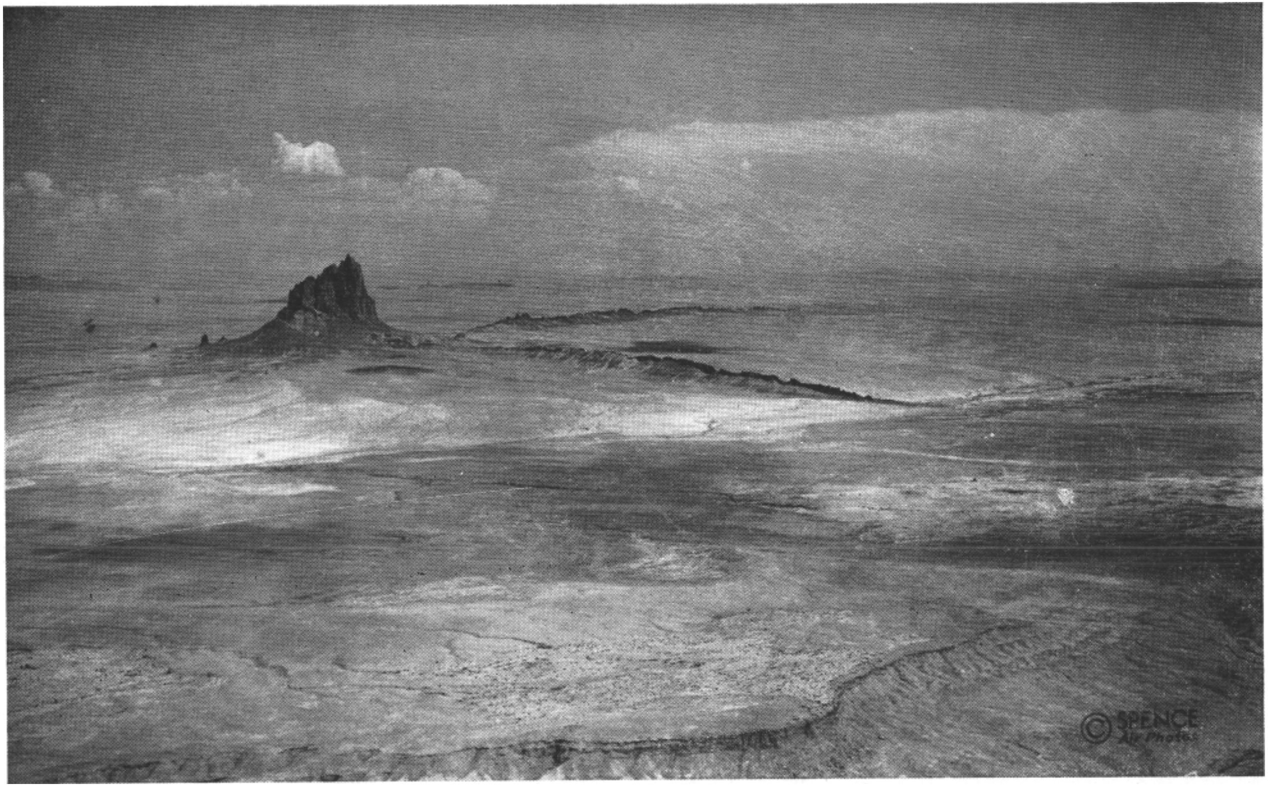

Ship Rock, northwestern San Juan County. An igneous intrusion with radiating dikes. In the Rattlesnake pool, less than five miles away, oil and gas have accumulated in Cretaceous strata similar to those in the foreground. (Spence Air Photos.)

NEW MEXICO SCHOOL OF MINES

STATE BUREAU OF MINES AND
MINERAL RESOURCES

RICHARD H. REECE President and Director

BULLETIN NO. 18

The Oil and Gas Resources of New Mexico
SECOND EDITION

Compiled by

ROBERT L. BATES
Geologist, State Bureau of Mines
and Mineral Resources

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THE STATE BUREAU OF MINES AND MINERAL RESOURCES

The New Mexico State Bureau of Mines and Mineral Resources, designated as "a department of the New Mexico School of Mines and under the direction of its Board of Regents," was established by the New Mexico Legislature of 1927. Its chief functions are to compile and distribute information regarding mineral industries in the State, through field studies and collections, laboratory and library research, and the publication of the results of such investigations. A full list of the publications of the New Mexico Bureau of Mines is given on the last pages of this Bulletin, following the index.

The Oil and Gas Resources of New Mexico

SECOND EDITION

Compiled by
ROBERT L. BATES

INTRODUCTION

GENERAL STATEMENT

In 1933 the New Mexico Bureau of Mines and Mineral Resources issued its Bulletin No. 9, "The Oil and Gas Resources of New Mexico," by Dean E. Winchester. This bulletin brought together a large amount of information and has been widely used by those interested in oil and gas in the State. As the petroleum industry expanded tremendously in the years following this publication, resulting in the discovery of new oil pools and adding immensely to the store of information on the geology of the State, it became apparent that a new report on the State's oil and gas resources would be needed. In 1941 the writer was commissioned by Dr. C. E. Needham, then Director of the Bureau of Mines and Mineral Resources, to prepare such a report.

The organization of the petroleum industry in New Mexico is such that the bulk of geologic information relating to oil and gas remains with the oil companies rather than with a State agency. Field offices of the U. S. Geological Survey also have on file considerable geological information, mostly relating to oil lands owned by the Federal government. Other geologic data, chiefly on stratigraphy, have been accumulated in recent years by geologists from other states, who have done extensive field work in New Mexico. Thus it was decided that, in order to be of maximum value, the new bulletin should be a compilation of papers from men in the various fields rather than the work of a single author. The solicitation of contributions met with such favor that the present bulletin boasts 24 contributors. They include 10 oil-company geologists; three consulting geologists or engineers; and 11 geologists or engineers from the academic, Federal survey, or State survey fields. Of the last-mentioned group, five are present or recent members of the State Bureau of Mines and Mineral Resources.

PURPOSE AND SCOPE OF THE REPORT

The purpose and scope of this bulletin remain the same as those of its predecessor, whose author stated:

> The purpose of this report is to present information dealing with the oil and gas resources and possibilities of New Mexico. . . An attempt has

been made not only to supply the reader with a picture of what has already taken place in the search for oil in the State, but also to inform him of undeveloped possibilities and to suggest some of the most practical methods of attacking those problems which have not been solved.

The general outline of Winchester's report has also been retained. This includes a general discussion of the State's rock units, followed by treatment of the general geology and petroleum resources under five regional headings. The large amount of new data has made necessary a number of additions and changes of emphasis, and has in the main been responsible for the increase in size of this bulletin over Bulletin No. 9. Deletions and changes in order of subject matter have been found advisable in some places. Finally, although the greatest part of the report represents new contributions, in some sections Winchester's words have been extensively quoted. Such quotations have been so indicated by footnotes.

ACKNOWLEDGMENTS

In a work of this nature, first acknowledgment should be extended to the contributors, who without exception have given valuable time and effort to the preparation of manuscripts and illustrations. The authenticity and accuracy of the report are in greatest part the result of their work.

Many other geologists besides those whose names appear as authors of papers have given information and assistance. In all cases except where anonymity was requested, acknowledgment is made in the proper place. The list includes representatives of many of the oil companies, pipe line companies, pressure-maintenance groups, and engineering associations operating in New Mexico, as well as members of the U. S. Geological Survey and of other State agencies besides the Bureau of Mines and Mineral Resources.

The preparation of the report has been under the supervision of C. E. Needham and John M. Kelly, both of whom have given assistance and encouragement. Members of the staff of the School of Mines have been most cooperative in all respects. Special appreciation is extended to S. B. Talmage, general editor of Bureau of Mines publications, and to C. D. Crosno and F. W. Hickman, who prepared the illustrations for publication.

GEOGRAPHY AND GENERAL GEOLOGY[1]

New Mexico is the fourth largest state in the United States, having an area of 122,634 square miles. It is bounded by Colorado on the north, Oklahoma and Texas on the east, Texas and Mexico on the south, and Arizona on the west. Its population in 1940 was 531,818.

The Rio Grande, whose source is in southern Colorado, flows in a general southward direction completely across the State to El Paso, Texas, where it turns southeastward and forms the international boundary between the United States and Mexico. The Pecos River, one of the principal tributaries of the Rio Grande in New Mexico, rises in the Truchas Mountains at the south end of the Sangre de Cristo Range, and, flowing southward, drains the southeastern part of the State. The San Juan River crosses the northwestern corner of the State and flows westward into the Colorado River, as does also the Gila River which has its headwaters in the southwestern part of the State. The northeastern part of the State is drained by the Canadian River, which flows eastward from its beginning in the Sangre de Cristo Range and is part of the Mississippi River drainage system.

The main Rocky Mountain range, which in New Mexico is represented by the Sangre de Cristo Mountains, enters the State from the north and continues southward to near Glorieta. These mountains have a general anticlinal structure. The high ridges, consisting largely of pre-Cambrian rocks, are flanked by large areas of Pennsylvanian strata. Beyond Glorieta to the south the Rocky Mountain uplift continues but is represented by detached mountains consisting of pre-Cambrian rocks, tilted and faulted Paleozoic and Mesozoic sedimentary formations, and Tertiary intrusions. Between these north-south ranges are wide valleys filled with thick deposits of sand and gravel which effectually conceal the bedrock structure. The Rio Grande flows through one of these valleys. Among the important mountains of this area are the Nacimiento Mountains, Sandia Mountains, Manzano Mountains, Magdalena Mountains, Sierra Caballos, San Andres Mountains, Sierra Blanca, Sacramento Mountains, and the Franklin Mountains near El Paso, Texas.

The area east of the Rocky Mountain uplift is characterized in the northern part by high rocky plateaus consisting largely of flat-lying Triassic and Cretaceous strata, surmounted in places by mesas and cones of lava. This plateau area is deeply trenched by the Canadian River, and the long sinuous line of high cliffs known as the Canadian escarpment is a notable feature. To the southeast these high plateaus merge into the Llano Estacado or Staked Plains which are covered with a mantle of

[1] Reprinted with minor changes from Winchester, D. E., The oil and gas resources of New Mexico: N. Mex. Bur. Mines Bull. 9, pp. 15-16, 1933.

caliche and other recent deposits. In the area between the Rocky Mountain uplift and the Llano Estacado is the broad, moderately dissected valley of the Pecos River. This valley is largely floored with Permian rocks, which in general dip eastward at low angles, and extend beneath the Llano Estacado.

