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# REGIONAL GEOLOGY AS RELATED TO THE PETROLEUM POTENTIAL OF THE LUCERO REGION, WEST-CENTRAL NEW MEXICO

by
SHERMAN A. WENGERD [1]

## INTRODUCTION

The Lucero region is about 100 miles long east-west and 50 miles wide north-south, and surrounds the common corner of Valencia, Catron, and Socorro Counties in west-central New Mexico (fig. 1). This region, which is less than half the size of the San Juan Basin, is a topographic basin bounded on the east by the Lucero uplift and the Rio Grande trench, on the south by the Ladron-Datil-Gallo Mountains, on the west by the Zuni Plateau, and on the northwest and north by the Zuni Mountains and Mount Taylor.

The average altitude of the Lucero region is 6,600 feet, with altitudes ranging from 7,800 feet on the highest plateaus to 5,800 feet in the drainage on the southeast. (see fig. 2.) D-Cross Mountain (8,400'), La Cruz (6,975'), and La Jara (6,875') are the highest volcanic plugs in the southeastern part of the area. Several high mesas are capped with thin lavas. Mesa del Oro and Cebolleta Mesa are 6,600 and 7,800 feet in altitude respectively, whereas the alluvial San Augustin Plains and North Plains valleys are 6,800 and 7,000 feet in altitude respectively.

The region is drained by the Rio San Jose and Arroyo Colorado to the northeast and the Rio Salado-Alamosa Creek drainage system to the southeast. Drainage to the west is by Carrizo Creek. Most of the San Augustin Plains and North Plains are areas of interior drainage with only minor surface drainage outlets. Only the Salado-Alamosa and San Jose approach perennial flow; all other arroyos are intermittent.

The following is a tabulation (adapted from Givens, 1957, p. 4) of average climatic conditions in the Lucero region:

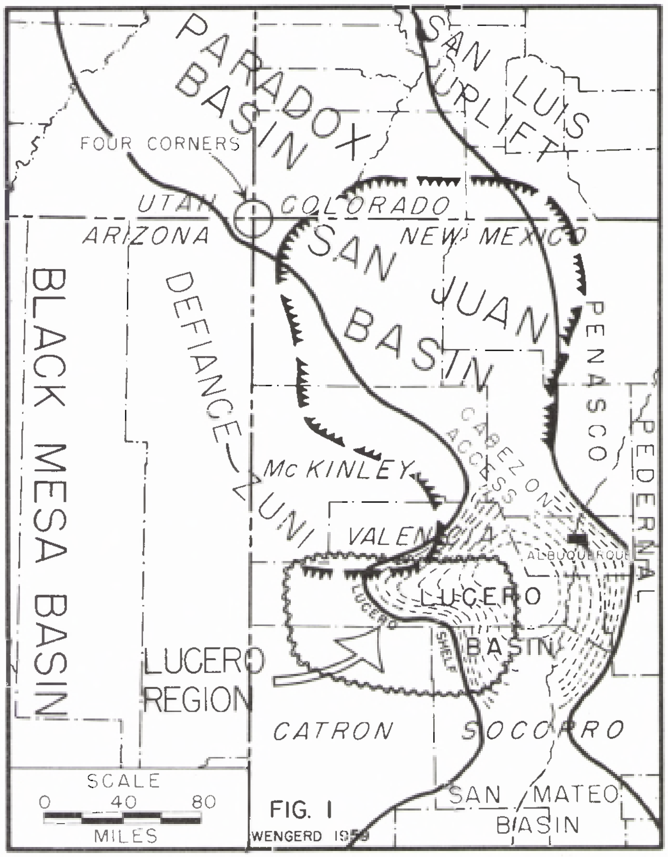
| | |
|---|---|
| Annual Precipitation | 13 inches |
| Annual Snowfall | 30 inches |
| Summer High Temperature | 82° F |
| Winter Low Temperature | 17° F |
| Highest Temperature | 100° F |
| Lowest Temperature | -20° F |

Snowfall season ranges from late November to April, but snow rarely stays on the ground more than a few days at altitudes below 7,000 feet. Spring thaw occurs from mid-March to late April, and the rainy season consists of afternoon showers during July and August.

The east side of the Lucero region is accessible via graded State Highway 52 between Correo on U. S. Highway 66 and Magdalena on U. S. Highway 60. The west-central and western parts of the region are accessible via state roads 36 and 117 between U. S. Highways 66 and 60. The east-central part of the region is accessible via several graded county roads. East-west travel across the Lucero region is difficult but possible on branch trails and newly bladed trails extending as laterals and diagonals off of the north-south system of county and state roads.

### Methods of Study

The Lucero project was considered by the writer as a logical effort pointed toward the discovery of petroleum reserves as early as 1954, when a reconnaissance trip into the region succeeded early search of the literature in order to determine why more wells had not been drilled south




of the Zuni uplift.

In August of 1957, intensive work was begun in the literature, and well data, maps, and air mosaics were assembled for initial study. It was recognized early in the study that the Pennsylvanian potential could not be appraised without also studying the Permian possibilities. The project was continued by specific photogeologic analysis of the regional and local structure. Field reconnaissance trips were made by airplane, jeep, and car, and stratigraphic sections were examined in the field. As acreage assembly by Ula Mining Corporation proceeded, more focus was brought to bear on specific anticlines widely scattered across stratal trends which could reasonably be expected to be porous and contain petroleum in rocks ranging from Cretaceous to Pennsylvanian in age.

### Acknowledgements

The writer is indebted to Darrow M. Thompson, President of Ula Mining Corporation, for the financial aid in this research and for permission to publish some of the results; to Cresson B. Kearny for long discussions and some data based on reconnaissance and detailed field work; to Florence M. Wengerd for typing the manuscript; and to Frank E. Frost, Jim S. Hinds, and Ted Wengerd for drafting the illustrations. Early guidance into the region, field checking, and supply of some literature came from Waldemere Bejnar of Socorro, and the initial photogeological analysis was made by Tom Beard and Lowell Bogart, photogeologic consultants of Albuquerque.

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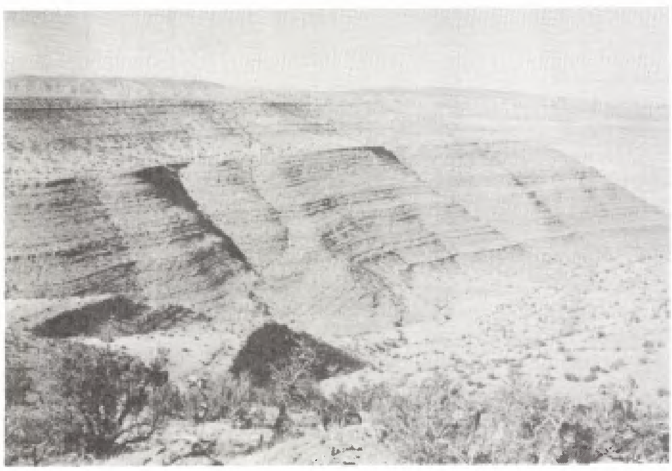
**Fig. 2—Photographs of the Lucero Region**

A. Sierra Lucero. East-facing scarp of Permian Glorieta-San Andres strata lying on Yeso strata in foreground. View west-southwest from east side of Lucero region.

B. Lucero region. View north across X-Cross structure from Broom Mountain on line between R. 7 W. and R. 8 W., in T. 5 N., Valencia County.



C. The lower 2/3 of the basinal Pennsylvanian section on Monte de Belen, Secs. 29-30, T. 4 N., R. 3 W., Socorro County.

D. Lucero region. View southeast from Broom Mountain across Broom Mountain anticline in foreground, south plunge Wedgeout anticline in far middleground, and Upper Red Lake anticline in right middle distance. Mountains in extreme distance are the Magadalenas.

**Stratigraphic Setting**

The Lucero region includes the west half of the Lucero sedimentational basin (fig. 1) and is underlain by Pennsylvanian marine rocks that range in thickness from 2,500 feet on the east to zero on the west; Permian continental and marine rocks that range from 2,800 and 2,600 feet on the southwest to 2,000 feet on the northeast; Triassic continental rocks that range from 1,700 feet on the northeast to zero on the far southwest; Jurrassic continental rocks that range from 800 feet on the north to zero in an east-west trend across the medial part of the region; and Cretaceous marine rocks, absent by erosion over the eastern one-third of the region, but ranging from 1,000 to 2,000 feet in thickness throughout the western two-thirds of the region. The total stratigraphic section in the area of maximum oil potential ranges from 4,000 to 6,500 feet in thickness (fig. 3).

