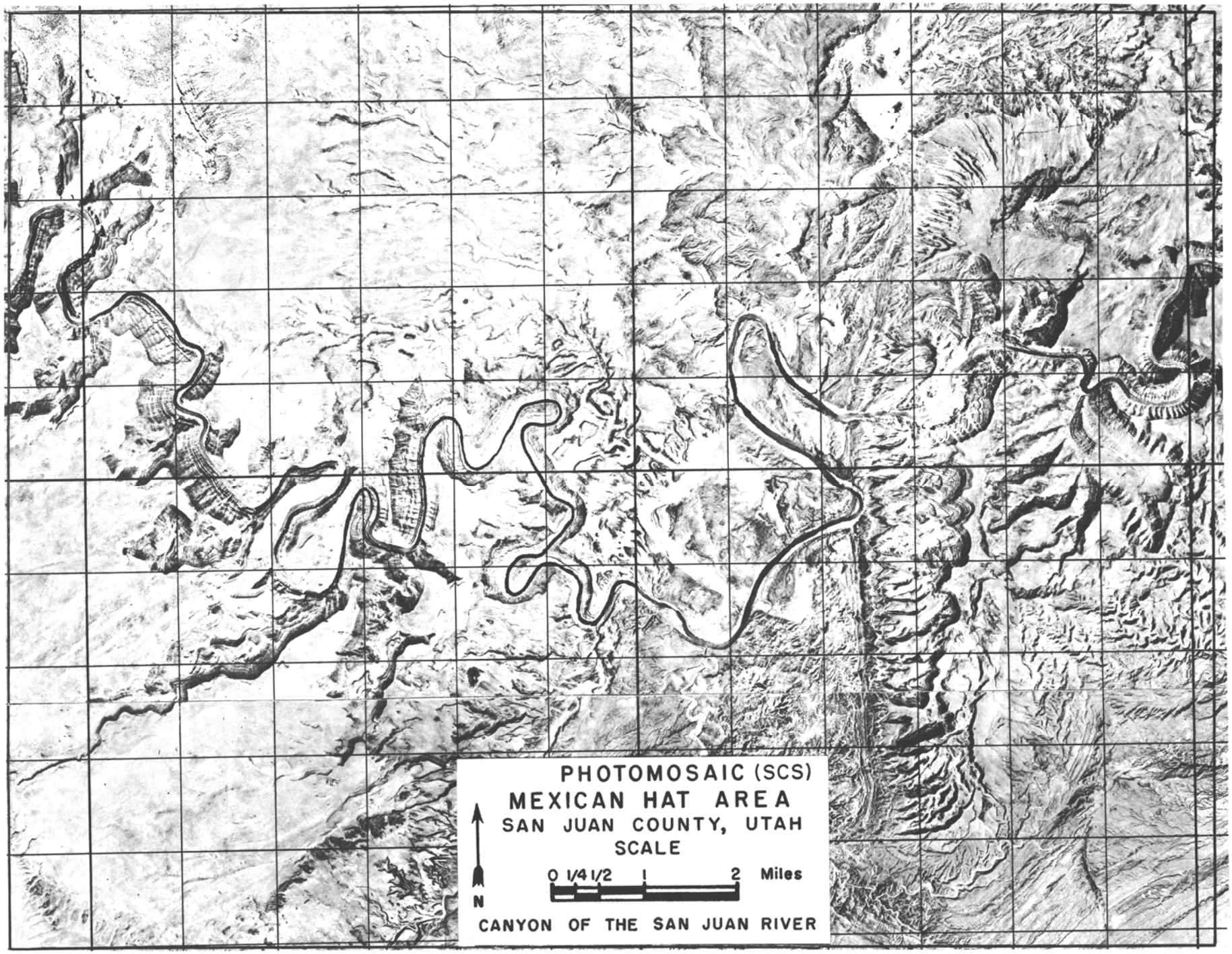
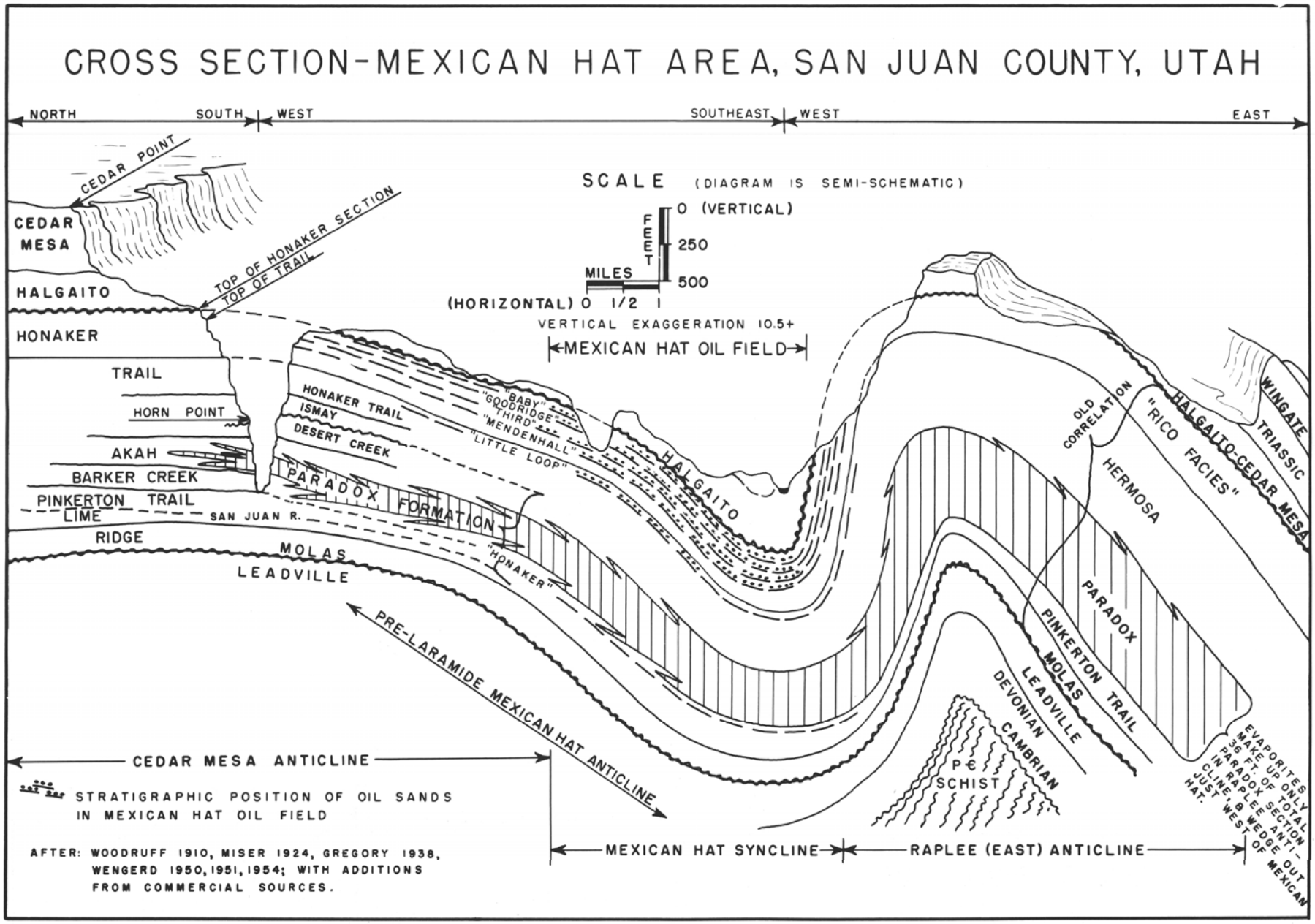