Most of the northwestern part of the State lies in the great Colorado Plateau province. Within this province one of the more conspicuous features is the great San Juan Basin which occupies that part of the State west of the Nacimiento Mountains, north of the Zuni Mountains and east of the Chuska Mountains together with part of Colorado south of the San Juan Mountains. Tertiary sediments occupy the middle portion of this basin, with Cretaceous and older sediments upturned and deeply dissected around the rim. In places, notably at Ship Rock and Mount Taylor, the sedimentary formations are intruded by igneous rocks which resist erosion and give rise to high conspicuous landmarks. To the south of the Zuni Mountains for some distance are plateaus and ridges consisting of thick and widespread accumulations of Tertiary volcanic rocks, and intervening valleys filled with sand and gravel. This plateau province gives place in the southwestern part of the State to the Basin and Range province, in which ridges and mountains consisting of igneous rocks and uplifted and faulted Paleozoic and associated strata are separated by wide desert valleys in which great thicknesses of detritus have accumulated. The Continental Divide, separating the tributary waters of the Pacific from those of the Atlantic, in general follows the eastern and southern rim of the San Juan Basin and thence takes a southerly course through the western part of the State to the Mexico line.

Surface elevations within the State range from a minimum of 2,850 feet above sea level on the Pecos River at the Texas state line to a maximum of 13,306 feet at Truchas Peak near Santa Fe.

The State is fairly well served by railroads. The main line of the Atchison, Topeka and Santa Fe railway crosses it from the northeast corner to the middle of the west line, and the Belen "cut-off" of the Santa Fe extends from near Belen to the eastern boundary. The Santa Fe has a line through the Rio Grande Valley from Albuquerque to El Paso, Texas, and a branch from Clovis southwest to Roswell, Artesia and Carlsbad, New Mexico, and Pecos, Texas, in the Pecos Valley. The Southern Pacific railway crosses the southwestern part of the State to El Paso, Texas, from which place it goes northward to Tucumcari and Dawson. At Tucumcari it connects with the Chicago, Rock Island & Pacific railway to the Texas Panhandle and the east. The Texas-New Mexico railroad (a branch of the Texas and Pacific railway) extends from Lovington in northern Lea County, south through Hobbs and Jal to connect with the main line at Monahans, Texas. The San Juan Basin in the northwest part of the

State is served only by the narrow-gauge line of the Denver & Rio Grande Western from Durango, Colorado, to Farmington. Numerous branch lines connect with the trunk lines.

During the past few years some of the best main highways in the southwest have been constructed in New Mexico. In the surfacing of these highways a large amount of road oil, made in part from New Mexico crude oil, has been used.

THE ROCKS

GENERAL STATEMENT

ROBERT L. BATES

The rocks of New Mexico were first comprehensively described by Darton[1] in his classic "Red Beds" report. This report is now out of print but still remains authoritative for many of the State's rock units. For these reasons Darton is quoted at length in the following pages. Since the time of the "Red Beds" report, however, considerable additional work has been done on the rocks of the State, especially on those of pre-Cambrian, Middle and Upper Paleozoic, and Tertiary ages. The compiler of the present bulletin has been fortunate in securing papers on several of these rock units from well-qualified investigators. Passages quoted from Darton are so indicated by footnote references; other papers carry the authors' names. A few remarks and additional references have been made by the writer, who in this task has benefited greatly from consultation with C. E. Needham.

GENERAL FEATURES[2]

There are in New Mexico many kinds of metamorphic, sedimentary and igneous rocks. The metamorphic rocks, which are mostly of pre-Cambrian age, comprise schist, quartzite, and a very small amount of marble. They are revealed by uplifts of the earth's crust and consequent removal of overlying sedimentary strata. The sedimentary series, extending from Cambrian to Quaternary in the southern part of the State and from Pennsylvanian to Quaternary in the northern part comprises limestone, sandstone, shale, sand and gravel. These strata have a combined thickness of about 16,000 feet, but no place is known where the entire column is present to this amount. In the deepest part of the San Juan Basin there may be 15,000 feet of beds, and borings in the central eastern part of the State have found about 4,000 feet.[3] The igneous rocks include granite, amphibolite, and some other rocks of pre-Cambrian age, many intrusive rocks of post-Cretaceous age, and eruptive rocks of late. Cretaceous, Tertiary, and Quaternary age.

PRE-CAMBRIAN ROCKS[4]

The pre-Cambrian rocks are bared in the southern prolongation of the Rocky Mountains, in the Sandia, Manzano, Nacimiento, Burro, Mimbres, Cooks, Lemitar, Ladrones, Oscura, San Andres, Magdalena, Fra Cristobal, and Sierra Caballo uplifts, in the region between Ojo Caliente and Brazos Peak, and in small areas in the west front of the Sacramento Mountains, in the Hatchet Mountains, in the hills east of Socorro, in the Klondike Hills, in the ridge northwest of Silver City, in Lone Mountain and near Hanover. There are also exposures in the Hills of Pedernal and the Zuni Mountains, which are parts of old ridges that survived far into Permian time.

[1] Darton, N. H., "Red Beds" and associated formations in New Mexico, with an outline of the geology of the State: U. S. Geol. Survey Bull. 794, pp. 3-65. 1928.

[2] Quoted from Darton, N. H., "Red Beds" etc.: U. S. Geol. Survey Bull. 794, p. 3. 1928.

Since Darton's report was written, a well in southern Roosevelt County encountered the pre-Cambrian at 7,957 feet.

[4] Quoted from Darton, N. H., "Red Beds" etc.: U. S. Geol. Survey Bull. 794, pp. 3-4, 1928.

Very little detailed study has been made of the pre-Cambrian rocks, which consist mainly of granite, gneiss, mica schist, and quartzite. Most of the granite cuts the schist and quartzite, but some of it may be older than these metamorphic rocks, and there are also granitic rocks of post-Cambrian age. Many facts regarding the pre-Cambrian rocks are given by Lindgren and Graton,[5] who describe briefly the gneiss, granite, mica schist, and quartzite at mining localities in the Sangre de Cristo Mountains in Taos, Santa Fe, and Mora counties.. .

Recent work on areas of pre-Cambrian rocks has been done by Just[6] and by Stark and Dapples.[7]

SEDIMENTARY ROCKS

The sedimentary formations in different parts of the State are correlated in the table, Plate 2.

CAMBRIAN SYSTEM[1]

BLISS SANDSTONE

The basal sandstone of the Paleozoic succession in southern New Mexico is known as the Bliss sandstone. Its age is upper Cambrian. It is a prominent feature in the type locality in the Franklin Mountains of Texas, which extend into New Mexico, and in other ranges in south-central and southwestern New Mexico. It thins out together with the overlying Ordovician strata just north of the San Andres Mountains and probably does not extend north of latitude 33° 30' in the western part of the State. It is well exposed at the base of the sedimentary section in the Hatchet Mountains. At all places it lies unconformably on granite or schist and apparently it grades up into the El Paso limestone, although the evidence of continuity is not conclusive.

In outcrops along the eastern base of the Franklin Mountains the Bliss sandstone consists mainly of small grains of quartz. The basal beds are mostly quartzitic and locally conglomeratic; the higher beds are softer and finer grained. The prevailing color is brown, but some portions have lighter tints. The thickness is 300 feet in places, but locally the formation thins out and the overlying limestone rests on the pre-Cambrian rocks. . . . In the Florida Mountains, Cooks Range, Mimbres Mountains, and Silver City region, where the thickness was not observed to exceed 180 feet, the formation consists of gray to brownish sandstone, in part quartzitic, with upper slabby members in part glauconitic. The thickness and local features vary from place to place. Beds of this character crop out all along the east side of the San Andres Mountains with thicknesses averaging about 100 feet to the south, . . . 30 to 40 feet near latitude 33°, and six feet in the northern part of the range. In the Sierra Caballo the average thickness of the Bliss sandstone is about 100 feet, and the upper members consist largely of green sandy shale . . . The small exposure of Bliss sandstone in the west face of the Sacramento Mountains, just south of the mouth of Agua Chiquita Canyon, shows only a few feet of sandstone separating dark granite from El Paso limestone.

[5] Lindgren, Waldemar, Graton, L. C., and Gordon, C. H., The ore deposits of New Mexico: U.S. Geol. Survey Prof. Paper 68, 1910.

[6] Just, Evan, Geology and economic features of the pegmatites of Taos and Rio Arriba Counties, New Mexico: N. Mex. Bur. Mines Bull. 13, 1937.7

[7] Stark, J. T., and Dapples, E. C., Structure of the Los Pinos Mountains, New Mexico (abstract) : Bull. Geol. Soc. Amer., Vol 52, No. 12, Part 2, p. 1936, December 1941.

[1] Quoted from Darton, N. H., "Red Beds" etc.: U. S. Geol. Survey Bull. 794, pp. 9-10. 1928.

Evidence that the Bliss sandstone is not Cambrian in age, but early Ordovician, has been presented by King.[2] The fauna of the formation where studied by King in the vicinity of Van Horn, Texas, includes Ordovician gastropods and a trilobite that is unknown in the Cambrian. Fossils in the Bliss at its type locality in the Franklin Mountains are not diagnostic, but include brachiopods like those occurring with Ordovician fossils in the Van Horn region. No detailed study of the Bliss has been made in New Mexico.

ORDOVICIAN SYSTEM[3]

GENERAL FEATURES

The strata of Ordovician age in New Mexico comprise the Lower Ordovician El Paso limestone and the Upper Ordovician Montoya limestone. Both formations appear extensively in the mountains and ridges of southwestern New Mexico, but they thin out near latitude 34°. The El Paso limestone appears to grade down into the Bliss sandstone, but it is separated from the Montoya limestone by a break in sedimentation representing part of Ordovician time, and the Montoya limestone is limited above by a break representing an interval of unknown duration.

EL PASO LIMESTONE

In the type locality in the Franklin Mountains, north of El Paso, Texas, the El Paso limestone consists of about 1,000 feet of somewhat magnesian gray limestone, in part slabby and in part massive, and containing locally in the lower part considerable sand. The surface of many layers is covered by thin reticulating brown deposits of silica, and most of the rock weathers to a pale-gray tint—two features which are distinctive throughout southwestern New Mexico. The El Paso limestone is very conspicuous in the outcrop zone along the east front of the San Andres Mountains, . . . where its thickness is 300 feet at the south but gradually diminishes to about half that amount in the northern part of the range; the last exposure to the north is seen in the southwestern ridge of the Oscura Mountains. In the west face of the Sacramento Mountains, southeast of Alamogordo, its thickness is 250 feet at the place where its base is exposed near the mouth of Agua Chiquita Canyon. . . . It is about 300 to 400 feet thick in the west face of the Sierra Caballo, but only about half as thick in the Lake Valley district and the Mimbres Mountains and 600 feet in the Cooks Range. About Silver City and Hanover and in the Florida Mountains, where the total thickness is about 800 feet, there are extensive exposures of the characteristic limestone. In the Klondike Hills and Vittorio Mountains the thickness is 640 feet, and in the Hatchet Mountains it is about 500 feet. The east end of the Snake Hills, which rise out of the plain a few miles southwest of Deming, consists of the medial and upper beds of the formation, and upper strata appear in a small outcrop in the Peloncillo Mountains, north of Granite Gap.