**Structural Setting**

The regional dips generally are westward from the Lucero uplift on the east, southward beneath the volcanic mountains on the south, eastward from the Zuni-Manuelito-Pinon Springs fault system on the west near the Arizona line, southwestward to southeastward from the Zuni uplift on the northwest, and northward on the north into the Acoma embayment which extends into the San Juan Basin.

Structurally the highest part of the central portion of the Lucero region is in the area of Tps. 5-6 N., Rs. 7-8 W. in the locale of the Broom Mountain and Arroyo Colorado anticlines (fig. 4); the major Red Lake normal fault, downthrown to the east, trends northward through the region, whereas the Hickman normal fault, downthrown to the west, trends northward through Rs. 9 to 11 W., from Tps. 3 to 9 N. Between the two fault systems lies a vast regional horst in the Lucero region, and the north-south trend in R. 6 W. is a regional synclinal sag (fig. 5).

Local structures comprise about 25 broad low anticlinal noses, structural terraces, broad low-closure anticlines, and sharply folded high-closure, faulted anticlines. All of these show diverse trends which indicate a complex geologic-tectonic history so typical of oil-productive regions throughout the Rocky Mountains.

## GEOLOGY

### Geologic History

Remnants of Mississippian limestones lying on the southeast edge of the region, combined with Pennsylvanian rocks lying on Precambrian "granite" over the remainder of the Lucero region, suggest that erosion predominated during all of early Paleozoic time (fig. 5).

During Pennsylvanian time the Lucero region was a broad, westward-projecting, sag-like shelf off of the basinal axis of the Cabezon-Lucero-Socorro-San Mateo-Orogrande marine accessway (see Thompson, 1948, p. 70-72) which joined the Paradox basin on the north to the Sonoran geosyncline on the south (fig. 1). The marine accessway here ranged from 40 to 100 miles in width, and over 3,000 feet of Pennsylvanian sediments were deposited in its deepest parts. It is this wide part of the seaway that is referred to as the Lucero basin. The Lucero region makes up approximately the western half of the basin. Pennsylvanian sedimentation was limited on the west by the Zuni positive area which shed some fine red, Supia-like, clastic sediments across the Lucero shelf. Coarser clastic Pennsylvanian and Permian sediments came into the region from the Penasco uplift on the north (fig. 1). Pennsylvanian strata, however, vary from gray shale, limy shale, shaly limestone, and limestone where the section is thickest near the axis of the accessway (fig. 6), to massive carbonates, possibly of reef origin, westward across the break-in-shelf slope within the Lucero region herein delineated. The stratigraphic situation is analagous to that on the southwest flank of the Paradox Basin where the Aneth field is located, except that no Paradox evaporites are known in the Pennsylvanian sections of the Lucero region.

Following deposition of continental redbeds during Permian (Wolfcamp) time, the Quemado-Cuchillo (St. Johns) basin came into existence (see fig. 7), and marine strata of Permian (Leonard) age were deposited over the southwestern two-thirds of the Lucero region (Foster, 1957). Triassic and Jurassic continental sedimentation followed, with northward and northeastward tilt of the region and erosion preceding Cretaceous marine encroachment from the Rocky Mountain geosyncline. With several minor exceptions, the geologic history of the Lucero region is much like that of the Four Corners region to the north, inasmuch as probable diverse-trending Pennsylvanian and Permian drape structures and minor folds were accentuated during the Laramide folding at the end of Cretaceous time. Tertiary faulting and scattered volcanism, followed by erosion, produced the scenery of today. The writer is of the opinion that the Lucero region is a part of the Four Corners region.

The Lucero basin was named (Wengerd and Matheny, 1958, p. 2,081) from the north-trending Sierra Lucero (Darton, 1928, p. 124) on the east side of the Lucero region. Prior to this time, parts of the Lucero region were called variously the Puertecito Basin (Wells, 1919, p. 7), the south part of the Acoma Basin, and the southeastern part of the San Juan Basin (Winchester, 1920, p. 11), and the Alamocito Basin. All of the local names referred to small areas which are topographic basins. Kelley recognized the existence of several of these basins (1955, fig. 2).

An analysis of regional dips strongly suggests that the structure of the Lucero region is saddle-shaped, with the pommel projecting westward to form the Zuni-Gallup basin on the south side of the Zuni uplift. Near the end

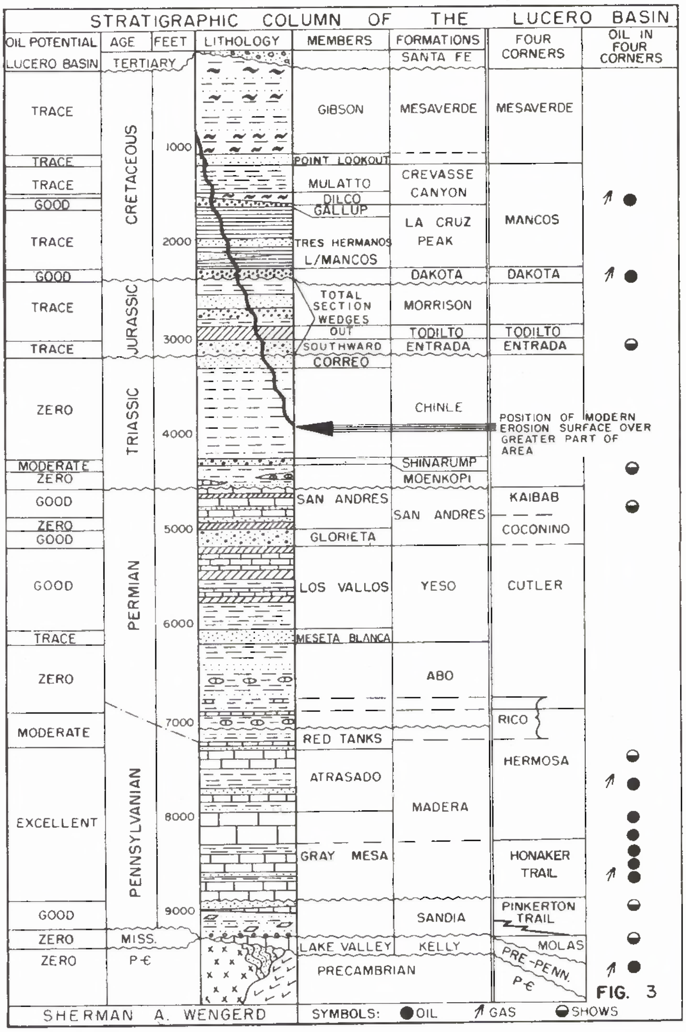


FIG. 3

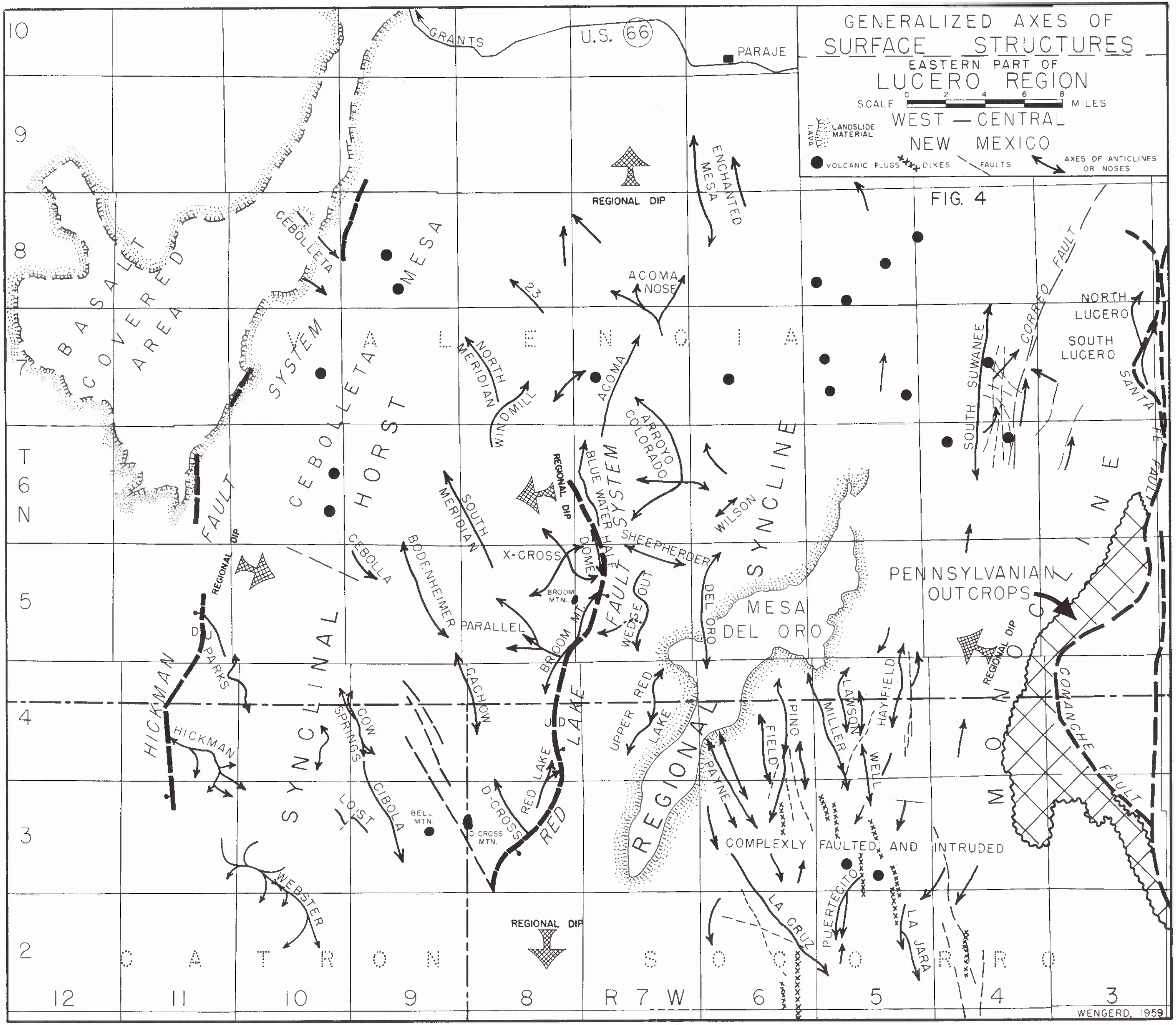
of Cretaceous time and in Tertiary time, the Zuni Mountains were uplifted on the northwest, and the Lucero anticline on the east was strongly folded and elevated. Sierra Lucero is the west flank of a gigantic anticline which separates the Lucero region from the Rio Grande trench (Kelley and Wood, 1946). The Acoma basin on the north is the north flank of the Lucero region, and the southernmost flank is hidden beneath Tertiary volcanic mountains outside the area of study.