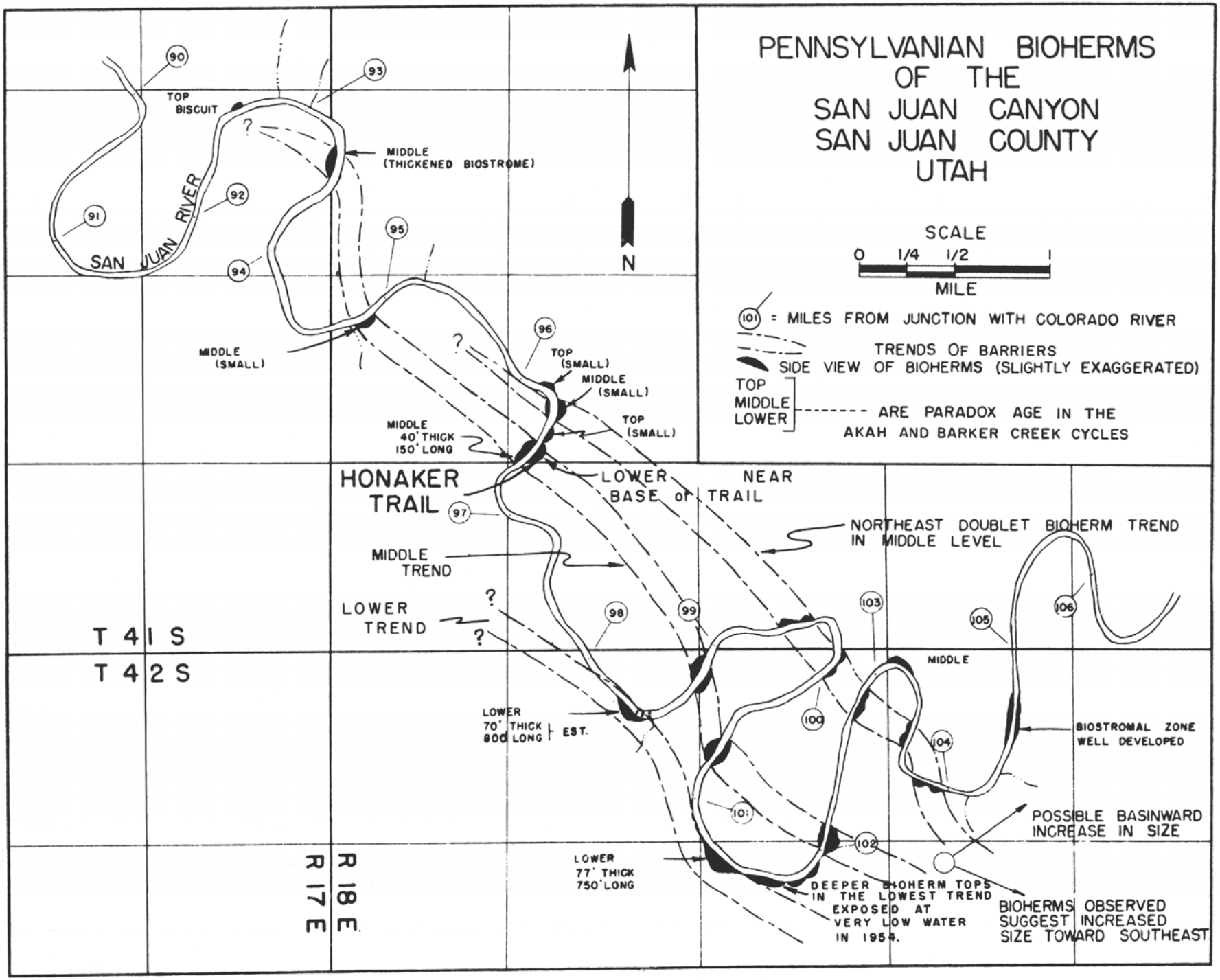