Fossils are not numerous in the El Paso limestone, and most of those obtained came from the medial and upper beds.. .

Kirk[4] has given a detailed description of the El Paso limestone, with a discussion of its distribution and relations in many areas, including New Mexico. The paper contains a list of references on this formation.

2 King. P. B., Older rocks of Van Horn region, Texas: Bull. Amer. Assoc. Petrol. Geol., Vol. 24. No. 1. pp. 153-155, January 1940.

3 Quoted from Darton, N. H., "Red Beds" etc.: U. S. Geol. Survey Bull. 794, pp. 10-13, 1928.

4 Kirk, Edwin, The Lower Ordovician El Paso limestone of Texas and its correlatives: Amer. Jour. Science, Vol. 28, pp. 443-463, 1934.

MONTOYA LIMESTONE

The Montoya limestone, of latest Ordovician (Richmond) age, underlies the portion of New Mexico south of latitude 33° and in places may extend farther north under overlapping beds. The thickness ranges from 200 to 300 feet at most outcrops, with local diminution due to erosion of the top; to the north the formation thins out rather rapidly. The formation comprises a lower member of dark-colored massive limestone, in places sandy, and an upper member of slabby beds with many thin layers of chert. The strata are all hard, and at most places the outcrop is a dark cliff in the mountain side. Along the east slope of the Franklin Mountains the formation is 250 feet thick. In the Cooks Range there is a top member of 60 feet of light-colored slabby limestone with a six-foot very fossiliferous layer at the base, underlain by 150 feet of limestone containing numerous cherty layers, and a basal member of 40 feet of dark massive limestone or sandstone. In the Snake Hills, a few miles west of Deming, the greater part of the formation, 300 feet in all, is exposed lying on the El Paso limestone. At the base is dark massive limestone; next above very cherty limestone with alternating layers of purer limestone; 30 feet of dark-gray sandy limestone grading upward into purer, partly massive limestone that weathers to an olive tint; then a 60-foot member of alternating layers of chert and limestone, with fossils; and at the top a thick mass of highly cherty rock constituting the crest of the ridge. In the Klondike Hills the basal member is a dark-gray sandstone six to eight feet thick, lying on the slightly irregular surface of the El Paso limestone. It is overlain by 30 or 40 feet of dark massive sandy limestone, capped as in other areas by a succession of alternating layers of chert and very fossiliferous limestone. In the Silver City region, where the formation is about 300 feet thick, it contains many chert layers, except at the top, where there is a member that consists of alternating thin beds of smooth white limestone and blue limestone with cherty beds at intervals. In the Sierra Caballo and the Mimbres Mountains the formation is extensively developed with its usual characteristics. At Lake Valley there is 20 feet of gray hard sandstone at the base, overlain by 25 feet or more of cherty limestone of strong Montoya aspect. The Montoya limestone is a prominent feature all along the great eastward-facing escarpment of the San Andres Mountains, . . . but it thins out in the south end of the Oscura Mountains. It consists of an upper member of alternating thin beds of limestone and chert, from 30 to 75 feet thick, and a lower member of very massive dark limestone, 100 feet thick near latitude 33° and southward but thinning to the north. Locally there is a basal deposit of sandstone which attains a thickness of 15 feet near San Andres Peak. In the southwestern portion of the Oscura Mountains the lower member of dark massive limestone, 35 feet thick, grades up into six feet of beds with cherty layers, overlain by red shale probably representing the Percha. In the west front of the Sacramento Mountains, southeast of Alamogordo, the Montoya limestone consists of the usual two members—the upper one 60 feet thick, of alternating thin beds of chert and fossiliferous limestone, and the lower one 75 to 120 feet thick, of dark massive limestone with local gray sandstone at the base, lying on the slightly channeled surface of the El Paso limestone. In the Hatchet Mountains, the upper member is about 120 feet thick and the lower member about 30 feet.

Fossils of the Richmond fauna occur throughout the Montoya limestone at nearly all exposures, but they are relatively scarce in the lower member, especially in Luna County. . .

SILURIAN SYSTEM[1]

FUSSELMAN LIMESTONE

Only a small portion of Silurian time is represented by the Fusselman limestone, which is confined to the part of New Mexico south of latitude 33°, though in that part it is of general occurrence. It carries abundant fossils of Niagara age. At the type locality in the Franklin Mountains, north of El Paso, Texas, its thickness is 1,000 feet and it is of considerable topographic prominence. In the Cooks Range near Lake Valley it is about 200 feet thick, in the Sacramento Mountains 100 to 130 feet, . . . near Silver City 40 feet, in the Hatchet and Victorio Mountains 100 feet or more and in the San Andres Mountains it ranges from 220 to 120 feet but thins out rapidly a short distance north of latitude 33°.

The formation everywhere lies on the Montoya limestone on a plane of erosional unconformity, in places marked by conglomerate consisting of pebbles of the underlying formation. Generally it is overlain abruptly by dark shale of the Percha (Devonian), but in the Franklin Mountains it is - overlain by limestone apparently of Pennsylvanian age, and in the Florida Mountains is overlapped by the Gym limestone (Permian). It is the ore-bearing rock in the Cooks Peak and Victorio mining districts. In most regions two members are present—an upper one about 50 feet thick, of hard dark massive limestone with fossils and a lower one 85 feet thick (southeast of Alamogordo), of compact fine-grained gray limestone that weathers nearly white.

In general, fossils are rare in the Fusselman limestone. . .

DEVONIAN SYSTEM

FRANK V. STEVENSON[2]
Fort Smith, Arkansas

GENERAL FEATURES

The Devonian strata of New Mexico are divided into three formations, all of late Devonian age. The divisions are based on sedimentary and faunal breaks, and to a certain extent on superposition. In ascending order the formations are named Canutillo, Sly Gap, and Percha. The last-named is readily divisible into two units, designated in this report as lower and upper Percha shale.

CANUTILLO FORMATION

Although the Canutillo formation in Texas is considered to be medial Devonian in age, its fauna and the geologic history of the southwest indicate that it is more probably early late Devonian. No middle Devonian forms have been found, and the sparse Canutillo fauna indicates a close relationship to the overlying Sly Gap formation. The faunal assemblage includes two species of *Atrypa*, a thin-shelled Stropheodontid, numerous brachiopods resembling *Liorhynchus,* and great numbers of bryozoa identified as *Sulcoretepora*. The bryozoa make up a large part of several thin beds near the top of the Canutillo formation ; these beds constitute an excellent horizon marker.

The Canutillo rests unconformably upon the Fusselman limestone of Silurian age. The basal part consists chiefly of mas-

[1] Quoted from Darton, N. H., "Red Beds" etc.: U. S. Geol. Survey Bull. 794, p. 14, 1928.
[2] Geologist.

sive calcareous siltstone. It is overlain by thin beds of varicolored shale interbedded with massive thick beds of calcareous brown siltstone. The shales, which constitute less than 20 percent of the formation, tend to pinch out laterally along the outcrop. The entire formation is more siliceous and massive than the overlying Sly Gap formation.

The Canutillo is the most limited in areal extent of all the Devonian formations in New Mexico. It has been found in the central and southern San Andres Mountains, in the Sacramento Mountains, and in the Franklin Mountains north of El Paso. The average thickness is between 25 and 30 feet. The most complete known exposure, with a thickness of 88 feet, is in San Andres Canyon in the San Andres Mountains.

SLY GAP FORMATION

The Sly Gap formation is late Devonian in age. The fauna, of 68 recognized genera and 135 species and varieties, includes five common index genera: *Atrypa, Cyrtina, Productella, Leptostrophia,* and *Macgeea. Atrypa* is predominant in numbers and variety.

The formation consists chiefly of thin alternating layers of shale and siltstone, with a few beds of limestone. A zone eight to ten feet thick at the base is more massive than the rest of the formation. It is easily noted on the outcrop due to its characteristic red-brown color, which is in contrast to the lighter colors of the sediments above and below. Many fragments of crinoids and brachiopods are also a feature of the basal beds. The shales range from black, fissile, and carbonaceous to light buff or tan. The siltstones and limestones are, in general, buff.

The Sly Gap formation averages approximately 100 feet thick in the Sacramento Mountains, and 110 to 135 feet thick in the San Andres Mountains. The westernmost exposure of the Sly Gap, in the Mud Springs Mountains near Hot Springs, and an exposure in the Sierra Caballo, show 80 to 90 feet.

At the south end of the San Andres Mountains the Sly Gap rests on the Canutillo formation; in the central part, on the Fusselman limestone; and north of Rhodes Pass, on the Montoya limestone. In the south and central parts of the Sacramento Mountains the Sly Gap rests unconformably on the Canutillo, whereas in the area north of Alamo Canyon and in its eastern tributaries it rests upon the Fusselman limestone. Siltstone beds without fossils, which have been found below typical lower Percha shale in the Mimbres Mountains, may or may not be equivalent to Sly Gap sediments to the east.

PERCHA SHALE

The Percha shale is readily divisible into two parts. The lower unit, which makes up two-thirds of the total thickness, consists of black carbonaceous fissile shale without fossils. The upper unit consists of gray and green shale with lenses and nodules of limestone. Fossils are generally confined to the limestone lenses and nodules in the shale.

Lower Percha Shale.—Black shales are found above the Canutillo formation in the Franklin Mountains near El Paso; between the Sly Gap and the Lake Valley formations in Marble Canyon in the Sacramento Mountains; and in the Cooks and Mimbres Mountains. These shales are believed to be lower Percha, but it is impossible to establish this correlation except by stratigraphic position. The thickness of the lower Percha black shale ranges from 10 feet in the Sacramento Mountains to 383 feet in the Silver City region.

Upper Percha Shale.—The upper Percha crops out in the general area of the Mimbres Mountains. Its lower contact shows gradation from black fissile shale upward to calcareous gray and green shale. The upper Percha in the Hillsboro-Lake Valley area contains small isolated limestone nodules; in the Silver City-Santa Rita area limestone beds as much as 22 feet thick are not uncommon. Average thickness of the upper Percha is between 70 and 90 feet.