During most of Cretaceous time, the Lucero region was the southeast and east flank of southerly segments of the Mesocordilleran geanticline. This area, similar to the San Juan Basin, was a southerly shelf of the Rocky Mountain geosyncline and thus experienced a rocking-tilting action of very diverse nature during the span of geologic time between Mississippian and latest Cretaceous marine sedimentation. Broad regional uplift and westward and northward tilting took place in Tertiary time.

The Lucero region is furrowed by numerous diverse-trending anticlines of Laramide age and older, and is cut by faults of Tertiary age.

### Regional Structure and Sedimentational History

The Lucero region includes the southeastermost exposed area of sedimentary rocks in the Colorado Plateau physiographic province. Although a true sedimentational


GENERALIZED AXES OF
SURFACE STRUCTURES
EASTERN PART OF
LUCERO REGION
SCALE 0 2 4 6 8 MILES
WEST — CENTRAL
NEW MEXICO
LAVA
LANDSLIDE MATERIAL
VOLCANIC PLUGS
DIKES
FAULTS
AXES OF ANTICLINES OR NOSES
U.S. 66
GRANTS
PARAJE
REGIONAL DIP
BASALT COVERED AREA
CEBOLLETA
MESA
CEBOLLETA HORST
SYSTEM
LENOCIA
ACOMA NOSE
23
NORTH MERIDIAN
WINDMILL
ACOMA
ARROYO COLORADO
ENCHANTED MESA
SOUTH SUWANEE
CORREO FAULT
NORTH LUCERO
SOUTH LUCERO
SANTA FE FAULT
BLUE WATER HALF DOME
FAULT SYSTEM
WILSON
SYNCLINE
SHEEPHERDER
X-CROSS
SOUTH MERIDIAN
BODENHEIMER
CEBOLLA
HICKMAN FAULT
DU PARKS
BROOM MTN.
BROOM MT.
PARALLEL
WEDGE OUT
DEL ORO
MESA DEL ORO
PENNSYLVANIAN OUTCROPS
MONOCLINE
SYNCLINAL
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COW SPRINGS
CACHOW
U D
RED LAKE
UPPER RED LAKE
REGIONAL
PAYNE
FIELD
PINO
MILLER
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HAYFIELD
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WENGERD, 1959

FIG. 4

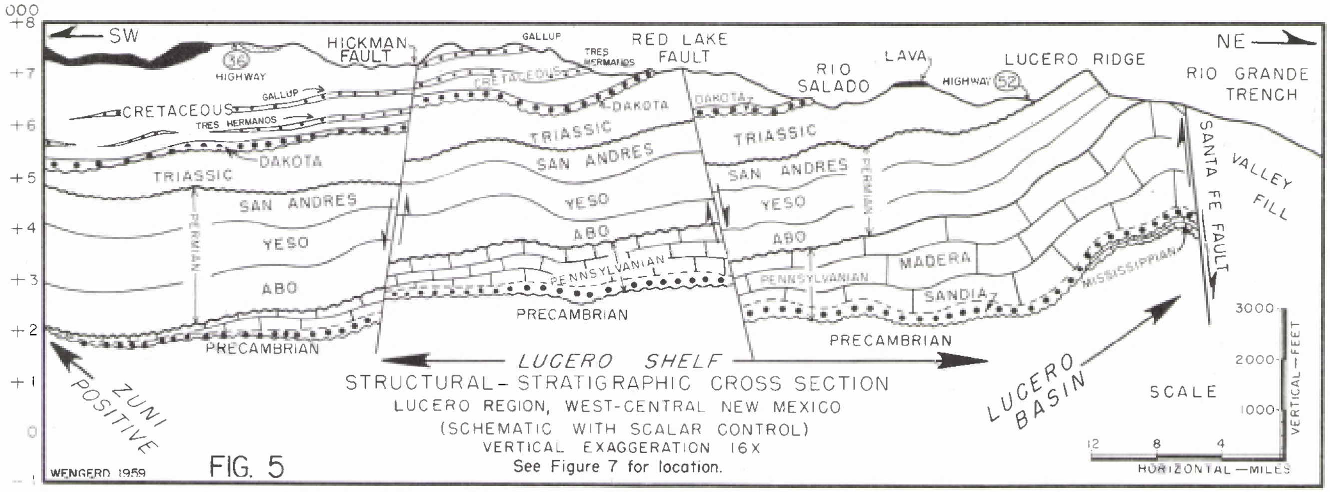



FIG. 5

STRUCTURAL-STRATIGRAPHIC CROSS SECTION
LUCERO REGION, WEST-CENTRAL NEW MEXICO
(SCHEMATIC WITH SCALAR CONTROL)
VERTICAL EXAGGERATION 16X
See Figure 7 for location.

basin only during two parts of Permian and Pennsylvanian time, the region is a relatively protected remnant of several sedimentational shelves which were present throughout geologic time. Its westward tilt from Laramide through Tertiary time gives it a semblance of a structural basin, inasmuch as its regional tilt in Pennsylvanian time was predominantly eastward. Similar opposing and oblique directional tilts were important to the early migration and entrapment of petroleum in many Rocky Mountain basins. The evolution of the Lucero region is remarkably similar to the later phases of the Paradox geosynclinal evolution. Indeed, it was a southern accessway-extension of the Paradox Basin. In later history, except for the great Tertiary sagging which took place in the San Juan Basin, the sedimentational history of the Lucero region is much like that of the San Juan Basin.

Parts of the Lucero region lie over the central sector of the pre-Pennsylvanian arch in central New Mexico. This arch appears to have connected the Apache-Mogollon Arch of Arizona with the Matador Arch of Texas and provided a great east-west island-studded sedimentational barrier to the early Paleozoic seas on the north flank of the Sonoran geosyncline.

In early Pennsylvanian time, this great barrier began to disintegrate into a long, discontinuous archipelago which allowed connections to form between the newly subsiding Paradox geosyncline on the north and the continuously subsiding broad shelf of the Sonoran geosyncline on the south. The southernmost San Juan Basin and Rio Grande trench regions were the locale of a broadening and tectonic sagging along the west side of an accessway during Pennsylvanian time. Pennsylvanian marine sediments in the Lucero region were deposited in the westward extension of this sag, south of the Zuni positive spur (fig. 8). The Penasco and San Pedro uplifts lay to the northeast of this accessway (Read and Wood, 1947, p. 226), the Joyita positive area may have been a late Pennsylvanian island (ibid.), whereas the Pedernal land mass, which contributed coarse clastics to the region, formed a north-south trending barrier in central New Mexico through most, if not all, of Pennsylvanian time (Thompson, 1948, p. 72). Thinning of the Pennsylvanian Madera marine section is strongly suggestive of the existence of a north-south trending platform which separated the Estancia sedimentational basin on the east from the Lucero sedimentational basin on the west (fig. 8). This postulated submarine platform is here called the "Manzanita platform". The broad, low, Zuni positive area stood to the west during the Pennsylvanian period. Here, then, lie remnants of a sedimentational regime of Pennsylvanian age similar to other regimes in Texas and in parts of the Rocky Mountains.