BLANDING BASIN
MONUMENT UPWARP
SLICKHORN GULCH
JOHNS CANYON
Pcm
Pcm.
Pcm
Pcm
Pcm
Pcm
Pr
Pr
Pr
Pr
Pr
Ch
Ch
Phg
Phg
Phg
Phg
GOOSENECKS
DOUGLAS MESA
MEXICAN HAT
COMB RIDGE
SAN JUAN R.
BLUFF
POST-CEDAR MESA FORMATIONS
POST-CEDAR MESA FORMATIONS
UTAH
ARIZONA
BLACK MESA BASIN
* HIGHLY GENERALIZED
38
39
40
41
42
T 43 S
R15E
R20E
R25E
16
17
18
19
21
22
23
24
26
27
FORMATIONAL CONTACTS*
SOUTHERN MONUMENT UPWARP, SAN JUAN Co. UTAH
FORMATION LEGEND
Pcm — CEDAR MESA SS.
Phg — HALGAITO sh.
Pr — } HERMOSA
Ch — } GROUP
0 3 6
SCALE in MILES
AFTER U.S.G.S. O & G MAP # 70

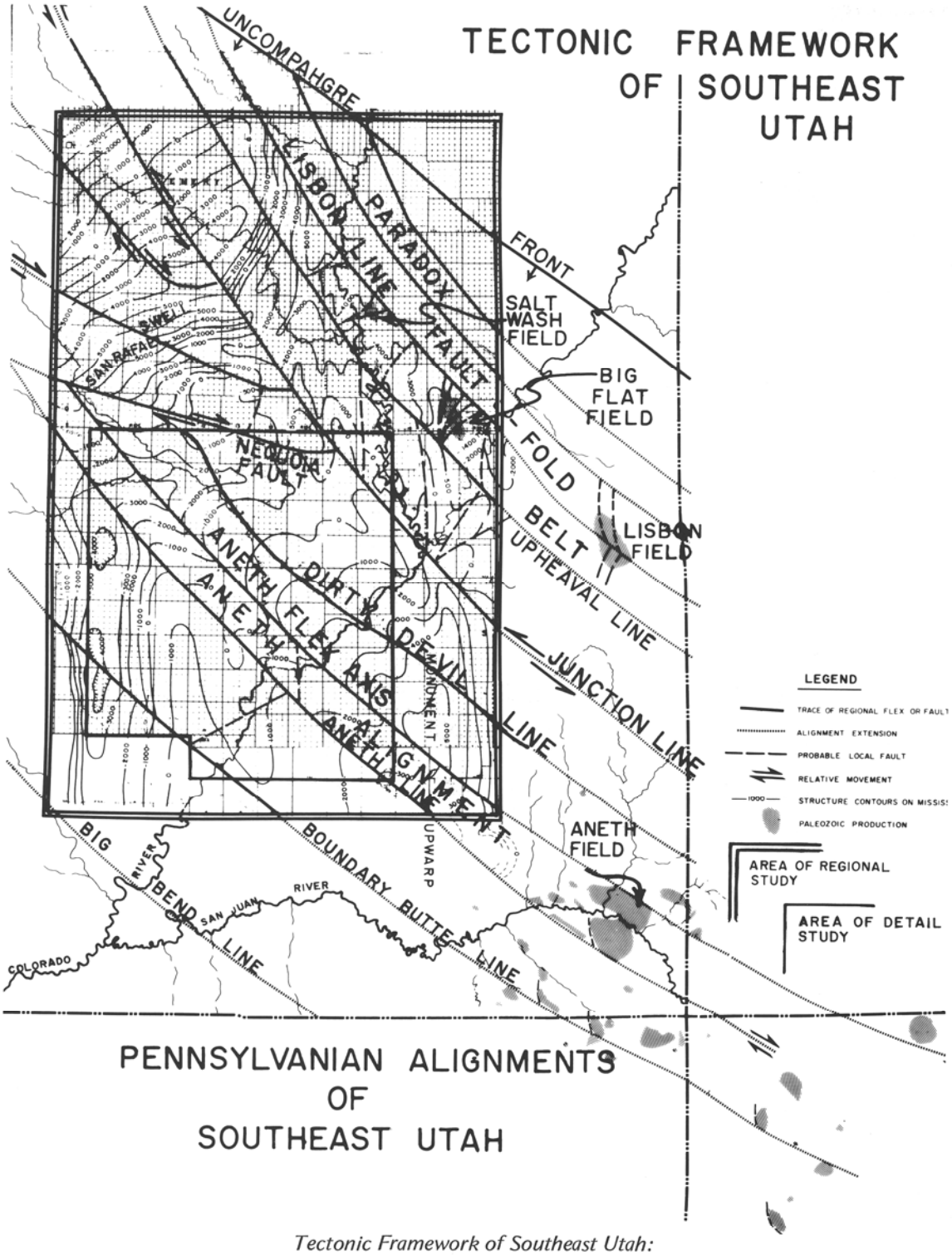

STRUCTURAL AXES
MEXICAN HAT REGION
SE UTAH-NE ARIZONA
0 3 6 12
SCALE IN MILES
OUTLINE OF MEXICAN HAT OIL FIELD
AXES OF ANTICLINES & SYNCLINES
KAIPAROWITS BASIN
SAN JUAN
PARADOX SALT BASIN
MONUMENT UPWARP
COMB RIDGE
BLANDING BASIN
BLACK MESA BASIN
ELK RIDGE
BLANDING
BEARS EARS
NORTHWEST FISHCREEK
POSSIBLE SOUTHWEST
FISHCREEK
COTTONWOOD
BULLET SPRINGS
BLUFF BENCH
ARROWHEAD BLUFF
ANETH AREA
NOKAI
SPRING SYNCLINE
NORTH ORGAN ROCK
OL JATO SYNCLINE
SLICK HORN
JOHNS CANYON
CEDAR MESA
MEXICAN HAT OIL FIELD
MEXICAN HAT SYNCLINE
LIME RIDGE
BIG BEND
BALANCE ROCK
SOUTH ORGAN ROCK
MOONLIGHT
HALGAITO
MONUMENT
MEXICAN
RAPLEE (EAST)
DESERT CREEK
NORTH BOUNDARY BUTTE
BOUNDARY BUTTE
HASKININI
GYPSUM CREEK
EL CAPITAN
UTAH
ARIZONA
T 43 S
41 N
40
39
R 20 E
R 25 E


GEOGRAPHY
MEXICAN HAT AREA
SAN JUAN COUNTY, UTAH
SCALE 0 1 2 MILES
PRODUCTIVE OUTLINE OF OIL FIELD
ROADS
OIL SEEP (GREGORY 1909, MISER 1924)
HALGAITO—CEDAR MESA ANTICLINE
MEXICAN HAT SYNCLINE
RAPLEE ANTICLINE
BELL BUTTE
CEDAR POINT
TO BLUFF
LIME CREEK
SODA BASIN
GOOSENECKS LOOKOUT
TO GOOSENECKS
HONAKER TRAIL
MAIN PART OF MEXICAN HAT OIL FIELD
GOOSE NECKS
CABIN
DISCOVERY WELL
MENDENHALL LOOP
BRIDGE
ALHAMBRA ROCK
TO KAYENTA
GYPSUM CREEK
T 41 S
T 42 S
R 18 E
R 19 E