CORRELATION

Little is known of the Canutillo fauna and its relations to other Devonian faunas of the southwest; hence no accurate correlations can be made. In the case of the Sly Gap, however, correlations on paleontologic grounds may be made both to the east and to the west. The Sly Gap shows definite faunal similarity with the Hackberry group of Iowa and the Snyder Creek formation of Missouri, and with the Martin limestone of Arizona and the Devils Gate formation[3] of Nevada.

The lower Percha shale, due to its lack of fossils, cannot be correlated accurately. *Camarotoechia endlichi*, found in the upper Percha shale, is characteristic of the Ouray limestone of Colorado and the "lower" Ouray of Arizona.

MISSISSIPPIAN SYSTEM

A. L. BOWSHER[1] AND L. R. LAUDON[2]
Lawrence, Kansas

GENERAL FEATURES

Rocks of Mississippian age are exposed in central and southwestern New Mexico. They have been demonstrated to contain units of the Kinderhook, Osage, Meramec, and Chester series as recognized in the Upper Mississippi Valley region. Rocks of the Kinderhook and Osage groups are found principally in the central southern part of New Mexico, while those of Meramec and Ches-

[3] Merriam, C. W., Devonian stratigraphy and paleontology of the Roberts Mountains region. Nevada: Geol. Soc. Amer., Special Paper No. 26, pp. 26-29, 1940.

[1] Geologist, State Geological Survey of Kansas.

[2] Associate Professor, Department of Geology, University of Kansas.

ter age are found farther to the south. The rock units are shown in the following table.

System	Series	Formation	Member
Mississippian	Chester, Meramec	Helms	
	Osage	Lake Valley	Dona Ana, Arcente, Alamogordo
	Kinderhook	Caballero	

CABALLERO FORMATION

The Caballero formation[3] consists of soft light gray nodular limestone beds, with thin irregular calcareous shale partings. It is commonly rather fossiliferous and is readily recognized by its characteristic rubbly weathered slope. The peculiar nodular lithology is persistent throughout the Sacramento and San Andres mountain areas wherever the Caballero formation is present, but is subject to considerable variation in areas farther south and west. In the Cooks Range the Caballero formation is represented by about 30 feet of dark gray argillaceous nodular limestone that contains thin irregular black chert nodules and is interbedded with gray silty shales. At Lake Valley the Caballero consists of soft thin-bedded gray marly silts with a few gray nodular limestone beds in the basal portion and harder gray nodular limestone at the top.

The Caballero formation is thickest in Lostman Canyon, in the San Andres Mountains, where it is approximately 80 feet thick. It diminishes in thickness both north and south from this area. In the Sacramento Mountains the maximum thickness of the Caballero formation is developed in the area between Mule and San Andreas Canyons where it commonly measures over 60 feet. It thins both to the north and south from this area, but is present throughout the full length of exposure of Mississippian rocks in the range. Farther to the southwest, at Lake Valley, it is 53 feet thick; here, however, the thickness is variable, due, apparently, to the fact that the formation was laid down on an erosion surface. The Caballero formation is missing a short distance north of Lake Valley at Wilson's ranch in sec. 10, T. 18 S., R. 7 W. It is present only locally in the Silver City area.

The Caballero formation lies unconformably on various parts of the underlying Devonian strata. The contact commonly shows evidence of erosion and oxidation. The basal beds of the Caballero formation normally consist of thin-bedded black fissile shale in which fish teeth and phosphatic nodules are abundant. The contact of the Caballero formation with the overlying Lake Valley formation is unconformable. Commonly the formations

[3] Laudon, L. R., and Bowsher, A. L., Mississippian formations of Sacramento Mountains, New Mexico: Bull. Amer. Assoc. Petrol. Geol., Vol. 25, No. 12, p. 2114, December 1941.

appear to grade insensibly into one another, due to the presence of considerable reworked Caballero material in the base of the Lake Valley formation.

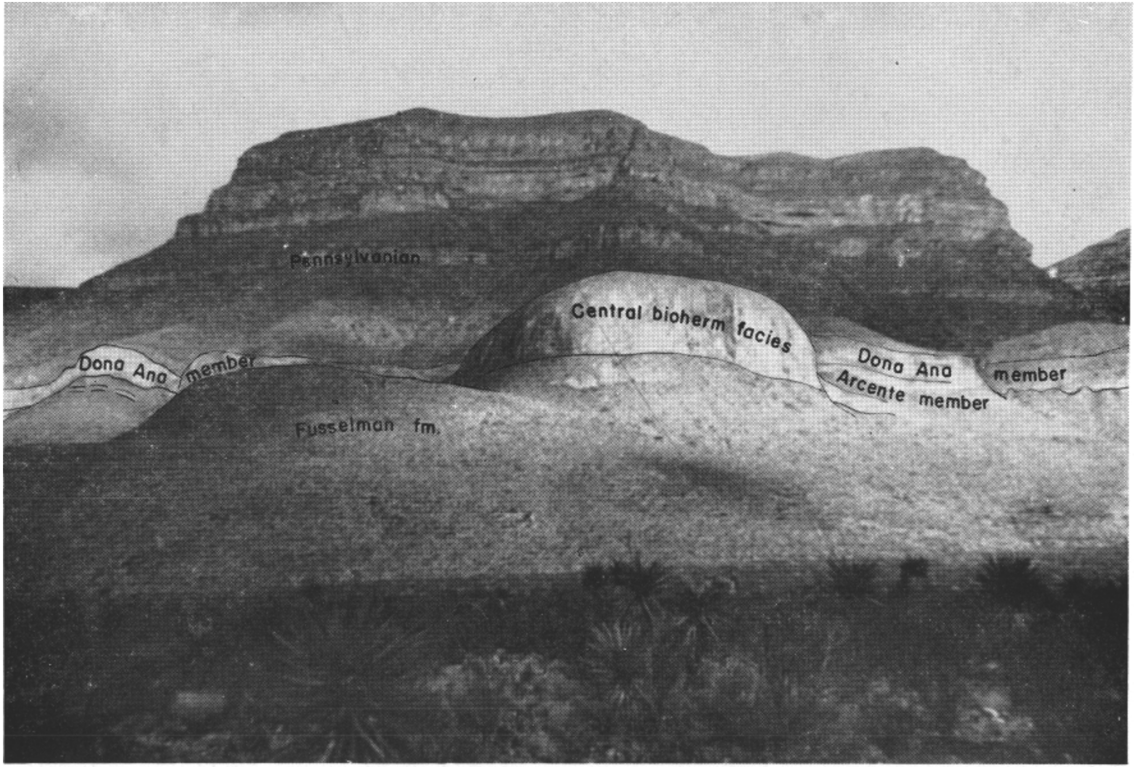
Most exposures of the Caballero formation are abundantly fossiliferous. The preponderance of this fauna consists of well recognized Kinderhook species such as *Productina sampsoni, Dictyoclostus chouteauensis, Schellwienella chouteauensis, Schizophoria poststriatula, Spirit er gregeri,* and *Reticularia cooperensis.* Both fauna and lithology indicate a direct correlation with the Chouteau limestone of the Upper Mississippi Valley region. It is well to point out, however, that there are some Osage species in the fauna. Such species as *Dictyoclostus fernglenensis, Ptychospira sexplicata, Brachythyris suborbicularis, Cliothyridina prouti,* and *Athyris lamellosa* are found commonly in Osage rocks. Their presence in the Caballero formation can be taken to indicate one of two things: either that Osage species appeared earlier in the western Mississippian seas, or that the Caballero formation is slightly younger than the Chouteau formation of the Upper Mississippi Valley region.

LAKE VALLEY FORMATION

The Lake Valley formation is the most conspicuous and widely distributed of the Mississippian formations of New Mexico. It consists of a variable section of limestone and siltstone beds that commonly are complicated stratigraphically by large bioherm (reef) structures. In the Sacramento and San Andres mountain areas the Lake Valley formation falls naturally into three easily recognizable members.[4] The basal member (Alamogordo) is made up predominantly of limestone beds and consequently is a scarp-making formation. The middle member (Arcente) is made up of interbedded soft gray thin-bedded silt-stone and light-gray shale that weathers to rubbly slopes. The upper member (Dona Ana) consists of hard gray massive cherty limestone beds and is also a scarp-making unit.

Alamogordo member.—The normal section of the Alamogordo member, when not complicated by bioherm structure, consists of four parts. The basal beds *(Taonurus* zone) are made up of soft light-gray thin-bedded calcareous siltstone interbedded with softer gray marl. The *Taonurus* siltstone zone is overlain by hard black thin-bedded sparsely fossiliferous cherty limestone beds that form conspicuous cliffs on the weathering mountain fronts. This hard black limestone bed is the most persistent portion of the Alamogordo member. Next occurs a succession of soft thin-bedded varicolored highly fossiliferous marl beds. This is the zone that carries the excellently preserved crinoid fauna at Lake Valley. The uppermost part of the Alamogordo member is a gray hard cherty crinoidal limestone that also makes a conspicuous cliff on the mountain front.

[4] Laudon, L. R., and Bowsher, A. L., Op. cit., p. 2125.



Bioherm (reef) structure in the Alamogordo member of the Lake Valley formation, west face of the Sacramento Mountains one mile north of San Andreas Canyon.

The sedimentary succession of the Alamogordo member is often complicated by the introduction of bioherm structures. (See Plate 3.) A bioherm consists of a rounded central mass of massive hard black nearly unfossiliferous limestone surrounded by related peripheral facies. In the Sacramento Mountains the central bioherm structures reach thicknesses of as much as 200 feet. The central bioherm masses grade outward into, and are interbedded with, the various facies related to the central mass itself. The peripheral beds, which consist predominantly of the disintegrated parts of crinoid skeletons, commonly dip away from the central mass at steep angles. The bioherm structures are excellently developed in the Sacramento Mountain area, and to a lesser extent over the entire area of exposure of the Lake Valley formation.

The coarsely crinoidal limestones associated with the peripheral facies of the bioherm structures have in places an unusually high porosity. As they are lenticular and dip steeply, they should make excellent stratigraphic traps for petroleum. Abundant production is now being obtained from supposedly similar structures in Mississippian rocks of the Wichita Falls region in Texas.

The Alamogordo member is the most widespread part of the Lake Valley formation, reaching a thickness of over 350 feet in many areas. Its maximum development is in the Cooks Range where it is nearly 400 feet thick. In the Santa Rita district it is approximately 300 feet in thickness, and more than 300 feet thick at the northern end of the Sacramento Mountains in the Marble Canyon area. Over most of the Sacramento Mountain area the member is less than 150 feet thick. Maximum development in the San Andres Mountain area is in San Andres Canyon where the member measures over 275 feet in thickness; throughout most of the northern part of the San Andres Range it is less than 75 feet thick.