During Permian time the Lucero region sagged again, but as a northwest-trending sedimentational axis in which continental clastics of the Abo formation were deposited. Subsequently the region was flooded by Yeso seas along the Quemado-Cuchillo axis. Deposition of the Glorieta sand followed, then deposition of the evaporite strata and marine to fresh-water limestones of the San Andres formation.

The only relatively localized structures which might be sorted out of the welter of Laramide folds and Tertiary faults at the present time are those diverse-trending noses and anticlines along the break-in-shelf slopes which probably existed in the Pennsylvanian and Permian seas. Rather rapid changes in thickness of both the Pennsylvanian and Permian systems appear to lie in sinuous northwest trends through the Lucero region west of the Tertiary Lucero uplift. These sinuous spurs and sags may have been important in localizing porosity trends in the carbonate, arkosic, and quartzose sediments deposited during Pennsylvanian and Permian time. There are too few subsurface data to locate these trends accurately, or to localize pre-Triassic folding that probably took place in the Lucero region. However, thickness data from outcrops and from wells that have penetrated Triassic continental sediments suggest that some local structural relief developed during late Leonard, Guadalupe, Ochoa, and Moenkopi time; further, that after deposition of Triassic beds, mainly the Chinle shale, this structural growth continued, and the Chinle was erosionally thinnned over the sites of early structural growth.

Permian marine strata of the Lucero region thin northeast and southwest from the Quemado-Cuchillo axis, and grade into nonmarine strata. Activation of the ancestral Rockies to the north, northeast, and east (the Penasco, San Luis, Pedernal uplifts), and the Zuni positive to the west, plus regional uplift and tilting, drove the Permian seas from the region.

Following diverse alluvial sedimentation of the Triassic, the region began to lift from the southwest to the north, so that there is a Triassic erosional wedge edge in the southwest part of the Lucero region, and the Jurassic continental section wedges out both depositionally and erosionally southward in an east-west trend through the medial part of the region.

During all of early Cretaceous time the region stood near sea level but was open to subaerial erosion. Some localized folding may have taken place during Jurassic time, as indicated by a minor angular unconformity between Triassic Chinle strata and the overlying Cretaceous Dakota sandstone south of the Jurassic wedge edge. With additional drill data, the mapping of the sinuosities of the Jurassic wedge edge should provide clues to the localization of these postulated pre-Laramide folds.

During late Cretaceous time, the tectonic pattern changed, as the northwest-trending Mesocordilleran geanticline became active and the Lucero region became part of the southwest flank of the Rocky Mountain Cretaceous geosyncline. The seas waxed southwestward across the region and waned northeastward, as the geanticline on the west and southwest poured varying amounts of quartz sand onto the shelf of an essentially mud-deposting sea. These complex transgressions and regressions make up the Dakota-Mancos-Tres Hermanos-La Cruz Peak-Gallup-Crevasse Canyon-Mesaverde section.

Here again there are too few thickness data in the Upper Cretaceous section to check early Laramide structural growth, but it may be expected that such structural growth did occur over the sites of mild Permian and Jurassic tectonism as a prelude to the localized folding of Laramide and Tertiary age.

**Local Structure**

**Folds**—Without more subsurface data, it is impossible to separate the surface anticlines of the Lucero region into definite age groups. If such were possible, the older anticlines would be logical traps for Pennsylvanian oil, whereas the younger anticlines might be traps for Cretaceous oil. However, certain morphologic habits of anticlines tested by drilling in other Rocky Mountain basins aid in determining logical places to drill in an untested basin. These characteristics apparently are:

1. Broad, low closure.
2. North, northeast, or east-west trends for the deeper production.
3. Northwest trends for the shallower production.
4. Bifurcation and noses off north-south trends.
5. Location on the western sedimentational flank of a Pennsylvanian basin.
6. Flank and plunge dips of less than 10° for the deeper production, and perhaps dips up to 20° for the shallower production.

Inasmuch as outcrop areas examined have shown no great local angular discordance between Pennsylvanian and Permian, Permian and Triassic, or Triassic and Cretaceous strata, it may be assumed that surface folds of the Lucero region are also folds of similar geometry at depth (fig. 4).

The folds mapped by photogeology and field mapping in the area of specific interest in the Lucero region, the greater number of which have been carefully rechecked in the field, fall into several diverse groups :

First—north-south trends, steep flank dips, high structural closure, relatively small area, cut by north-south faults. Examples are found in the southeastern part of the region. These anticlines have somewhat steeper east limbs than west limbs and are structurally highest on their south ends. Their associated low-throw, north-trending faults cut either flank slightly obliquely in medial positions. A similar group, called the South Suwanee dome, lies in the northeasternmost part of the region.

Second—large, high-closure anticlines such as Red Lake and Broom Mountain anticlines; trending predominantly northward, faulted on the east side with stratigraphic throw ranging up to 800 feet. The Red Lake-Broom Mountain fold and fault system is 20 miles long and extends from T. 3 N., R. 8 W., northward into T. 5 N., R. 7 W. (fig. 4). In places along this fault system, Triassic Chinle rocks on the western upthrown side of the fault lie against Cretaceous Tres Hermanos and Gallup sandstones and Mancos shale on the eastern, downthrown side. Stratal dips on the east flank of this major structure range from 90° to 40° toward the fault. The similar north-trending Hickman fault system, as yet unmapped in detail because of surficial cover, extends from T. 3 N., R. 11 W., to T. 9 N., R. 9 W., across the Valencia-Catron County line.

Third—the group of greatest immediate interest consists of broad, low-closure, low flank dip, diverse-trending closures and noses such as those lying east and north of the Red Lake-Broom Mountain faulted anticlinal trend. The bifurcation, trend, low closure, and shallow dips are suggestive of the type of older anticline having maximum possibilities for oil and gas production from Pennsylvanian strata.

Fourth—a predominantly northwest-trending group of low closure but large-area anticlines lies in the northwest part of the area of interest. These anticlines range from two to six miles in length and have estimated closures ranging from 75 to 250 feet. Their regional disposition suggests that they may have possibilities for oil production from the Dakota at shallow depths.

Fifth—scattered through the area are similar northeast-trending anticlines, some of which "nose" only to the southwest, others to the northeast. These are generally of low closure and small area with low to moderate dips on the limbs and plunges.

Throughout the Four Corners region, such structures have been found to be remnant closures of older shelf spurs which controlled sedimentation on the southwest shelf of the Paradox Basin. Each one deserves careful analysis for deeper trap possibilities athwart porosity trends in Pennsylvanian strata.

According to Tonking (1957) and Givens (1957), the major part of the folding in the Puertecito and Dog Springs quadrangles (southeastern Lucero region) took place from late Cretaceous to mid-Tertiary time, with the faulting having taken place almost simultaneously with igneous intrusion and volcanism in late Tertiary and Quaternary time.

**Faults**—Faults in the Lucero region are dominantly normal and of Tertiary age. They show trend variations somewhat like the anticlinal axes. Most faults of the region are vertical and of low throw, with oblique strike-slip movement. Many in the southeastern part of the area have a north-northwest trend parallel to igneous dikes of late Tertiary age; however, more sparsely distributed faults in the central part of the region have northwesterly trends parallel to the Laramide anticlines. The major Red Lake fault with a north-northeast trend has a maximum stratigraphic throw of about 800 feet, and cuts strata as young as the Crevasse Canyon formation.

It may be surmised that some of the faults in the Lucero region are of Laramide age, having been rejuvenated during Tertairy time. Generally, the throw on most of the faults in the area of greatest interest is less than 100 feet. Until each one of the surface closures related to these faults is analyzed after drilling and related to possible pressure patterns in hydrodynamic flow, no positive statements can be made as to their importance in the entrapment of oil and gas.

**Stratigraphy**

Rocks of Precambrian, Mississippian, Pennsylvanian, Permian, Triassic, Jurassic, Cretaceous, and Tertiary age are present in and around the Lucero region. In general, Mississippian strata thin northward and wedge out in the southern part of the region; Pennsylvanian strata thin westward by both depositional thinning and erosion; Permian strata thin both northeastward and southwestward; Triassic strata thin southwestward with local diverse thicknesses caused by both sedimentary variation and post-Triassic erosion; Jurassic strata thin southward and wedge out in the central part of the region (Silver, 1948); Cretaceous rocks thin southwestward and westward with notable local variations in thickness. Tertiary sediments and volcanic rocks are thick south of the Lucero region.