PHOTOMOSAIC (SCS)
MEXICAN HAT AREA
SAN JUAN COUNTY, UTAH
SCALE
0 1/4 1/2 1 2 Miles
N
CANYON OF THE SAN JUAN RIVER

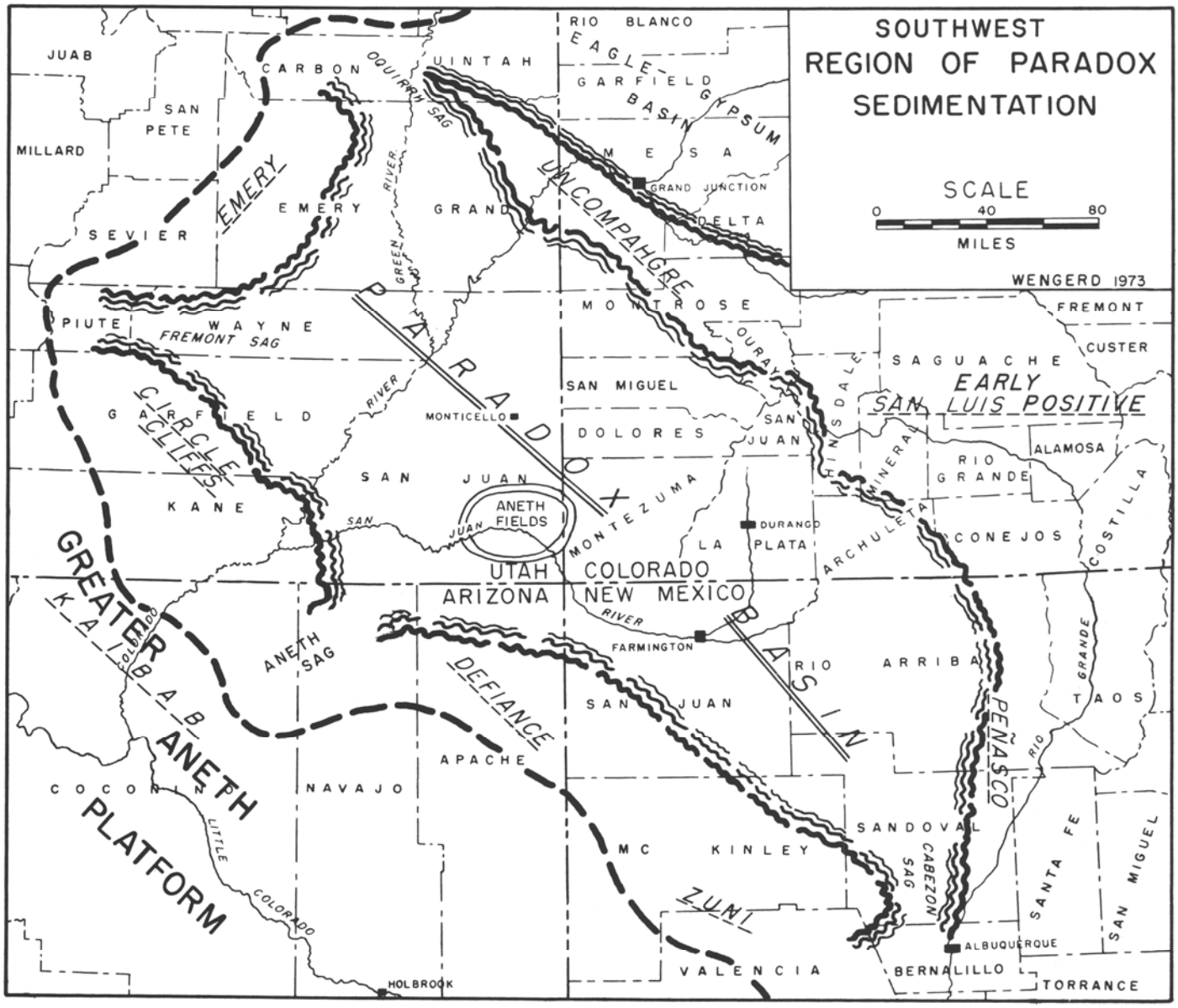

CROSS SECTION-MEXICAN HAT AREA, SAN JUAN COUNTY, UTAH
NORTH
SOUTH
WEST
SOUTHEAST
WEST
EAST
CEDAR POINT
CEDAR MESA
TOP OF HONAKER SECTION
TOP OF TRAIL
HALGAITO
HONAKER
TRAIL
HORN POINT
AKAH
BARKER CREEK
PINKERTON TRAIL
LIME
RIDGE
SAN JUAN R.
MOLAS
LEADVILLE
HONAKER TRAIL
ISMAY
DESERT CREEK
PARADOX FORMATION
"BABY"
"GOODRIDGE"
"THIRD"
"MENDENHALL"
"LITTLE LOOP"
"HONAKER"
HALGAITO
SCALE (DIAGRAM IS SEMI-SCHEMATIC)
FEET
0 (VERTICAL)
250
500
MILES
(HORIZONTAL) 0 1/2 1
VERTICAL EXAGGERATION 10.5+
MEXICAN HAT OIL FIELD
OLD CORRELATION
"RICO FACIES"
HALGAITO-CEDAR MESA
WINGATE
TRIASSIC
HERMOSA
PARADOX
PINKERTON TRAIL
MOLAS
LEADVILLE
DEVONIAN
CAMBRIAN
P€
SCHIST
PRE-LARAMIDE MEXICAN HAT ANTICLINE
EVAPORITES MAKE UP ONLY 36 FT. OF TOTAL PARADOX SECTION IN RAPLEE ANTICLINE, & WEDGE OUT JUST WEST OF MEXICAN HAT.
CEDAR MESA ANTICLINE
STRATIGRAPHIC POSITION OF OIL SANDS IN MEXICAN HAT OIL FIELD
AFTER: WOODRUFF 1910, MISER 1924, GREGORY 1938, WENGERD 1950, 1951, 1954; WITH ADDITIONS FROM COMMERCIAL SOURCES.
MEXICAN HAT SYNCLINE
RAPLEE (EAST) ANTICLINE


PENNSYLVANIAN BIOHERMS
OF THE
SAN JUAN CANYON
SAN JUAN COUNTY
UTAH
SCALE
0 1/4 1/2 1
MILE
(101) = MILES FROM JUNCTION WITH COLORADO RIVER
TRENDS OF BARRIERS
SIDE VIEW OF BIOHERMS (SLIGHTLY EXAGGERATED)
TOP
MIDDLE
LOWER
ARE PARADOX AGE IN THE
AKAH AND BARKER CREEK CYCLES
N
SAN JUAN RIVER
TOP
BISCUIT
MIDDLE
(THICKENED BIOSTROME)
MIDDLE
(SMALL)
TOP
(SMALL)
MIDDLE
(SMALL)
TOP
(SMALL)
MIDDLE
40' THICK
150' LONG
HONAKER
TRAIL
LOWER
BASE of TRAIL
NEAR
NORTHEAST DOUBLET BIOHERM TREND
IN MIDDLE LEVEL
MIDDLE
TREND
LOWER
TREND
T 41 S
T 42 S
R 18 E
R 17 E
LOWER
70' THICK
800 LONG
EST.
MIDDLE
BIOSTROMAL ZONE
WELL DEVELOPED
POSSIBLE BASINWARD
INCREASE IN SIZE
LOWER
77' THICK
750' LONG
DEEPER BIOHERM TOPS
IN THE LOWEST TREND
EXPOSED AT
VERY LOW WATER
IN 1954.
BIOHERMS OBSERVED
SUGGEST INCREASED
SIZE TOWARD SOUTHEAST