The Alamogordo member is the most fossiliferous portion of the Lake Valley formation. The excellently preserved crinoid fauna at Lake Valley occurs in a marly part of this member. Unusually fossiliferous zones are found in the Sacramento Mountains in marly parts of the interbiohermal facies. An analysis of the fauna shows it to be of early Osage age and a direct correlative of the St. Joe, Fern Glen, and New Providence formations of the Upper Mississippi Valley region. Typical index fossils are *Dictyoclostus fernglenensis, Rhipidomella missouriensis, Spirifer rowleyi, Rhodocrinus barrisi, Uperocrinus pyriformis, Actinocrinus rubra,* and *Steganocrinus pentagonus.*

Arcente member.—The Arcente member consists of soft dove-gray thin-bedded siltstone interbedded with soft gray shale. The shales commonly make up 50 percent of the section in the lower part of the member. The upper portion of the member is made up almost entirely of siltstone and the beds are more massive. In the San Andres Mountain area the Arcente member is considerably more limy and appears as dense hard black limestone. In all areas the Arcente member weathers to retreating gray blocky rubbly slopes, in coloration not markedly unlike the Caballero formation but lacking the nodular beds of the Caballero.

The Arcente member has been identified only in the Sacramento and San Andres mountain areas. It reaches its maximum development in the Sacramento Mountains in Alamo Canyon where it measures over 225 feet in thickness. It is thinly developed throughout the San Andres Mountain area, where it seldom exceeds 25 feet in thickness.

In comparison with other members of the Lake Valley formation, the Arcente member is decidedly unfossiliferous. Large numbers of fenestelloid bryozoans are found in the upper part of the member. Typical Osage brachiopods such as *Dictyoclostus fernglenensis*, *Schizophoria poststriatula, Spirifer rowleyi,* and *Ptychospira sexplicata* are found occasionally.

Dona Ana member.—The Dona Ana member consists of relatively massive, predominantly gray, coarsely crystalline, very cherty crinoidal limestone beds that crop out as bold overhanging cliffs. The lower part commonly contains soft crinoidal marls that make retreating zones at the base of the cliff. The contact of the Dona Ana member with the overlying Pennsylvanian formations is markedly unconformable. The upper part of the Dona Ana member is commonly made up almost entirely of residual chert.

The Dona Ana member has been identified only in the Sacramento and San Andres mountain areas. It reaches its maximum development in the vicinity of San Andreas Canyon in the Sacramento Mountains where it measures 175 feet in thickness. In the San Andres Mountains it is rarely over 20 feet thick. In some parts of the area it has been removed by erosion.

The Dona Ana member is very fossiliferous through much of the area in which it is exposed. The lower marly beds particularly carry abundant fossils. An analysis of the fauna shows many species that are found in the lower Burlington limestone of the Upper Mississippi Valley region. None of the highly specialized crinoids that characterize the late upper Burlington beds are found in the Dona Ana member. According to this evidence, the Lake Valley formation appears to represent strata from earliest Osage age until the end of lower Burlington times.

HELMS FORMATION

The so-called Helms formation is exposed in only the southern part of the State. The type section is located in the Hueco Mountains and excellent sections are to be found in the Franklin

Mountains.[5] Rocks belonging to the Helms group are also exposed at the southern end of the San Andres Mountains.

The lower part of the Helms contains a variable series of black limestones, grits, siltstones, and silty shales. This lower unit carries the *Liorhynchus carboniferum* fauna that characterizes the Moorfield formation of Meramec age in the northwestern Arkansas region. The thin-bedded black silty limestone beds that weather to a rusty brown color are also strikingly similar to those of the Moorfield formation as exposed in Arkansas and Oklahoma. Since the Moorfield fauna is so strikingly different from any other known Mississippian fauna, a direct correlation between these beds can be made.

The Moorfield portion of the Helms group is unconformably overlain by shales and limestones of Chester age. The lower part normally consists of thin-bedded fissile green shale interbedded with thin sandstone beds. These grade upward into nodular lenticular gray fossiliferous limestone beds. The *Graphiodactylus fayettevillensis* fauna and the lithology exhibited by the upper portion of the Helms group are much like those of the Fayetteville formation of northwestern Arkansas and northeastern Oklahoma. It is not possible to make a direct correlation because of insufficient evidence. The Chester portion of the Helms group is slightly over 100 feet in thickness.

MISSISSIPPIAN-PENNSYLVANIAN CONTACT

Rocks of Pennsylvanian age are markedly unconformable on the underlying Mississippian rocks all over southwestern New Mexico. They may be seen in contact with almost all parts of the Mississippian section from the top of the Helms down to the lower portion of the Alamogordo member of the Lake Valley formation. In many areas the relief on the Mississippian surface was great, allowing considerable thicknesses of reworked Mississippian chert to collect in valleys cut into the Mississippian surface. Many such erosion channels can be seen in both the Sacramento and San Andres mountain areas. In some places relief of over 100 feet may be demonstrated on this surface in distances of less than a quarter of a mile.

PENNSYLVANIAN SYSTEM

M. L. THOMPSON[1]

Socorro, New Mexico

GENERAL FEATURES

Rocks of Pennsylvanian age are exposed in nearly all the mountain ranges of central New Mexico, from the Sangre de Cristo Range near the Colorado state line to the Texas line on the south. No Pennsylvanian rocks are at the surface in the eastern

[5] Nelson, L. A., Paleontology and stratigraphy of the Franklin Mountains, West Texas: Bull. Amer. Assoc. Petrol. Geol., Vol. 24, No. 1, p. 165, January 1940.

[1] Associate Professor of Geology and Paleontology, New Mexico School of Mines.

one-third or in the north part of the western one-fourth of the State.

Pennsylvanian rocks have been encountered in deep wells in east central New Mexico[2] and in the Rattlesnake field in the extreme northwestern part of the State.[3] They have also been found in the subsurface at several localities in the central part of the State, nearer to surface exposures.[4] Although Pennsylvanian rocks have been reported with question from wells drilled in New Mexico east of the Sangre de Cristo Range,[5] it seems doubtful that they are present in the subsurface over most of northeastern New Mexico.

The Pennsylvanian in the Rio Grande Valley south of the Jemez Mountains and south of Albuquerque is composed largely of marine limestone and calcareous shale. Sections typical of this region are exposed at the north end of the Oscura Mountains, Socorro County, and in the Mud Springs Mountains, Sierra County. Samples from wells drilled in the Rattlesnake field, San Juan County, indicate that the Pennsylvanian of northwestern New Mexico is also largely marine limestone and shale. Over the general area of the Sangre de Cristo Range in north central New Mexico, the Pennsylvanian rocks are largely shales, arkosic sandstones and conglomerates, siltstones, and argillaceous dark gray limestones.

The total thickness of the Pennsylvanian system varies markedly among different localities. One of the thinnest essentially complete sections in New Mexico is found in the Santa Rita area and measures about 820 feet in thickness. The thickest sections are in the Sangre de Cristo Range, where the system is over 3,500 feet thick, although only the lower part is present. Measured thicknesses in some of the mountain ranges in central New Mexico are as follows: Sacramento Mountains, 3,065 feet; San Andres Mountains, 3,067 feet; Mud Springs Mountains, 1,703 feet; Oscura Mountains, 946 feet; Ladron Mountains, more than 2,250 feet; and Jemez Mountains, 850 feet.

CLASSIFICATION

Until recently all rocks of Pennsylvanian age in New Mexico were included by the State Bureau of Mines and Mineral Resources in the Magdalena formation[6] or the Magdalena group.[7] Some earlier workers subdivided the Magdalena group into the Sandia formation below and the Madera limestone above, but the

[2] Hills, J. M., Rhythm of Permian seas--a paleogeographic study: Bull. Amer. Assoc. Petrol. Geol., Vol. 26, No. 2, pp. 217-255, February, 1942.

[3] Thompson, M. L., Pennsylvanian system in New Mexico: N. Mex. Bur. Mines Bull. 17, pp. 10, 17, 1942.

Darton, N. H., "Red Beds" etc. : U. S. Geol. Survey Bull. 794, p. 132, 1928.

Winchester, D. E., The oil and gas resources of New Mexico: N. Mex. Bur. Mines Bull. 9, pp. 93 and 188, 1933.

Thompson, M. L., Op. cit., pp. 10, 27, pl. I.

[5] Darton, N. H., Op. cit., pp. 307, 308, and 312.

[6] Needham, C. E., Some New Mexico fusulinidae: N. Mex. Bur. Mines Bull. 14, 1937.

[7] Harley, G. T., The geology and ore deposits of northeastern New Mexico: N. Mex. Bur. Mines Bull. 15, 1940.

THE PENNSYLVANIAN SYSTEM IN CENTRAL AND SOUTHERN NEW MEXICO[8]

SERIES	GROUP	FORMATIONS AND MEMBERS	
Virgil	Fresnal		
		Bruton formation	
	Keller	Moya formation	
		Del Cuerto formation	
Missouri	Hansonburg	Story formation	
		Burrego formation	
	Veredas	Council Spring limestone	
		Adobe formation	
		Coane formation	
Des Moines	Bolander		
	Armendaris	Garcia formation	
		Whiskey Canyon limestone	
		Elephant Butte formation	
			Warmington limestone member
Derry	Mud Springs	Cuchillo Negro formation	
		Hot Springs formation	
	Green Canyon	Apodaca formation	
		Arrey formation	

stratigraphic limits of these formations were generally not clearly stated. The Pennsylvanian rocks of the State have been re-classified by Thompson,[8] as shown in the table above. It will be noted that the term Magdalena has been abandoned, as it was essentially synonymous with the systemic term Pennsylvanian. The new classification is based on extensive field studies, numerous mea-

[8] Thompson, M. L., Pennsylvanian system in New Mexico: N. Mex. Bur. Mines Bull. 17, 1942.

sured sections, and exhaustive laboratory and microscopic studies of the fossils, especially fusulinid foraminifera which, in many places, are diagnostic. Brief notes on the thickness and lithology of the formations are given below.

DERRY SERIES-GREEN CANYON GROUP

Arrey formation.—The type section of the Arrey formation is about three-fourths of a mile east of the town of Derry, Sierra County, and consists of massive limestones and calcareous shales. The thickness of the formation is about 32 feet at the type section and exceeds 300 feet in some other areas.

Apodaca formation.—In its type section, which is near that of the Arrey, the Apodaca formation is composed of dense gray highly cherty limestone, calcareous shale, greenish gray shale, and black to dark gray calcareous siltstone. It is about 55 feet thick.

DERRY SERIES-MUD SPRINGS GROUP

Hot Springs formation.—This formation consists of dark to light gray massive to nodular highly cherty limestone, and thick beds of gray shale. It is 85 feet thick at its type locality in the Mud Springs Mountains northwest of Hot Springs.