The following stratigraphic summary is aimed principally at those rocks important to the search for petroleum within the Lucero region. Discussions of strata not thought to be oil- or gas-bearing or not directly applicable to this study are included for the following reasons:

1. They add to total drilling depth necessary in exploration.
2. They provide "seals" or "cap-rocks" for petroleum reservoirs.
3. They have contributed sediments that make up younger rocks.
4. They may include thickness variations that reveal the depositional-erosional history necessary to the appraisal of early structural growth. These growths often provide oil and gas traps in subjacent strata.
5. Structures mapped in these non-petroleum-bearing rocks, where they are exposed, may be structural traps in porous reservoir rocks at depth.

Details of the lithology, thickness, and stratal variations of the rocks underlying the Lucero region are presented in figures 3, 5, and 9 (Fig. 9 in pocket). The stratigraphic discussions which follow are generalized and historical mainly because the accumulation of oil is an historical event controlled by physico-chemical laws involving sedimentation, structural growth, and hydraulic dynamics.

**Precambrian Rocks —**

Precambrian rocks, mainly granite, are exposed in the core of the Zuni Mountains and in the Ladron Mountains, where they are about 9,000 feet above sea level. The Ladron Mountains, the Lemitar Mountains, Socorro Mountain, and the Magdalena Mountains also have metasediments, schists, gneisses, and diabase dikes of Precambrian age (Loughlin and Koschmann, 1942). Precambrian granite and granite regolith underlie only 70 feet of nonmarine Pennsylvanian rocks in the Huckleberry Federal No. 1 in T. 2 N., R. 16 W., Catron County (fig. 9). The basement is overlain by Permian rocks at Red Hill in T. 1 S., R. 20 W. (Foster, 1957, p. 67), and over most of the Zuni uplift. This vast, slightly positive, deeply weathered Precambrian massif, known as the Zuni positive thus limited Pennsylvanian sedimentation on the west and also supplied sediments to form clastic lentils in the Sandia and Madera formations of the Magdalena group in the Lucero region.

Precambrian rocks lie at depths of 3,000 to 6,500 feet throughout that part of the Lucero region where maximum oil potential is suspected.

**Mississippian Rocks —**

Mississippian rocks are absent over the greater part of the Lucero region. The Lake Valley limestone is about 135 feet thick in the Magdalena Mountains southeast of the area, and about 85 feet thick in the Ladron Mountains on the east. No wells in the region have penetrated Mississippian rocks although they may be present in an east-west strip covering the southern one-fouth of the Lucero region. These northward-wedging carbonates have little oil potential and probably represent the eroded north edge of the Sonoran geosynclinal flank.

**Pennsylvanian Rocks —**

The Sandia and Madera formations comprise the Magdalena group of Pennsylvanian age in the Lucero Basin (fig. 6). Prime objectives for oil exploration in the Lucero region, these rocks contain thin porosity zones in the basinal sandstone and limestone lentils exposed in the Lucero uplift (Monte de Belen and Gray Mesa) and in deep wells drilled on South Suwanee dome in T. 7 N., R. 4 W., Valencia County.

Tectonic spurs extending eastward and northeastward from the Zuni positive area on the west, with intervening sags extending southwestward from the seaway that traversed central New Mexico during Pennsylvanian time, may have controlled the distribution of sands from northerly sources (fig. 8). During deposition of the Madera formation, these spurs and sags may also have controlled the growth of marine animals and plants along breaks-in-slope on the west flank of the seaway in central New Mexico. This situation existed on the southwest flank of the Paradox Basin where important oil accumulations have been discovered in rocks of equivalent age. Examination of the Pennsylvanian section in the Manzano Mountains in 1954 revealed bioherms (organic reefs) made up of abundant Chaetetes corals in the Pennsylvanian rocks on the east side of the seaway where the section is only 1,200 to 1,600 feet thick. Smaller bioherms are present in Madera strata of the Sandia Mountains where the Pennsylvanian rocks are only 900 to 1,200 feet thick. A similar situation can be expected in the Lucero region on the west side of the seaway along the break-in-shelf slopes of the Lucero basin. The exact positions of these postulated break-in-shelf slopes are not known owing to the paucity of subsurface data (fig. 7).

**Permian Rocks —**

Pennsylvanian marine rocks grade upward into Permian nonmarine rocks via the Red Tanks member of the Madera formation (Kelley and Wood, 1946). The Abo formation lies conformably on the Red Tanks member in the eastern one-third of the area; however, areas of regional angular discordance may be present to the west as indicated in the Mitchell Red Lake No. 1, in sec. 2, T. 3 N., R. 8 W., and in the Huckleberry test in T. 2 N ., R. 16 W. (fig. 9). Isopach studies of the Pennsylvanian rocks suggest that this apparent discordance probably has a highly sinuous trend between the Magdalena Mountains on the southeast and the southeast end of the Zuni Mountains on the northwest. Such discordance may in part have been caused by continuance of the early structural growth in the approximate locality where the Madera break-in-shelf slope is thought to have been (fig. 7).

The reddish-brown alluvial sandstone, siltstone, and shale of the Abo formation is overlain by the Yeso formation which is made up of marine limestone, shale, sandstone, and gypsum. The axis of maximum Yeso marine sedimen-

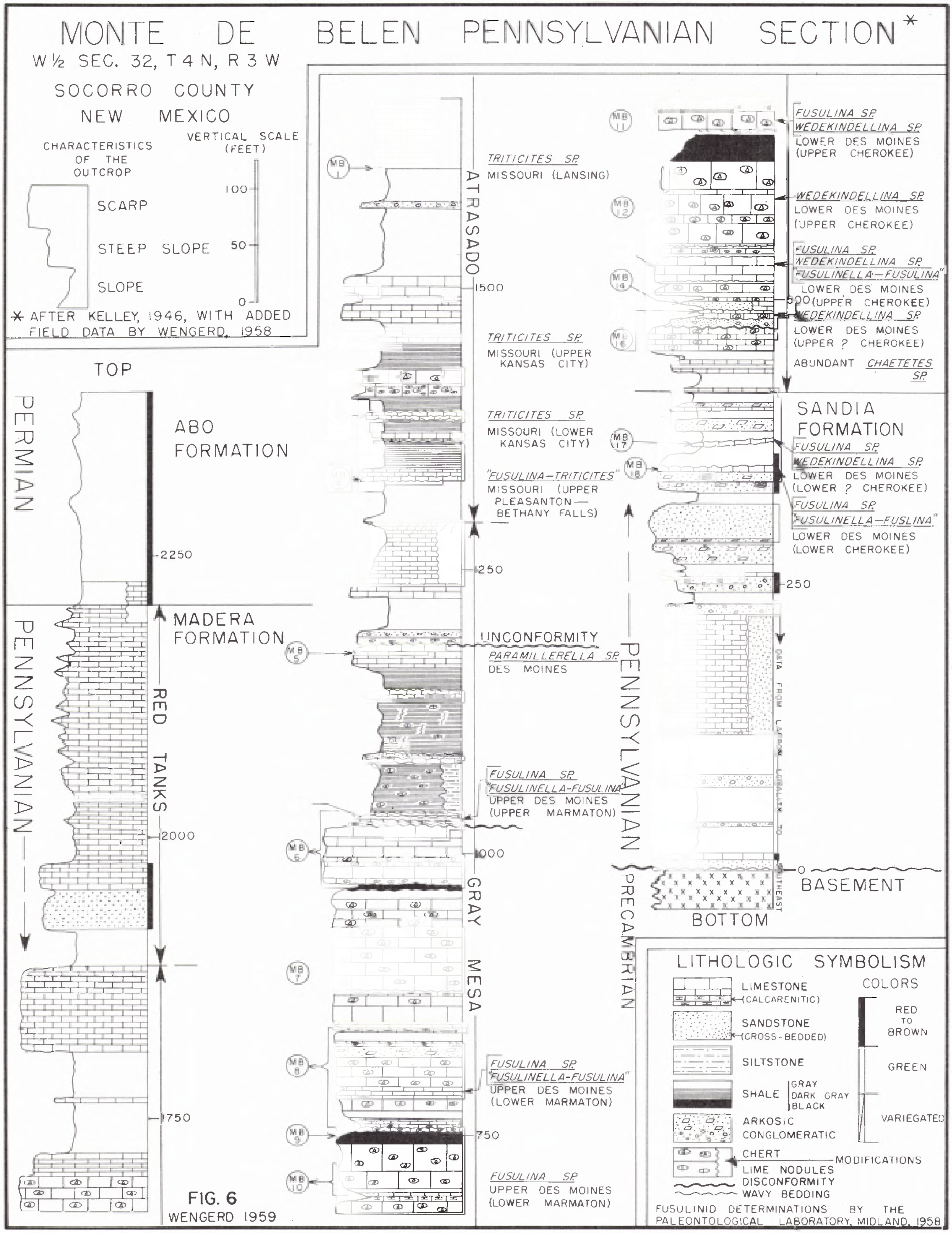



FIG. 6
WENGERD 1959

tation trends northwesterly and is known as the Quemado-Cuchillo basin (Foster, 1957, p. 67). Permian strata range up to 3,000 feet thick along this basinal axis, thinning both northeasterly and southwesterly (fig. 7). Too few wells have penetrated the Permian rocks to allow anything but pure surmise as to the location of a possible Yeso break-in-shelf slope (fig. 9).