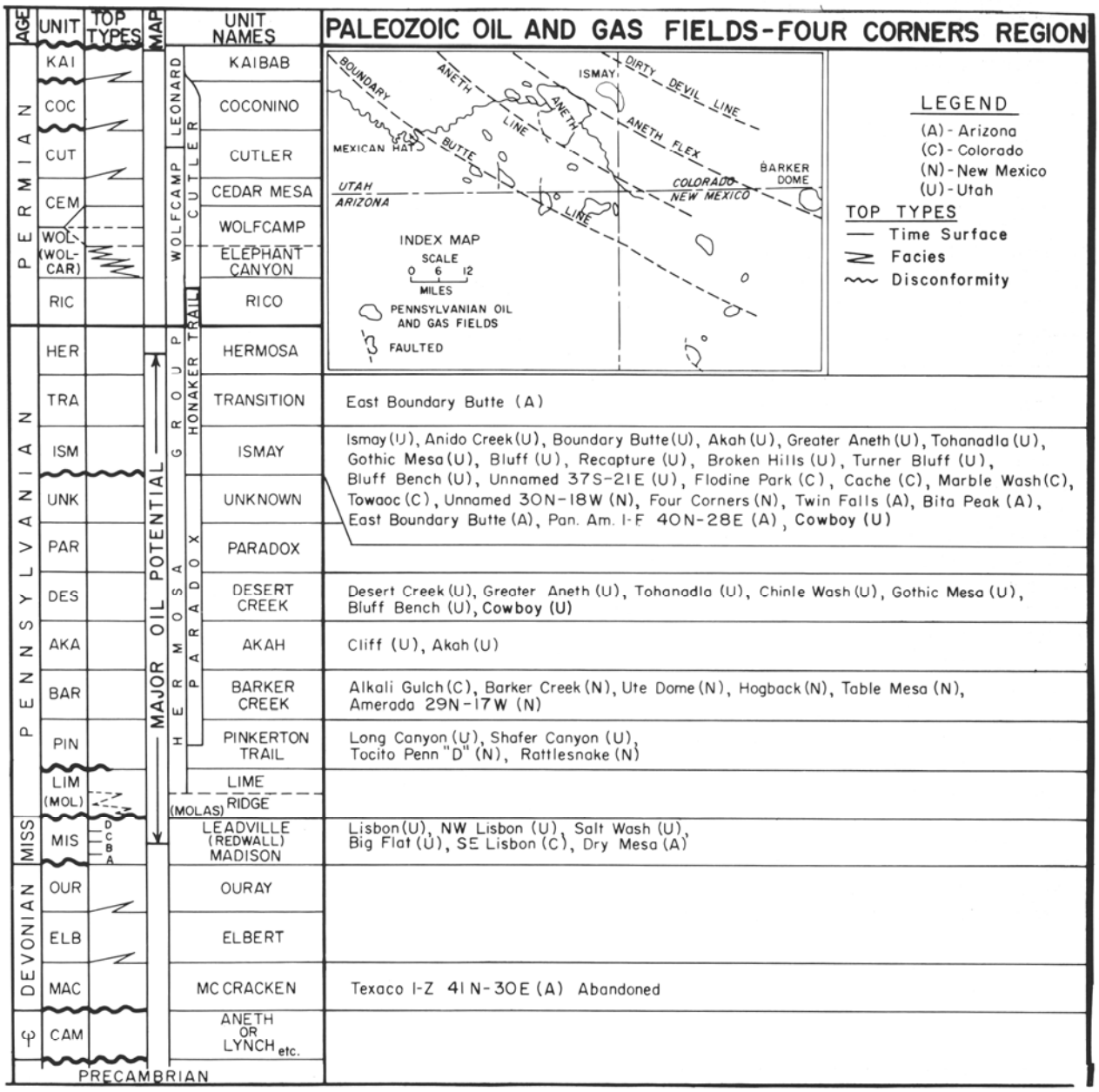
Tectonic Framework of Southeast Utah:
Pennsylvanian Alignments of Southeast Utah:

A geographic location of regional study is shown with respect to southeast Utah. Generalized structure contours are on the Mississippian at 1,000-foot intervals, based on well control plus projection and interpretation. Major fault and flexure alignments are shown by heavy lines. Abundant evidence for the existence of these Pennsylvanian sediment-controlling alignments is present in surface rocks as well as from subsurface information. Directions and amounts of strike-slip movement, indicated by arrows, are highly variable and were revealed only by detailed subsurface studies in the Aneth area on the southeast, along the entire Aneth alignment and on both sides of the Nequoia arch southeast of the San Rafael Swell. Paleozoic production in the Four Corners region, shown by hachure areas, is genetically related to these major structural alignments. Sedimentational, stratigraphic and structural conditions similar to those in the area of oil and gas production in proved areas are also present along the Aneth alignment northwest of the Monument upwarp on the western Paradox shelf. Exploration should most logically be done along these trends proved productive southeast of the Monument upwarp.



Southwest Region of Paradox Sedimentation:

Showing by a double oval the general area of the Aneth complex of oil fields which lie along the Aneth alignment in the Blanding basin of southeastern Utah. The Aneth fields lie directly northeast of the Aneth sag. The triple wavy lines record, in a highly generalized way, the location of Paradox facies of Pennsylvanian Desmoinesian age. These boundaries are a complex combination of depositional-erosional wedgeouts. The map shows uplifts underlined by dashed lines, the named sags, the Eagle-Gypsum basin and the Paradox basin. Until latest Desmoinesian time, the Eagle-Gypsum and Paradox basins were one intracratonic basin of Pennsylvanian sedimentation; later in Pennsylvanian and Permian time, the Uncompahgre uplift rose to split the region into two structural basins. The very heavy dashed line on the west and southwest is the first attempt by the author to place on a map the eastern edge of the greater Aneth platform which separated the Paradox basin from the Cordilleran miogeosyncline on the west. Middle Pennsylvanian tectonism followed by Late Pennsylvanian and Early Permian uplifts and erosion resulted in destruction of the Paradox high shelf sediments along the eastern flank of this major platform in areas of the labelled uplifts. Such tectonic disintegration is typical of the Colorado Ancestral Rockies.



Paleozoic Oil and Gas Fields—Four Corners Region:

Compilation of most of the oil and gas fields in the Paradox basin to show their relation to the time-stratigraphic zones of the complex Paradox shelf strata genetically related to basin-subsidence alignments. Major hydrocarbon discoveries have been made since 1954 in Ismay, Desert Creek, Barker Creek, Pinkerton Trail and Leadville strata. A major oil potential also lies in carbonate and quartz sand facies in the Transition (Tra), Hermosa (Her) and Akah-Barker Creek-Pinkerton Trail strata. Only a few of these fields are predominantly gas fields, such as East Boundary Butte, Twin Falls, Dry Mesa and Bita Peak in Arizona; the important Boundary Butte and Chinle Wash in Utah, Alkali Gulch in Colorado and Barker Dome in New Mexico. Lisbon, north of the inset Index Map, is a combination Mississippian-Devonian field producing large quantities of both oil and gas, whereas Big Flat and Salt Wash are Mississippian oil fields far to the north. The columns on the left record time surfaces, facies boundaries, and the major disconformities of mappable units utilized by Dr. Ernest Szabo and the author for commercial research projects, utilizing names in the literature. It is recognized that the name "Rico" is now invalid as a time-transgressive transition zone ranging in age from Desmoinesian near Moab, Utah, to Wolfcampian marine carbonates described by Dr. Don Baars as the Permian Elephant Canyon Formation.