Cuchillo Negro formation.—At the type locality in Whiskey Canyon, northern Mud Springs Mountains, this formation consists almost entirely of gray massive to nodular cherty limestone. It is about 28 feet thick.

DES MOINES SERIES-ARMENDARIS GROUP

Elephant Butte formation.—In its type section in the Mud Springs Mountains the Elephant Butte formation is composed chiefly of limestone, with thin beds of silty micaceous shale, and a thin conglomeratic sandstone about 22 feet above the base. The total thickness at the type section is 82 feet. The name Warming-ton limestone member is applied to the lower 22 feet of medium to light gray cherty limestone.

Sandia formation.—The term Sandia formation is applied to 127 feet of coarse-grained sandstones and conglomerates typically exposed in Las Huertas Canyon on the northeast side of the Sandia Mountains. The Sandia grades into the lower limestones of the Elephant Butte formation southward from the Sandia Mountains.

Whiskey Canyon limestone.—The Whiskey Canyon limestone is 163 feet thick at its type locality in the Mud Springs Mountains and is composed almost entirely of cherty gray limestone.

Garcia formation.—The Garcia formation, as exposed in Whiskey Canyon, Mud Springs Mountains, consists of limestone which is in part pure and in part argillaceous, together with several thin beds of gray to red shale and a basal bed of conglomeratic sandstone. It is 213 feet thick at the type section.

DES MOINES SERIES-BOLANDER GROUP

The term Bolander group is applied to the upper part of the Des Moines series of central New Mexico. It has not been subdivided into formations. The group is about 233 feet thick at its type locality in Whiskey Canyon, Mud Springs Mountains, and consists largely of gray highly fossiliferous limestones, interbedded with conglomerates, coarse-grained sandstones, and gray fossiliferous shales.

MISSOURI SERIES-VEREDAS GROUP

Rocks of the Missouri series in New Mexico are well developed and exposed in the northern Oscura Mountains, Socorro County, from which area the names of the formations have been taken.

Coane formation.—The Coane formation is largely limestone, although in some areas it contains beds of shale and sandstone. At its type locality the formation is about 59 feet thick.

Adobe formation.—In its type section the Adobe formation is largely gray limestone, with thin beds of gray shale and arkosic sandstone. The thickness of the formation in central New Mexico is from 47 feet to more than 200 feet.

Council Spring limestone.—The Council Spring is composed entirely of light gray to white massive limestone. It measures 18 to 30 feet in thickness.

MISSOURI SERIES-HANSONBURG GROUP

Burrego formation.—At its type locality the Burrego formation is made up of massively bedded to highly nodular limestone and is 52 feet thick. In some other areas the limestone is interbedded with gray fossiliferous shale.

Story formation.—The type section of the Story formation is divisible into two lithologic units, an upper massive limestone about 38 feet thick and a lower unit of red shales and arkosic sandstones about 20 feet thick. Both of these units are recognizable over large areas in central New Mexico.

VIRGIL SERIES-KELLER GROUP

Del Cuerto formation.—This formation, which is about 81 feet thick at its type locality in the northern Oscura Mountains, contains nodular to irregularly bedded limestone, limestone conglomerate, and arkosic sandstone.

Moya formation.—The Moya formation is composed almost entirely of massively bedded light gray limestone. It is 51 feet thick at its type locality in the northern Oscura Mountains.

VIRGIL SERIES—FRESNAL GROUP

At its type locality in Fresnal Canyon, Sacramento Mountains, the Fresnal group is about 530 feet thick and is composed largely of limestone, gray to red shale, arkosic sandstone, and conglomerate. Only one formation, the Bruton, has been named in the Fresnal group.

Bruton formation.—The Bruton formation is referred to the lower part of the Fresnal group. The type section of the formation is largely red shale, with thin interbedded strata of nodular limestones and arkosic coarse-grained to conglomeratic sandstone. At its type locality in the northern Oscura Mountains the formation is 114 feet thick.

PERMIAN SYSTEM OF CENTRAL NEW MEXICO

C. E. NEEDHAM[1]
Socorro, New Mexico

GENERAL FEATURES

Above a basal Permian limestone that is being described by Thompson[2] are four other Permian formations well developed in many parts of New Mexico. These are in ascending order the Abo formation, the Yeso formation, the Glorieta sandstone, and the San Andres limestone. These formations are of wide distribution, being present from the Zuni, Jemez, and Rincon Mountains on the north and northwest to the Guadalupe and Sacramento Mountains on the southeast. One or more of the formations are thought to extend southwestward into Grant County, although Permian relations in this part of the State are not well understood.

ABO FORMATION

The main body of red sandstones and shales lying above Pennsylvanian limestones in Abo Canyon in Valencia and Torrance Counties, New Mexico, was designated the Abo sandstone by Lee.[3] However, the exact type locality was not given, the upper and lower limits of the formation were not stated, and the geologic section was not accurately described. Recently, Needham and Bates[4] have attempted to supply the information omitted by Lee.

At the type locality near Scholle in Abo Canyon the Abo is about 915 feet thick, is almost entirely redbeds, and is 60 to 65 percent shale and 35 to 40 percent sandstone. It rests unconformably on a thin Permian limestone.[5] The Abo formation is of non-marine origin, as is shown in numerous localities by such sedi-

[1] Formerly Director, State Bureau of Mines and Mineral Resources.
[2] Thompson, M. L., Marine Permian Wolfcamp in New Mexico (in preparation).
[3] Lee, W. T., The Manzano group of the Rio Grande Valley, New Mexico: U. S. Geol. Survey Bull. 389, pp. 12 and 20-21, 1909.
[4] Needham, C. E., and Bates, R. L., Permian type sections in central New Mexico (in preparation).
[5] Thompson, M. L., Op. cit.

mentary features as mud cracks, bones and tracks of land vertebrates, remains of land plants, and lack of limestones suggesting marine origin. Salt casts, cross bedding, current and oscillation ripple mark are also common features in many places.

The Abo is well developed in the Jemez, Zuni, Sangre de Cristo, Sandia, Los Pinos, Ladron, Magdalena, Oscura, Caballos, San Andres, and Sacramento Mountains. In the northern Hueco Mountains the Abo formation grades southward into the Hueco limestones.

The Abo is believed to 'belong entirely to the Wolfcamp series of early Permian age. To the northwest it is believed to be the equivalent of the Rico limestone of southwestern Colorado.

YESO FORMATION

Lying on the Abo redbeds with apparent conformity is a succession of soft variegated sands, silts, shales, gray limestones, and gypsum beds, to which Lee[6] gave the name Yeso formation. The name was taken from Mesa del Yeso about 12 miles northeast of Socorro, New Mexico. Needham and Bates[7] believe that Lee intended the type section to be about two miles southeast of Mesa del Yeso and have so designated it.

At the type locality the Yeso is 593 feet thick and consists of about 10 percent limestone, 13 percent gypsum, and 77 percent red, pink, and light-colored sand and silt. It is overlain by the massive quartzitic Glorieta sandstone.

The Yeso thickens to the southeast and is about 1,050 feet thick in Chupadera Mesa, 900 feet in Rhodes Canyon in the San Andres Mountains, 1,200 feet in Tularosa Canyon in the Sacramento Mountains, and 1,800 feet in the Dunken dome, southwestern Chaves County. The amount of limestone increases southeastward; it constitutes about 40 per cent of the beds in Dunken dome.

To the northeast the Yeso shows a marked change in lithology and thickness. From Glorieta Mesa to Mora Canyon it is virtually all orange and pink sandstone and silt; only very slight amounts of gypsum and limestone are present. The thickness ranges from 200 to 300 feet. To the northwest the Yeso consists mainly of sands and silts in the Jemez Mountains, and also in the Zuni Mountains where Reiche[8] reports a thickness of about 900 feet of pink, orange, and red silts, shales, and sandstones, and a few feet of limestone.

The Yeso is believed to change laterally into the Bone Spring limestone of the Guadalupe Mountains and to be equivalent to about the lower two-thirds of the Leonard series.

[6] Lee, W. T., The Manzano group of the Rio Grande Valley : U. S. Geol. Survey Bull. 389, pp. 12 and 21-23, 1909.

[7] Needham, C. E., and Bates, R. L., Op. cit.

[8] Reiche, Parry, Personal communication, 1942.

GLORIETA SANDSTONE

Keyes[9] was first to use the term Glorieta sandstone, although he applied it to the main body of the Dakota sandstone (Cretaceous) around the south end of the Rocky Mountains. Cretaceous formations are not present in that vicinity, and Keyes gave no type locality for his Glorieta. Consequently, it is impossible to determine which sandstone he had in mind, although presumably it was one of the sandstones in Glorieta Mesa. Usage has since determined the Glorieta to be the prominent sandstone of Permian age exposed in Glorieta Mesa and lying above the pink and orange sand of the Yeso.

Needham and Bates[10] have designated the type locality as in Glorieta Mesa about one mile west of the village of Rowe in San Miguel County, New Mexico. Here the formation is 136 feet thick and rests on soft pink and orange silts of the Yeso. At the top is 20 feet of thin-bedded earthy gray limestone belonging to the San Andres formation. The Glorieta consists mainly of very clean white to light-colored heavy-bedded quartzitic sandstone. The lower few feet are somewhat friable and discolored. The heavy resistant beds form a cliff that can be followed for many miles along the mesa.

The Glorieta thickens eastward, northward, and westward from the type locality. In Mesa Jumanes, south of Willard, Torrance County, it is 278 feet thick; in Mora Canyon, 225 feet; and in the Zuni Mountains, Reiche[11] found 287 feet. It thins southward to about 75 feet northeast of Socorro and 15 feet in Rhodes Canyon in the San Andres Mountains, but thickens to 70 feet in the Dunken dome in southwestern Chaves County.

The Glorieta appears to be a marine sand laid down by an advancing sea prior to San Andres time. It is given formational rank because of its thickness, wide distribution, and distinctive character. It is placed in the Leonard series.

SAN ANDRES LIMESTONE

Lee[12] named the San Andres limestone from exposures along the walls of the canyon through which the road passes from Engle to Rhodes ranch in the San Andres Mountains, Socorro County, New Mexico. This is Rhodes Canyon, but otherwise Lee's type locality was indefinite. Needham and Bates[13] have designated the type locality as in the south wall of Rhodes Canyon, two miles west of the summit of Rhodes Pass.

In this canyon wall the formation lies on a 15-foot bed of white to pale-yellow sandstone believed to be the Glorieta. The top of the San Andres has been eroded, so that the full thickness cannot be determined. The formation here is about 595 feet

[9] Keyes, C. R., Foundation of exact geologic correlation: Iowa Acad. Sci. Proc., Vol. 22, pp. 257 and 262, 1915.