The Quemado-Cuchillo basin persisted through the deposition of the San Andres group which consists of the porous Glorieta sandstone at the base, and the limestone, sandstone, and gypsum of the San Andres formation (figs. 3 and 9) above. These strata, considered to be equivalent to the Kaibab-Toroweap-Coconino section of the Grand Canyon region, crop out prominently in the Lucero uplift on the east side of the Lucero region, and on the south flank of the Zuni Mountains northwest of the Lucero region.

**Triassic Rocks —**

Triassic rocks, widely exposed over the eastern one-fourth of the Lucero region, are made up of the reddish-brown continental Chinle shale at the top, Shinarump(?) sandstone, and Moenkopi(?) fluviatile sandstones and shales at the base. In the northern one-third of the region, Triassic rocks are overlain by Jurassic sandstone. In the southern two-thirds of the region the Triassic is overlain by the Dakota sandstone. Triassic continental rocks show a wide variation in thickness both on the surface and in the few tests that have penetrated the section. They are known to wedge to zero (fig. 7) along a northwest trend south of Red Hill in T. 1 S., R. 20 W. (Foster, 1957, p. 69).

**Jurassic Rocks —**

Jurassic continental rocks, mainly sandstone in the Morrison formation, gypsum and limestone in the Todilto formation, and sandstone in the Entrada formation, wedge out southward in the approximate latitude of middle Sierra Lucero, northeastern Mesa del Oro, southern Cebolleta Mesa (Silver, 1948, p. 70), and in the northern third of the Lucero region.

The southward wedgeout of these rocks provides northward reversal of several important anticlines in Tps. 6 and 7 N., Rs. 5 to 11 W., and their absence south of the wedgeout suggests that considerable erosion of the Chinle shale took place during Jurassic time. As wells are drilled, additional data on the erosional thinning of the Chinle shale and sinuosity of the Jurassic in the subsurface may provide clues to trends of pre-Jurassic structural growth.

**Cretaceous Rocks —**

The Cretaceous rocks, themselves important petroleum objectives in the western half of the Lucero region, are discussed briefly because they cover wide areas of Pennsylvanian oil and gas potential. These Cretaceous strata comprise a double cycle of transgression complexes consisting of marine sandstone and shale grading upward into a nonmarine section, all of which is equivalent to, but thinner than, the Dakota-Mancos-Gallup-Mesaverde section in the San Juan Basin (Beaumont et al, 1956, p. 2,149).

The Cretaceous section ranges from 1,000 to perhaps 2,000 feet in thickness in the west-central Lucero region. The section thins somewhat and becomes progressively more sandy southwestward. Five formations, from bottom to top, comprise the system here: the Dakota sandstone; the Mancos shale including the important Tres Hermanos sandstone member; the La Cruz Peak formation, containing several important thick lentils of Gallup sandstone; the Crevasse Canyon formation; and the Mesaverde formation, with the important Point Lookout sandstone member (Gievens, 1957; Jicha, 1958; Tonking, 1957).

Most of the Cretaceous sandstones are porous, range from 20 to 60 feet in thickness, and are interbedded with thick marine shale or swamp-type carbonaceous shale. As of June 1959 only one well has penerated these strata in the Lucero region; the Huckleberry Federal No. 1 in T. 2 N. R. 16 W. encountered 1,830 feet of Cretaceous rocks. This well was drilled some distance to the southwest of the area of major Pennsylvanian potential in the Lucero region.

**Post-Cretaceous Rocks —**

Tertiary continental sediments overlie, with pronounced unconformity, rocks ranging from Cretaceous to Precambrian in age in the region, thus indicating that the major part of the folding in the region took place prior to Tertiary time. These sediments are overlain by younger volcanics in thicknesses up to 1,000 feet in the area south of the Lucero region.

In the area of interest, some Tertiary volcanic rocks crop out, but the thin Quaternary lava flows which cap Mesa del Oro and Cebolleta Mesa are more conspicuous. These lavas in few places are more than 50 feet thick. Volcanic plugs, small dikes, and thin sills are present within the region and intrude the south ends of several large anticlines These recent volcanic rocks have baked the intruded adjacent rocks to thicknesses varying from inches to about five feet. As in the San Juan Basin, they are not considered to be deleterious to the oil and gas potential of the Lucero region, excepting insofar as they mask the structure of the subjacent rocks.

## PETROLEUM POTENTIAL

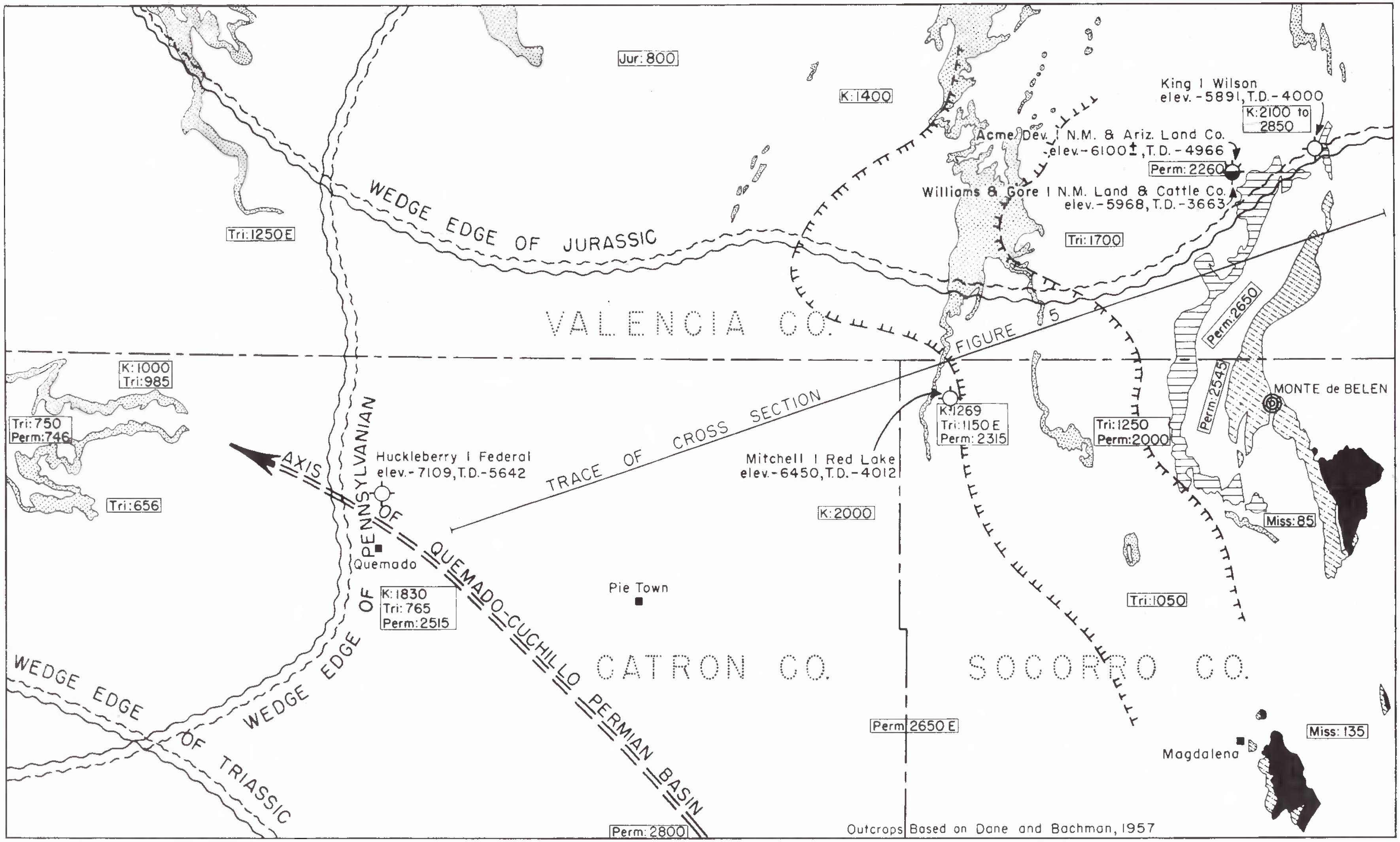
The petroleum potential of the Lucero region lies at depths of 1,000 to 6,500 feet in Cretaceous, Permian, and Pennsylvanian strata. Oil and gas shows have been noted in wells drilled in the Dakota sandstone, San Andres limestone and Glorieta sandstone, Yeso sandstones and limestones, Madera limestone, and the Sandia formation.