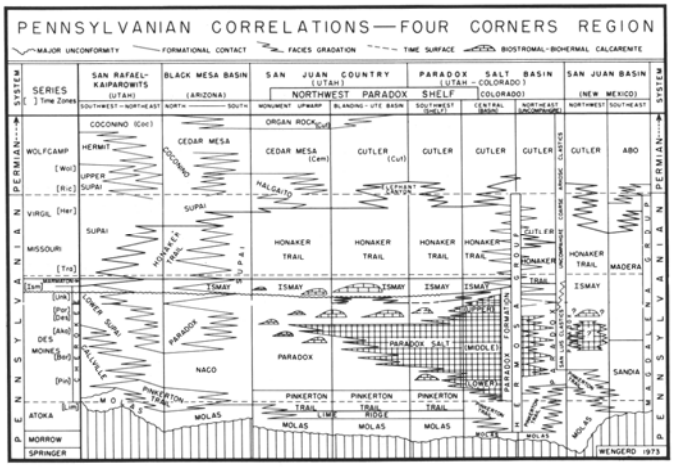
The "time-slices" labelled Unknown (Unk) and Paradox (Par) represent unnamed Paradox facies in the central part of the Paradox basin, beneath Ismay evaporites and above Desert Creek evaporites. Southwestward and westward from the basin axis, these mappable units thin to become time surfaces represented successively by black sapropelic dolomites (black shale) which merge into the unconformity between the Ismay above (cycle 3) and the Desert Creek below (cycle 4).

		FORMATION		CYCLES *	AGE	
PENNSYLVANIAN	HON TR'L	ISMAY		1 – 3	MARMATON	PENNSYLVANIAN
	PARADOX	DESERT CREEK		4 – 5	CHEROKEE	DESMOINESIAN
		AKAH		6 – 10		
		BARKER CREEK	UPPER	11 – 13		
			MIDDLE	14 – 15		
			LOWER	16 – 19		
		ALKALI GULCH		20 – 24		
		PINKERTON TRAIL		25 – 29		
		LIME RIDGE		30 – 34 ?	ATOKAN	PENNSYLVANIAN
		MOLAS FACIES			MORROWAN	
		MANNING CANYON			MISSISSIPPIAN	
		LEADVILLE				

* IN PART AFTER HITE (1960) WENGERD – SZABO 1968

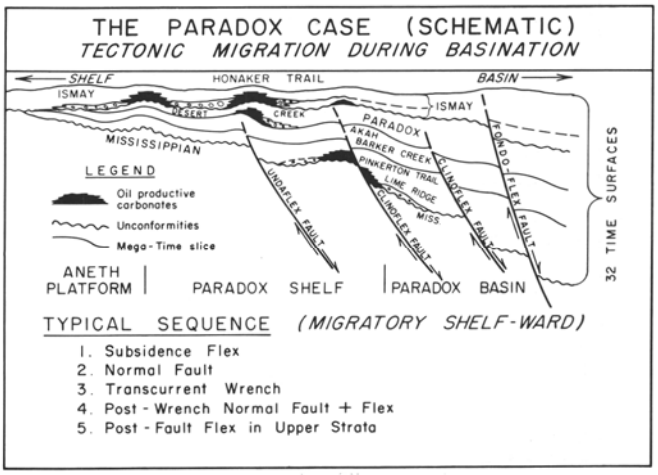
Table of Formations, Cycles and Ages:

This tabulation relates presently named formal cycles of the Paradox Formation as suggested by Wengerd and Szabo in 1968, based in large part after Hite's pioneering work of 1960. As more wells are drilled, one can predict that the named cycles will be called formations within a Paradox "group," and both the Honaker Trail and pre-Paradox sections may attain group status. Such informal proposals usually precede formal publication of revised type localities in national publications. In this article, no other mention is recorded for the Alkali Gulch cycle which Szabo and Wengerd include as the upper five subcycles of the Pinkerton Trail. Although some subcycle boundaries are difficult to pick, they are considered to be time surfaces, recognizable in almost all wells where present and a full suite of geophysical (mechanical) logs is available. Also, it must be recognized that fusulinid determinations of the Marmaton-Cherokee boundary are notably unreliable as to the species of Fusulina *involved. The Ismay, whose base is a regional disconformity over all of the southwest shelf of the Paradox basin, may in some areas find subcycle 3 to be of latest Cherokee age according to fusulinid determinations.*



Pennsylvanian Correlations—Four Corners Region:

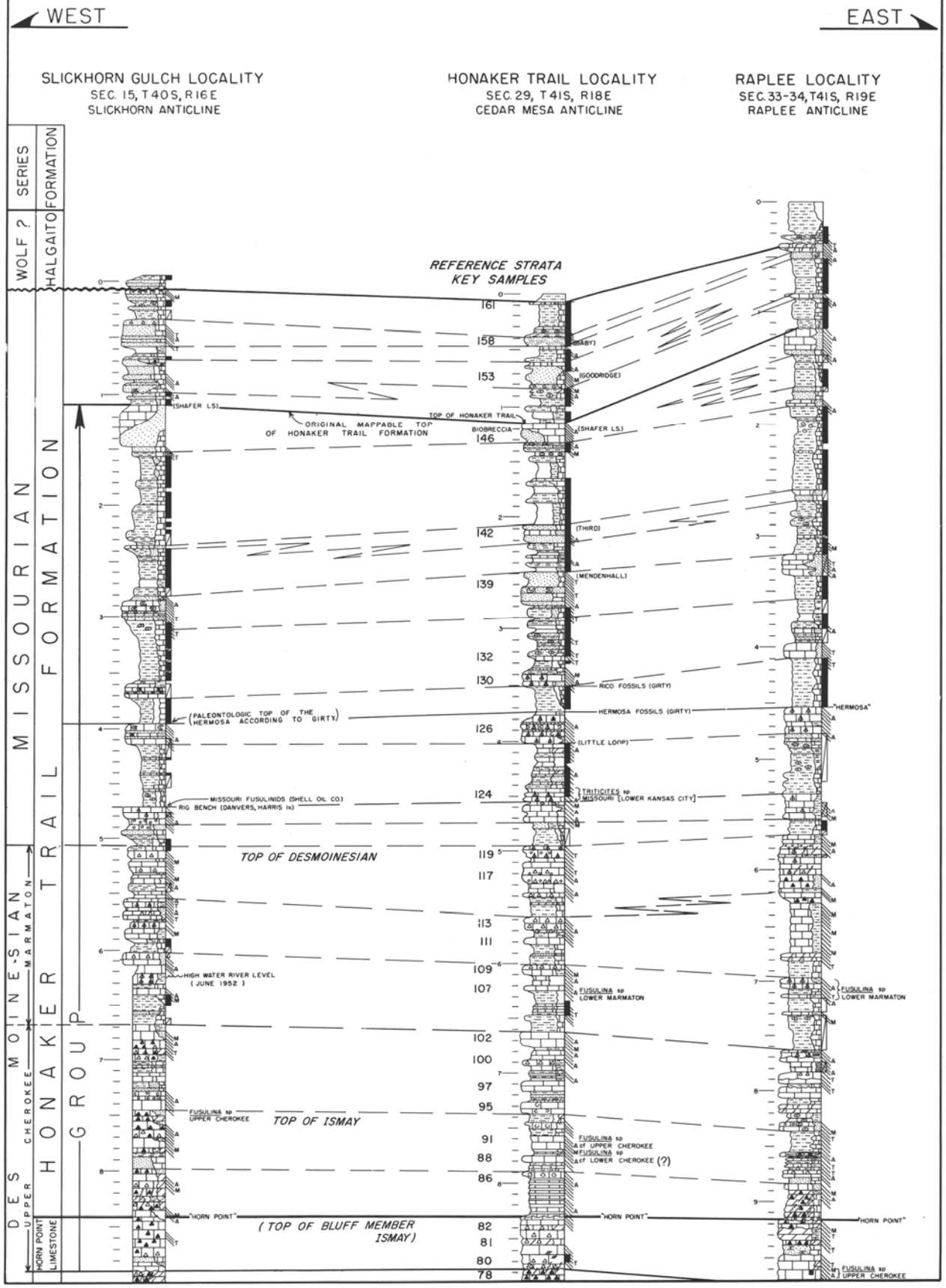
The left-hand columns of this compilation indicate Pennsylvanian and Early Permian series names combined with three-letter time-zone designations for major sedimentary cycles on the shelf of the Paradox basin. These informal designations relate commonly used formation names to more specific mappable time zones. Work is continuing to divide the Honaker Trail Formation into valid time-zone cycles. Numerous local and regional complications such as ringing disconformities, intra-systemic angular unconformities associated with the ringing uplifts such as the Nequoia arch and the Emery uplift, and salt intrusion in the Paradox fault-fold belt, complicate the search for oil and gas. The present Paradox basin is in fact the southwest part of a greater Paradox Basin which included the Maroon slope (Eagle-Gypsum basin) in northwestern Colorado; the site of the present Uncompahgre uplift, the Paradox salt basin, and the eastern shelf of the Aneth platform.