[10] Needham, C. E., and Bates, R. L., Op. cit.

[11] Reiche, Parry, Personal communication, 1942.

[12] Lee, W. T., Op. cit., pp. 12-13 and 29-30.

[13] Needham, C. E., and Bates, R. L., Op. cit.

thick, and consists almost entirely of medium to heavy-bedded dark gray to black petroliferous limestone. Many of the beds carry brachiopods, gastropods, crinoid stems, and other fossils.

The San Andres thins northward to about 200 feet northeast of Socorro, 110 feet at the mouth of Bluewater Canyon in the Zuni Mountains, 20 feet in Glorieta Mesa at Rowe, and 10 feet at Montezuma Hot Springs west of Las Vegas. It thickens gradually eastward to 625 feet in Tularosa Canyon in the Sacramento Mountains, and to 710 feet in the Dunken dome in southwestern Chaves County. Over most of central and northwestern New Mexico, one or two thin sandstones of Glorieta type are found near the base of the formation.

From the Socorro region to the Zuni Mountains the San Andres is overlain by Upper Triassic red and purple shales and sandstones of the Chinle formation; in Glorieta Mesa by orange to pink shaly silt and sand of unknown age; and in the Permian Basin by younger Permian beds. The San Andres of the type locality is believed to belong entirely in the upper part of the Leonard series.

PERMIAN SYSTEM OF SOUTHEASTERN NEW MEXICO

ROBERT L. BATES

GENERAL STATEMENT

The presence of three distinct areas of Permian sedimentation in southeastern New Mexico necessitates discussing the formations under three headings, namely Delaware Basin Section, Reef-Zone Section, and Shelf (Back-Reef) Section. The relations of these sections are discussed under Stratigraphy of the Southeast Area, pages 163 to 166, and are shown on the cross section, Fig. 11.

DELAWARE BASIN SECTION

Hueco limestone.—The Hueco limestone is best developed in the mountains north and east of El Paso, Texas. (For detailed discussion, see pages 40, 41.) However, beds of Hueco age have been identified in two deep Delaware Basin wells in Texas south of Guadalupe Peak,[1] and it is thought likely that the Hueco is present at great depth in the part of the Delaware Basin in New Mexico.

Bone Spring limestone.—The Bone Spring limestone was named by Blanchard and Davis[2] from a locality near Bone Spring in Bone Canyon on the west slope of Guadalupe Peak, Texas. As shown on the cross section, Fig. 11, the formation is present on

[1] King, P. B., Permian of West Texas and southeastern New Mexico: Bull. Amer. Assoc. Petrol. Geol., Vol. 26, No. 4, p. 563, April 1942.

[2] Blanchard, W. G., and Davis, M. J., Permian stratigraphy and structure of parts of southeastern New Mexico and southwestern Texas: Bull. Amer. Assoc. Petrol. Geol., Vol. 13, pp. 961-964, 1929.

the shelf area as well as in the Delaware Basin. According to King:[3]

> The Bone Spring consists largely of limestones, but these are of varied types, the different sorts being complexly interbedded and interfingered. Those laid down in the shelf area outside the Delaware Basin, now exposed in the Guadalupe Mountains and the Sierra Diablo, are of different facies from those laid down within the basin, now exposed in the Delaware Mountains. In the intervening marginal area, rocks of the two facies interfinger.

In the Delaware Basin the formation appears to be between 1,500 and about 3,000 feet in thickness. According to King, in its lower part the Bone Spring is "a monotonous succession of platy, siliceous shale," with much granular black limestone in the form of nodules. The upper part of the formation in the basin consists of "several hundred feet of siliceous shales, containing lenses and beds of black limestone like that below, and some beds of slabby sandstone . . . "

Although the Bone Spring is best known from surface sections and wells in Texas, it forms a considerable part of the Delaware Basin section in New Mexico.

Delaware Mountain group.—King[4] describes the Delaware Mountain group in part as follows:

> The Delaware Mountain formation, as proposed by Richardson,[5] was later restricted[6] to beds above the Bone Spring limestone. It is now applied to the sandstones and thin limestones of the Guadalupe series in the Delaware Basin area. These have a general lithologic unity, and have much the same aspect from base to top. However, . . the lithologic character and faunal content of the sequence changes somewhat from base to top, so that the unit can be divided into three parts... These are here classed as formations, and the Delaware Mountain given the rank of a group.
>
> In most of the Delaware Basin, the Delaware Mountain group has the same upper and lower limits as the Guadalupe series, but it does not have the same lateral extent. Along the margins of the basin, the Delaware Mountain group ends where its characteristic deposits are replaced by units of the same age but different facies. The Guadalupe series, on the other hand, includes all rocks of Delaware Mountain age, wherever they occur, and regardless of their lithologic character and faunal content. The group is a lithologic unit, the series a chronologic unit.
>
> The three formations of the Delaware Mountain group are named, in ascending order, the Brushy Canyon, the Cherry Canyon, and the Bell Canyon. The names are taken from drainage courses which cross the broad belts of outcrop in the northern Delaware Mountains. . . . The two lower formations have a thickness of 1,000 feet each, and the upper formation a thickness of 700 feet.

As indicated by logs of deep wells, the Delaware Mountain group is considerably thicker near the middle of the basin than on the outcrop along its edges.

[3] King, P. B., Op. cit., p. 567.
[4] King, P. B., Op. cit., pp. 576-577.
[5] Richardson, G. B., Report of a reconnaissance in trans-Pecos Texas north of the Texas and Pacific Railway: Univ. Texas Bull. 23, pp. 38-41, 1904.
[6] As in King, P. B., Permian stratigraphy of trans-Pecos Texas: Bull. Geol. Soc. Amer., Vol. 45, p. 765, 1934.

Castile formation.—According to King:[7]

> The Castile, or lowest formation of the Ochoa series, crops out in the low, rolling Gypsum Plain east of the Delaware Mountains, and southeast of the Reef Escarpment [extending from Guadalupe Point in Texas to Carlsbad, New Mexico]. Its basal beds are exposed a few hundred yards south of U. S. Highway 62, where this highway leaves the eastern hills of the Delaware Mountains. Some of the higher beds of the Castile are splendidly exposed in new, deep roadcuts on the same highway farther northeast, not far beyond the Texas-New Mexico line.
>
> The formation consists largely of anhydrite, which is marked throughout by thin, light and dark laminae, that may be varves. . . Limestones a few inches thick are interbedded at long intervals higher in the section, and appear in the road-cuts north of the Texas-New Mexico line previously mentioned. Drilling east of the outcrop shows the existence of several salt beds in the lower part of the formation. Drill records also indicate that, near the center of the Delaware Basin, the formation reaches a maximum thickness of somewhat more than 1,500 feet.

Salado formation.—The Salado was named by Lang.[8] In the Delaware Basin it consists predominantly of salt, with thin zones of anhydrite and redbeds. Layers of potash minerals are being mined from the Salado east of Carlsbad. The formation wedges out abruptly on the west side of the Delaware Basin, and does not crop out. It has been suggested by Kroenlein[9] that the present western edge of the Salado is not far from the original limits of deposition. The maximum thickness of the formation in the basin area is about 2,000 feet.

Three members of the Salado formation have recently been described. The Cowden member, named by Giesey and Fulk,[10] is a persistent bed of anhydrite 10 to 50 feet thick which lies 150 to 200 feet above the base of the formation. The La Huerta silt member and the Fletcher anhydrite member, both named by Lang,[11] occupy the interval between the base of the main Salado halite section ("Base salt") and the top of the underlying Carlsbad limestone or Tansill formation.

Rustler formation.—Richardson[12] gave the name Rustler formation to a unit of limestone and sandstone exposed in the Rustler Hills, Culberson County, Texas. In the area of the type locality the Rustler rests on the Castile anhydrite, the Salado formation being absent. In the central part of the Delaware Basin, where it overlies the Salado, the Rustler has an upper member which consists of salt, anhydrite, and redbeds. Its maximum thickness approaches 400 feet.

[7] King, P. B., Permian of west Texas and southeastern New Mexico: Bull. Amer. Assoc. Petrol. Geol., Vol. 26, No. 4, p. 611, April 1942.

[8] Lang, W. B., Upper Permian formations of Delaware Basin of Texas and New Mexico: Bull. Amer. Assoc. Petrol. Geol., Vol. 19, No. 2, pp. 262-270, February 1935.

[9] Kroenlein, G. A., Salt, potash, and anhydrite in Castile formation of southeast New Mexico: Bull. Amer. Assoc. Petrol. Geol., Vol. 23, pp. 1682-93, 1939.10

[10] Giesey, S. C., and Fulk, F. F., North Cowden field, Ector County, Texas: Bull. Amer. Assoc. Petrol. Geol., Vol. 25, No. 4, pp. 601-603, April 1941.11

[11] Lang, W. B., Basal beds of Salado formation in Fletcher potash core test, near Carlsbad, New Mexico: Bull. Amer. Assoc. Petrol. Geol., Vol. 26, No. 1, pp. 63-79, January 1942.

[12] Richardson, G. B., Report of a reconnaissance in trans-Pecos Texas north of the Texas and Pacific Railway: Univ. Texas Bull. 23, p. 44, 1904.

Dewey Lake formation.—Overlying the Salado formation in the Delaware Basin is a thick succession of redbeds, the age and correlation of which are in doubt. The lowermost of these beds may belong in the Dewey Lake formation, of youngest Permian age, which has been described by Page and Adams[13] from the Midland Basin farther east in Texas.

REEF-ZONE SECTION

Capitan limestone.—Concerning the Capitan limestone King[14] makes the following statements:

The Capitan limestone, which takes the place of the Bell Canyon, or upper formation of the Delaware Mountain group along the northwest edge of the Delaware Basin, crops out for many miles along the face of the Reef Escarpment and in the canyons of the Guadalupe Mountains behind the escarpment. It has also been penetrated in wells along the same trend northeast. Although of great linear extent northeastward, it maintains its typical character only a few miles northwest. Beyond, its place is taken by the thin-bedded limestones of the back-reef area that are termed the Carlsbad limestone.

Individual beds of the Capitan range from 15 to 100 feet thick, with a few massive members up to 300 feet thick. At all places, they slope southeast at angles of 10°-30°. To a large extent, this dip is not shared by the Delaware Mountain beds beneath, and is apparently original in the deposit. Each layer in the Capitan mass is continuous southeastward with beds in the Bell Canyon formation, and northwestward with beds in the Carlsbad limestone. That part of each layer which has a Capitan facies is one or two miles wide. Such parts do not, however, lie directly over each other. Instead, they are arranged like shingles, the oldest resting directly on the face of the Goat Seep mass, and each younger one lying a little farther southeastward than the one below it. The width of the whole Capitan mass is thus several times greater than any of its component parts.. .