Pennsylvanian tests had been drilled in only three widely scattered localities in the Lucero region until the drilling of mid-1959, and shallow wells are equally sparse. The writer considers the region to be virtually untested (fig. 7).

Why such a large region, with a total stratigraphic section ranging from a few thousand feet in the east to almost 6,500 feet in the west and having a multitude of good anticlinal folds should have remained untested during the 1945 to 1958 era of intensive oil exploration in the western United States may be attributed to one or all of the following factors:

1. Complicated acreage picture.
2. Relative inaccessibility until as recently as 1956.
3 Lack of recognition of the oil and gas potential, stratigraphically and structurally.
4. Siphoning off of oil exploratory efforts by major companies into the more accessible areas of Canada, Williston Basin, Denver-Julesburg Basin, West Texas, southeast New Mexico, San Juan Basin, and the Paradox Basin.
5. Previous lack of market and pipeline facilities.
6. Fear of localized volcanism and thin lava cover in some parts of the region.

In the absence of commercial oil or gas production in the Lucero region to date, a summary of petroleum potential must be based entirely upon surmise controlled by known geologic data, rather than projection of production.




# PALEOGEOLOGY of the LUCERO REGION

## WEST-CENTRAL NEW MEXICO

SCALE

0 6 12 18

MILES

LEGEND

IMPORTANT OUTCROPS
- Dakota fm.
- San Andres-Glorieta fms.
- Pennsylvanian rocks
- Precambrian

SYSTEMIC THICKNESSES (FROM MANY SOURCES)
Perm: 2147

SYSTEMIC WEDGE EDGES

WILDCAT OIL TEST
Mitchell I Red Lake elev. - 6450, T.D. - 4012

POSSIBLE AREA OF THE POSTULATED PENNSYLVANIAN BREAK-IN-SHELF SLOPE

FIG. 7

WENGERD 1959

This wildcat province has an average of one deep wildcat test per 1,000 square miles of area. Southeastern Utah, an area of about 20,000 square miles, had an average of one wildcat test per 200 square miles prior to discovery of the Desert Creek field in 1954. The following discussions of reservoir rocks, porosity trends, traps, unconformities, timing, and reservoir drives, and prognosis of a typical wildcat well is based on the oucrop stratigraphic data and information from wells drilled in localities great distances apart.

**Reservoir Rocks**

Carbonate reservoirs may be expected in the San Andres formation and the Yeso formation of Permian age, and in the Atrasado and Gray Mesa members of the Madera formation of Pennsylvanian age. These carbonate reservoirs may range from 10 to 150 feet in thickness and may contain intercrystalline and intergranular porosity, slightly dolomitized reefoid limestone with intergranular porosity, and solution porosity developed along disconformities. It may be possible, particularly in the Yeso formation, to find fracture accumulations of oil and gas. The most widespread potential reservoirs are thought to be in the Madera biostromal carbonate strata.

Quartzose and arkosic sandstones are present in lentil thicknesses ranging from 5 feet to over 175 feet in Cretaceous, Permian, and Pennsylvanian strata of the Lucero region. These sandstones may range from fine to coarse in texture, may contain 5 to 30 percent porosity, and may be cemented by clay, calcite, and silica in varying proportions.

The reservoir strata may lie in the following members and formations, from top to bottom:

**Cretaceous**
- Gallup sandstone*
- Tres Hermanos sandstone*
- Dakota sandstone*

**Triassic**
- Shinarump sandstone**

**Permian**
- San Andres formation**
- Glorieta sandstone*
- Yeso formation*
- Abo formation*

**Pennsylvanian**
- Atrasado member } Madera formation***
- Gray Mesa member } Madera formation***
- Sandia formation*

* Best opportunities for production in the western part of the Lucero region.

** Best developed in the south-central part of the area.

***Best developed in the eastern half of the Lucero region.

**Porosity Trends**

Although the exact location of porosity trends is not known, the paleogeologic data available or those which may be inferred suggest the following:

1. Wedge-outs and neritic sand bars trending northwest-southeast in Cretaceous sandstone at depths of 1,000 to 2,000 feet in the western half of the Lucero Basin. These are interbedded with carbanoceous and bituminous shales of the Cretaceous which could have been source rocks for oil and gas compactionally discharged with connate fluids into the reservoir rocks shortly after deposition.

2. Blanket-type to wedge-out sandstone in the marine San Andres, Glorieta, and Yeso formations, whose location and composition was controlled by the subsidence and rate of clastic supply to the Permian Quemado-Cuchillo sedimentation basin in the southwest central part of the Lucero region.

3. Carbonate intercrystalline and intergranular porosity in the San Andres limestone and the limestone and gypseous dolomite of the Yeso formation on the northeast shelf of the Quemado-Cuchillo basin.

4. Carbonate reefoid (biohermal and biostromal) porosity trends in the Atrasado and Gray Mesa members of the Madera formation in sinuous trends between the 800 and 2,000 foot isopach lines for the Pennsylvanian section (fig. 8).

5. Along disconformity trends known to be present as the Madera formation thins westward between the Pennsylvanian outcrops on the Lucero and Ladron uplifts to the east and the Zuni positive area to the west.

6. In the westward wedge-outs of individual sandstones of the Sandia formation between the Lucero uplift on the east, and the Zuni positive area on the west.

The only way to find these porosity trends is to drill wells in those localities where focus is provided by the existence of anticlinal and fault traps represented in surface structure.

**Traps**

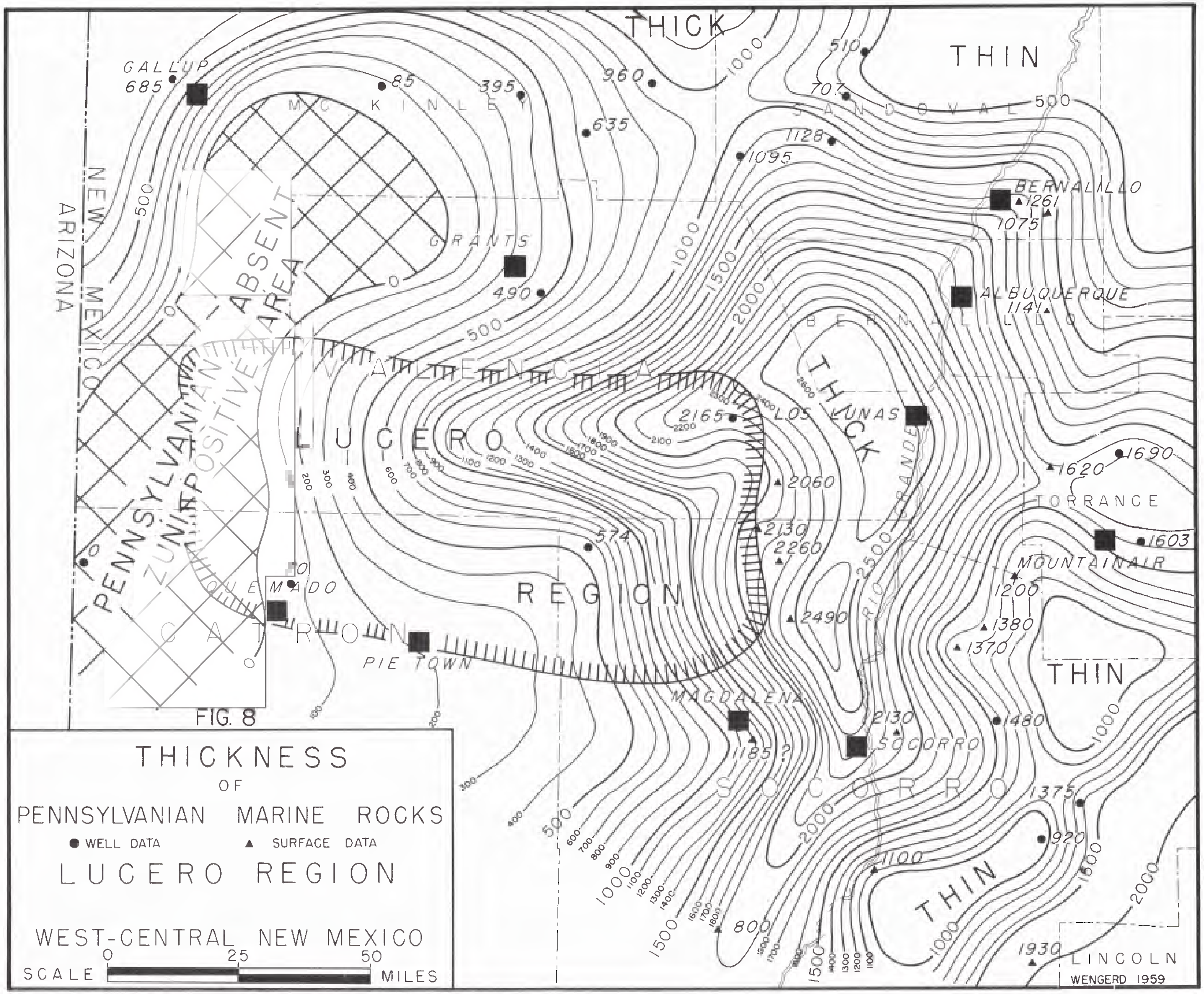
An area the size of the Lucero region, with a maximum stratigraphic section of 6,500 feet, having the number of diverse-trending anticlines of low to moderate closure, cannot fail to have suitable traps. Only drilling can establish the existence of the complete coincidence of trap, reservoir rock, porosity, fluid drive, timing, and petroleum necessary to make the Lucero region commercially productive.