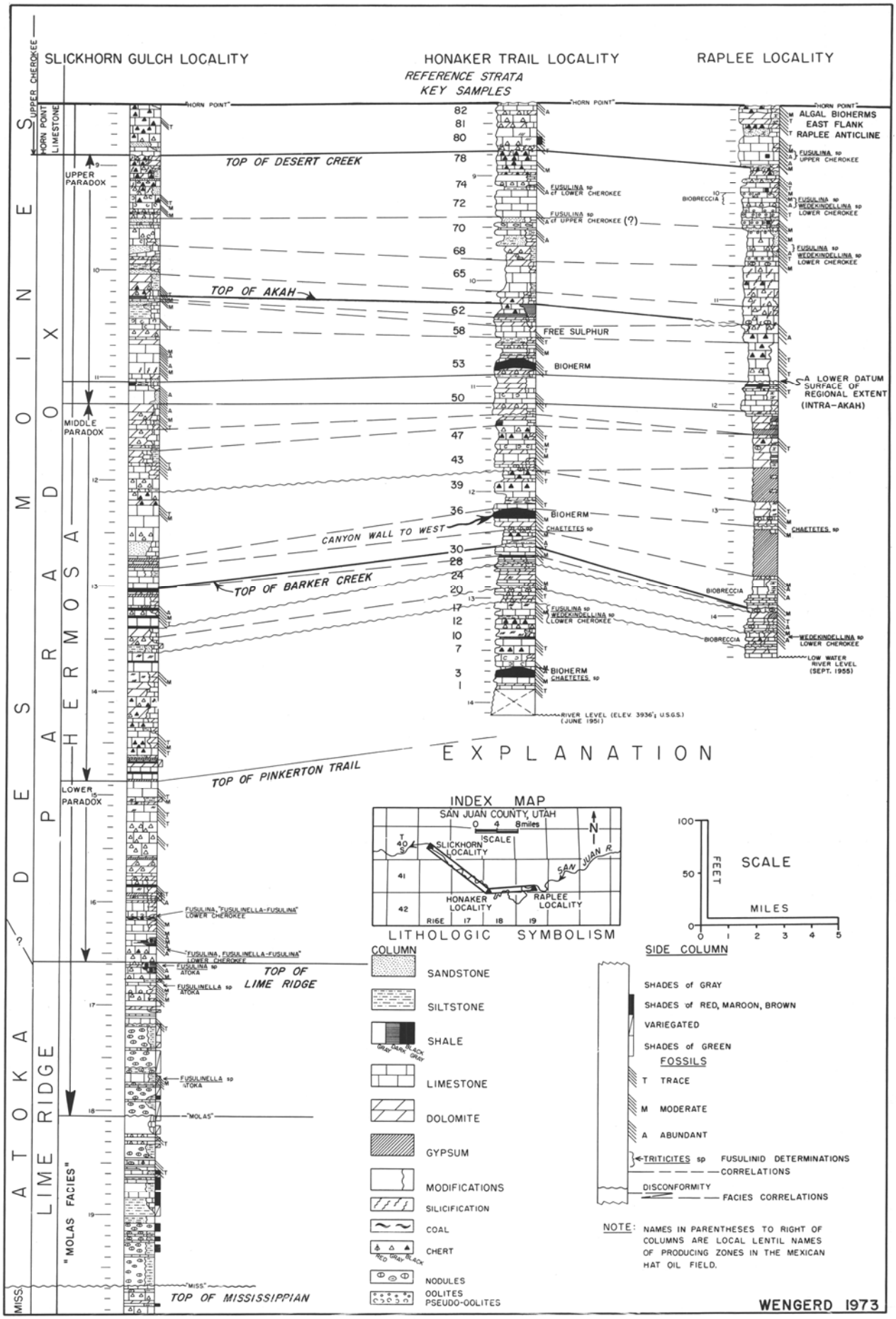


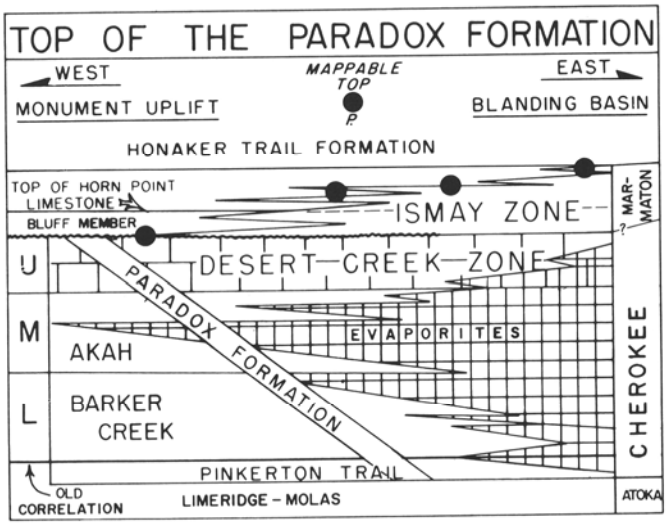
The Paradox Case (schematic):

A summary of probable subsidence flexing and subsequent faulting along one cross section from the high-shelf Aneth platform on the left across the Paradox shelf to Paradox basin on the right. Major cycle designations are shown, not to represent a true-scale section, but to depict relations of some flexes and faults to sedimentary patterns important to oil accumulations in different parts of the Paradox basin and its western shelf, southeast of the Monument upwarp. Structural genesis of the subsiding basin controlled sedimentation of the southwest shelf of the Paradox basin as well as the accumulation of oil in Pennsylvanian strata. This diagram depicts barrier carbonate trends and reef-associated and detrital quartz sand sediments. Potentially oil-productive situations similar to this are logically expectable northwest of the Monument upwarp on the Paradox shelf. Basinward development of Paradox evaporites is well documented northeast of the clinoflex faults—in the thickest Paradox sections. Thus this typical sequence of structural deformation is usually developed along clinoflex faults northeast of the Aneth alignment in areas of thicker Paradox salt.

LITHOLOGIC—STRATIGRAPHIC CROSS SECTION
MONUMENT UPWARP–SAN JUAN CANYON
SAN JUAN COUNTY, UTAH

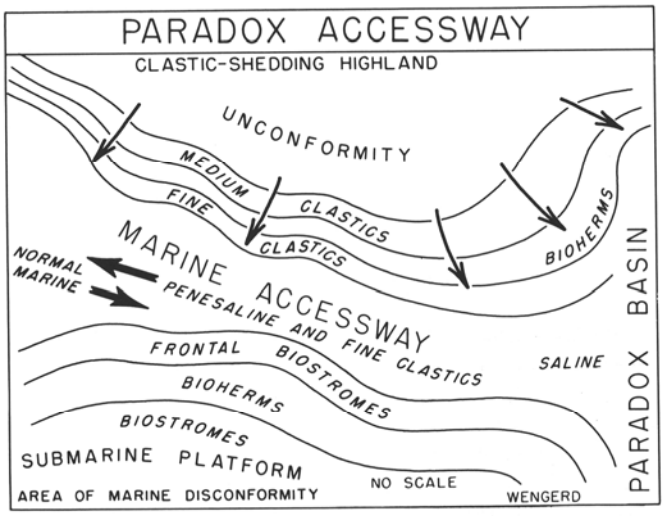



SLICKHORN GULCH LOCALITY
HONAKER TRAIL LOCALITY
REFERENCE STRATA
KEY SAMPLES
RAPLEE LOCALITY
UPPER CHEROKEE
HORN POINT LIMESTONE
"HORN POINT"
ALGAL BIOHERMS
EAST FLANK
RAPLEE ANTICLINE
TOP OF DESERT CREEK
UPPER PARADOX
MIDDLE PARADOX
LOWER PARADOX
TOP OF AKAH
FREE SULPHUR
BIOHERM
A LOWER DATUM SURFACE OF REGIONAL EXTENT (INTRA-AKAH)
CANYON WALL TO WEST
TOP OF BARKER CREEK
TOP OF PINKERTON TRAIL
TOP OF LIME RIDGE
"MOLAS"
"MOLAS FACIES"
"MISS"
TOP OF MISSISSIPPIAN
MISS
ATOKA
LIME RIDGE
PARADOX
HERMOSA
MOENKOPI
RIVER LEVEL (ELEV. 3936'; U.S.G.S.) (JUNE 1951)
LOW WATER RIVER LEVEL (SEPT. 1955)
EXPLANATION
INDEX MAP
SAN JUAN COUNTY, UTAH
SCALE
SLICKHORN LOCALITY
HONAKER LOCALITY
RAPLEE LOCALITY
SAN JUAN R.
LITHOLOGIC SYMBOLISM
COLUMN
SANDSTONE
SILTSTONE
SHALE
LIMESTONE
DOLOMITE
GYPSUM
MODIFICATIONS
SILICIFICATION
COAL
CHERT
NODULES
OOLITES
PSEUDO-OOLITES
SCALE
FEET
MILES
SIDE COLUMN
SHADES of GRAY
SHADES of RED, MAROON, BROWN
VARIEGATED
SHADES of GREEN
FOSSILS
T TRACE
M MODERATE
A ABUNDANT
TRITICITES sp FUSULINID DETERMINATIONS
CORRELATIONS
DISCONFORMITY
FACIES CORRELATIONS
NOTE: NAMES IN PARENTHESES TO RIGHT OF COLUMNS ARE LOCAL LENTIL NAMES OF PRODUCING ZONES IN THE MEXICAN HAT OIL FIELD.
WENGERD 1973



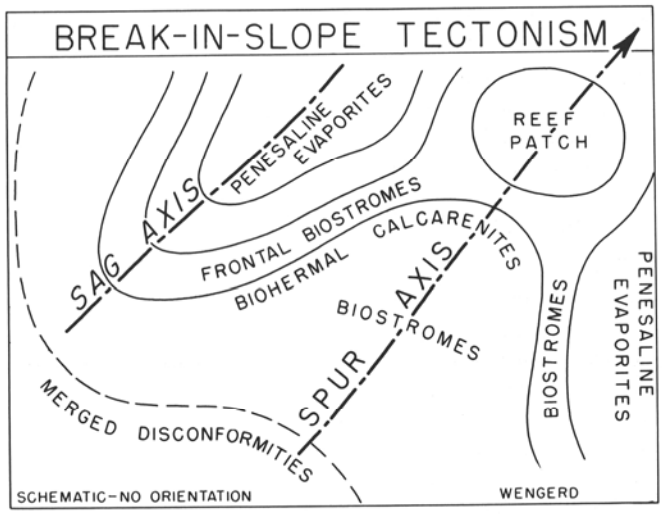
Top of the Paradox Formation:

Earlier published works on the Paradox basin, when well densities were much lower, noted the presence of evaporites in the Ismay cycle (then called a zone), whereupon the Ismay in the central part of the basin was put into the Paradox; later drilling and lentil-by-lentil correlation utilizing time-surfaces controlled in part by fusulinids, allowed recognition of the Ismay as a valid time zone of Fusulina *sp (despite the Marmaton-Cherokee problem) that lies disconformably on deeper and deeper formations westward on the Paradox shelf, i.e., the east flank of the greater Aneth platform. The Ismay is now considered to be a lower cycle of the Honaker Trail Formation whose base is far more easily recognized than its top. Correlations by Dr. Dennis Irwin and Dr. Don Baars indicate that the top of the Horn Point limestone of Hugh Miser at the Honaker Trail locality is in fact the Bluff member of the Ismay, productive of oil and gas in the Bluff field of the Blanding basin. Over most of the southwest Paradox shelf, there is a distinct unconformity (recognized in 1953 by Clair as a pre-Des Moines unconformity) between what we now call Pinkerton Trail and Lime Ridge, whose basal member is the ubiquitous and puzzling Molas section.*



Paradox Accessway:

A rim sag across the ancient greater Aneth platform on the west side of the Paradox basin. Normal sea water entry from the left (west); wind direction from the northeast. This model is the Fremont accessway.



Break-in-Slope Tectonism:

Schematic model of the Aneth complex of Pennsylvanian oil and gas fields of southeastern Utah and northeastern Arizona. Although no true orientation is intended, rotation of this diagram about 60° to the right represents the author's concept of the paleographic orientation and conditions of Paradox sedimentation east of the Fremont accessway along the east side of the Aneth platform. This is the area where the Akah to Transition sections are preserved northwest of the Monument upwarp.