In the absence of specific reservoir and porosity-trend control, the only focus available to the petroleum explorationist in a new region is anticlinal or domal folds and faults. Such traps are abundantly present in the Lucero region, and the first place to search is in the widely distributed areas of low-closure folds, not too severely faulted, lying athwart areas of optimum thickness of the Pennsylvanian strata.

**Timing**

One of the foremost concepts in petroleum exploration is that the age of trap formation should follow closely the deposition of the source rocks. For Pennsylvanian production, those areas should be tested which underwent reverse tilt during Permian time. The entire central Lucero region experienced exactly such a reversal of tilt. During Pennsylvanian time, the axis of maximum deposition appears to have lain in a northwesterly trend from the Ladron area to Acoma; during Yeso-San Andres time, a basin developed in a northwesterly trend from the Cuchillo Mountains to Quemado (Foster, 1957, p. 67). This means that original sedimentational dips were generally northeastward in Pennsylvanian time, then dips were reversed to the southwest in Permian time. During Triassic and Jurassic time, the area of thickest Permian sediments rose bodily, tilting the region northeastward once again. Such rocking action is known to be critical to the separation of oil and gas from connate waters. The rocks were later folded transversely during late Cretaceous time, thus improving the chance for possible localization of gas and oil in structural traps that are now expressed as surface folds.

The same Laramide folding may have created traps for oil and gas, if present in Upper Cretaceous rocks.



THICK
THIN
THICK
THIN
THIN
GALLUP
GRANTS
BERNALILLO
ALBUQUERQUE
LOS LUNAS
MOUNTAINAIR
QUEMADO
PIE TOWN
MAGDALENA
SOCORRO
McKINLEY
SANDOVAL
BERNALILLO
VALENCIA
TORRANCE
CATRON
SOCORRO
LINCOLN
NEW MEXICO
ARIZONA
RIO GRANDE
LUCERO
REGION
PENNSYLVANIAN ABSENT AREA
ZUNI POSITIVE
FIG. 8
THICKNESS
OF
PENNSYLVANIAN MARINE ROCKS
WELL DATA
SURFACE DATA
LUCERO REGION
WEST-CENTRAL NEW MEXICO
SCALE
0
25
50
MILES
WENGERD 1959

Since latest Cretaceous (Laramide) time, Tertiary folding, faulting, intrusion, and regional westward tilting have affected these earlier reservoir rocks, porosity trends, fold traps, and stratigraphic traps. As erosion proceeded, fresh-water incursion into the outcropping Cretaceous and Permo-Pennsylvanian reservoir strata may have taken place, which might create some hydrodynamic shifts in the west-central part of the Lucero basin.

The major problem in any exploratory drilling program in a new region, such as the Lucero region, is to minimize, by careful selection of drill sites, the risks imposed by possible destruction of petroleum traps owing to late Tertiary and Quaternary faulting and igneous intrusion. Wide areas of the Lucero region, containing broad, low-closure traps, appear to be uneffected by these deleterious geologic occurrences, and the timing of geologic events in the Lucero region appears to compare favorably to those in other Rocky Mountain basins already producing oil and gas in commercial quantities.

**Types of Drive**

Data from the few wells drilled to date, and similarity of structure and stratigraphy to other Rocky Mountain basins, suggest that the following types of fluid drive may have caused migration and accumulation of oil and gas in traps formed in the following rocks:

| Rock Units | Drive | Type of Pressures |
|---|---|---|
| Cretaceous sandstones | Fresh water or dissolved gas | Hydrodynamic to less than Hydrostatic |
| San Andres limestone | Gas, fresh or salt water | Hydrostatic |
| Glorieta sandstone | Fresh or salt water | Hydrostatic or Hydrodynamic |
| Yeso limestone and sandstone | Dissolved gas or salt water | Hydrostatic |
| Madera formation | Dissolved gas, gas cap, or salt water | Hydrostatic |
| Sandia formation | Salt water | Hydrostatic |

The type of drive and the pressures preserved are of course dependent upon the following characteristics of the trap:

1. Proximity to outcrop
2. Pervasiveness of permeability
3. Fluid availability
4. Amount of original and final porosity
5. Ratios of oil, gas, and water
6. Fault influences

**Prognosis of a Typical Well**

The following prognosis of depths to be drilled is regional in scope and does not presume accuracy for specific sites or exact stratal thicknesses. The purpose of a regional prognosis is to guide the reader in the general thicknesses of strata. Specific prognoses must be constructed for each drill site chosen, once a drilling program is planned.

A well drilled in the general vicinity east of Field, New Mexico, in that part of T. 4 N., R. 5 W. where Triassic strata crop out, may reasonably expect to find the following stratigraphic section, if the well is spudded in the medial part of the Triassic section:

| Stratigraphic Unit | Depth (feet) | Petroleum potential |
|---|---|---|
| Chinle shale | surface | none |
| Shinarump(?) sandstone | 700 | moderate |
| Moenkopi(?) formation | 850 | none |
| San Andres limestone | 1,050 | poor |
| Glorieta sandstone | 1,300 | poor |
| Yeso formation | 1,525 | poor |
| Abo formation | 2,625 | poor |
| Red Tanks member of Madera formation | 3,625 | moderate |
| Gray Mesa and Atrasado members of Madera formation | 3,775 | excellent |
| Sandia formation | 4,875 | good |
| Precambrian | 5,000 | none |

## CONCLUSIONS

1. The Lucero region, which covers an area of about 5,000 square miles in west-central New Mexico, has a stratigraphic section ranging up to 6,500 feet in thickness, comprising Mississippian, Pennsylvanian, Permian, Trassic, Jurassic, Cretaceous, and Tertiary rocks of marine and non-marine origin.

2. These strata include certain potentially porous marine sandstones and limestones in the Sandia, Madera, and Yeso formations, Glorieta sandstone, San Andres limestone, Dakota, Tres Hermanos, and Gallup sandstones in members lying at depths of 1,000 to 6,500 feet in the Lucero region.

3. The stratigraphic section of the Lucero region has undergone diverse regional tilts typical of sedimentary shelves and basins whose axes and break-in-shelf slopes have shifted and migrated throughout geologic time. Regional tilts have changed from south to northeast, to south-west, to north and northeast between Mississippian and late Cretaceous time.

4. Formation of traps by structural deformation may have started as early as Pennsylvanian time in the biohermal "draped" structures, continued in Permian and Triassic-Jurrassic time in response to general uplift of the area, culminated in the Laramide orogeny near the end of Cretaceous time in the formation of many anticlines of low to moderate closure over the general locales of older folds. Several of these folds were probably rejuvenated and their closures were increased by faulting during middle to late Tertiary time.

5. Athwart porosity trends thought to be present in rocks of Pennsylvanian, Permian, and Cretaceous age, one can reasonably expect to find hydrostatic, hydrodynamic, and dissolved-gas fluid drives in various types of stratigraphic and structural traps in the Lucero region.

6. Based solely on regional geologic analysis and surface structural appraisal, at least ten areas in the region merit deep tests in the search for oil and gas. Before much added thinking can be done as to the projection of geologic controls on oil and gas, additional deep tests should be drilled, utilizing all available geologic data to locate drill sites.

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