The Capitan consists of light gray, cream-colored, or white, calcitic or dolomitic limestone, the calcitic and dolomitic parts being irregularly interbedded, and with the second predominating.. .

The evidence so far presented seems amply to confirm the interpretation already made by many geologists that the Capitan limestone is a reef deposit.[15] The massive character of the limestone, its steep original dips, its narrow transverse extent, and rapid transition into other deposits are all features that would be anticipated in deposits of reef type. Moreover, the make-up of its fauna indicates that it was built with the aid of such lime-secreting organisms as sponges, crinoids, and algae. The great linear, and narrow transverse extent of the deposit suggests that in some respects it resembled the barrier reefs growing to-day on the shores of the tropical seas.

SHELF (BACK-REEF) SECTION

Hueco limestone.[1]—The name Hueco limestone was applied by Richardson[2] to the Upper Paleozoic limestones (Mississippian,

[13] Page, L. R., and Adams, J. E., Stratigraphy, eastern Midland basin, Texas: Bull. Amer. Assoc. Petrol. Geol., Vol. 24, No. 1, pp. 61-63, January 1940.

[14] King, P. B., Op. cit., pp. 590-592.

[15] First suggested by Rudolf Ruedemann in King, P. B., and King, R. E., The Pennsylvanian and Permian stratigraphy of the Glass Mountains : Univ. Texas Bull. 2801, p. 139. 1926. It was later worked out in more detail by Lloyd, E. R., Capitan limestone and associated formations : Bull. Amer. Assoc. Petrol. Geol., Vol. 13, pp. 645-648, 1929, and is now generally accepted by geologists working in the region.

[1] By M. L. Thompson.

[2] Richardson, G. B., Report of a reconnaissance in trans-Pecos Texas north of the Texas and Pacific Railway: Univ. Texas Bull. 23, pp. 32-38, 1904.

Pennsylvanian, and Permian) exposed in the Hueco Mountains of Texas and south central New Mexico. The term has since been greatly restricted, and it now applies only to the Permian limestones exposed in the Hueco Mountains, and to their marine equivalents.

King[3] has divided the Hueco limestone in the Hueco Mountains into lower, middle, and upper parts. At the type locality the lower Hueco is about 450 feet thick and is made up of massive to thick-bedded light gray slightly cherty limestone. The middle Hueco is about 330 feet thick and is composed of gray thin-bedded cherty limestone. The upper Hueco is over 750 feet thick and consists largely of massive to thick-bedded light gray limestone, with a 200-foot zone of red shales, sandstones, and thin-bedded nodular argillaceous limestones lying 270 to 470 feet below the top. This dominantly elastic zone has been named the Deer Mountain member by King and King.[4]

The Hueco limestone in New Mexico is confined to the southern one-third of the State. Northward from the Hueco and Franklin Mountains the Hueco is gradually replaced by redbeds of the Abo formation. The northernmost extensions of the Hueco limestone contain gray highly argillaceous and arenaceous limestones. The sparse faunas found in these northern marginal areas of the Hueco limestone suggest brackish-water environments of deposition.

The Hueco has been studied in the following mountain ranges of southern New Mexico: Hueco, Sacramento, Jarilla, Oscura, San Andres, Organ, Franklin, Robledo, and Florida. A detailed report on the Hueco limestone of New Mexico is under preparation.

Bone Spring limestone.—Although the greatest thickness of Bone Spring limestone is found in the Delaware Basin (see pages 37-38) the formation is also present on the shelf area. According to King:[5]

The part of the Bone Spring limestone laid down in the marginal area is exposed in the Sierra Diablo and southern Guadalupe Mountains. Along the face of the Sierra Diablo escarpment, the formation is about 2,500 feet thick.

In this area the Bone Spring consists of two members, concerning which the following brief notes are taken from King's report. The lower half of the formation, exposed in the Sierra Diablo, consists of black bituminous cherty limestone with some interbedded siliceous shales and sandy marls. Beds of gray fossiliferous crystalline limestone are found toward the base. The upper member, called the Victorio Peak gray limestone, consists

[3] King, P. B., Permian stratigraphy of trans-Pecos Texas : Bull. Geol. Soc. Amer., Vol. 45, pp. 697-798, 1934.

[4] King, P. B., and *King,* R. E., Stratigraphy of outcropping Carboniferous and Permian rocks of trans-Pecos Texas : Bull. Amer. Assoc. Petrol. Geol., Vol. 13, pp. 907-926, 1929.

[5] King, P. B., Permian of west Texas and southeastern New Mexico : Bull. Amer. Assoc. Petrol. Geol., Vol. 26, No. 4, pp. 568-569, April 1942.

of gray calcitic limestone in thick fairly even beds with a thickness that ranges from 500 to 1,000 feet. The gray limestones of the Victorio Peak member are conformable on the black limestones beneath and in places grade laterally into black limestone.

Goat Seep limestone.—On Bartlett Peak, in the southern Guadalupe Mountains, the Goat Seep limestone consists of gray thick-bedded dolomitic limestone which is 1,200 feet thick and has a markedly reef-like appearance. Regarding its character farther from the reef zone, King[6] states as follows:

> North of Bartlett Peak in the Guadalupe Mountains, the Goat Seep limestone loses its massive, reef-like character, becomes thinner-bedded, contains much sandstone, and thins out. On Cutoff Mountain, on the Texas-New Mexico line, it is less than 600 feet thick. Here many of the sandstone beds are relatively coarse-grained (up to $^1/_2$ millimeter) and resemble the older sandstones in the Brushy Canyon formation at the southeast, rather than the contemporaneous ones in the Cherry Canyon. The limestones in this area are drab-gray, dolomitic ; they form beds a few feet thick, and many contain innumerable moulds of poorly preserved fusulinids.
>
> The Goat Seep limestone has much the same character for many miles northward in the Guadalupe Mountains, although the details of its stratigraphy are less well known than farther south. The Goat Seep is well exposed on the escarpment on the west side of the central ridge, overlooking Dog Canyon, as well as in the Brokeoff Mountains on the west and the various canyons that trench the east side of the ridge, at least as far north as Rocky Arroyo. . .

Carlsbad limestone.—King[7] states as follows concerning the Carlsbad limestone:

> Northwestward from the reef zone in the Guadalupe Mountains, each bed of the thick-bedded Capitan limestone changes in turn into thin-bedded limestones of the Carlsbad.[8] The change from the reef facies to the back-reef facies takes place farthest southeast in the upper beds, and farthest northwest in the lower.. .
>
> Immediately back of the reef zone, the Carlsbad consists of white or light gray limestone, mainly dolomitic, whose straight, smooth bedding planes are a few inches to a foot apart. Many of the beds are crowded with sub-spherical, concentric pisolites up to an inch in diameter.[9] Other beds are crowded with the tests of fusulinids which, as in the Delaware Mountain group, commonly lie in parallel, northwestward orientation. . . Farther northwest the Carlsbad limestone changes gradually into unfossiliferous, dolomitic limestone of dense, lithographic texture, and of white, tan, or red color. Such beds may be direct chemical precipitates, laid down in water barren of organisms.
>
> Interbedded with the limestones of the Carlsbad are many beds of brown sandstone, some of which are calcareous. . .

Whitehorse group.—Lying some distance northwest of the reef zone and grading laterally into the Goat Seep and Carlsbad limestones is a section belonging to the Guadalupe series which consists of five distinct formations. These formations, which are

[6] King, P. B., Op. cit., p. 593.
[7] King, P. B., Op. cit., pp. 593-595.
[8] The name was first adequately defined in this sense by Lang, W. B., The Permian formations of the Pecos Valley of New Mexico and Texas: Bull. Amer. Assoc. Petrol. Geol., Vol.. 21, No. 7, p. 868, 1937.
[9] A typical specimen is figured by Lang, W. B., Op. cit., Fig. 18, p. 869.

restricted to the shelf (back-reef) area, are named in ascending order the Grayburg, Queen, Seven Rivers, Yates, and Tansill. They have been penetrated in hundreds of wells in southeastern New Mexico, and their characteristics in the subsurface are described in considerable detail in the discussions of individual oil pools in the Southeast Area, pages 167 to 283. Consequently the brief discussion given here is limited to their surface exposures in the Guadalupe Mountains and foothills west of Carlsbad.

The type localities of all the formations except the Yates are in southeastern New Mexico. The Grayburg was named by Dickey[10] from a section penetrated in a well in the Grayburg-Jackson pool, Eddy County. The formation is presumably at the surface in the Guadalupe Mountains area, but its field relations remain uncertain. It is probably equivalent in part to the Goat Seep limestone and to the Dog Canyon limestone of Lang.[11] The Queen formation was first formally named by Crandall[12] from exposures in the vicinity of Queen Post Office 30 miles southwest of Carlsbad. It consists of fine brown and buff sandstone and silt-stone interbedded with dense dolomitic limestone. The Seven Rivers formation was named by Meinzer, Renick, and Bryan.[13] It shows a marked lateral gradation in surface exposures from dolomitic limestone toward the reef to gypsum farther away. This gradation as exposed in Rocky Arroyo 12 miles northwest of Carlsbad has been described in detail by Bates.[14]

The Yates formation, named from the Yates pool in Pecos County, Texas, is well developed in the Dark Canyon area west of Carlsbad, where it consists of five sandstone zones separated by dolomitic limestone.[15] The Tansill formation has been named and described in detail by DeFord and Riggs.[16] It is chiefly magnesian limestone with a few thin beds of silt and fine sand. One of the silt beds has been termed the Ocotillo silt member.

The Whitehorse group is essentially the same as the Chalk Bluff formation of Lang.[17]

Ochoa series.—Overlying the rocks of the Whitehorse group in the back-reef area is the Ochoa series, which includes in ascending order the Salado, Rustler, and Dewey Lake formations.

[10] Dickey, R. I., Geologic section from Fisher County through Andrews County, Texas, to Eddy County, New Mexico: Bull. Amer. Assoc. Petrol. Geol., Vol. 24, No. 1, pp. 44-47, January 1940.

[11] Lang, W. B., The Permian formations of the Pecos Valley of New Mexico and Texas: Bull. Amer. Assoc. Petrol. Geol., Vol. 21, No. 7, pp. 858-859, July 1937.

[12] Crandall, K. H., Permian stratigraphy of parts of southeastern New Mexico and adjacent parts of western Texas: Bull. Amer. Assoc. Petrol. Geol., Vol. 13, No. 8, pp. 929 and 940, August 1929.

[13] Meinzer, 0. E., Renick, B. C., and Bryan, K., Geology of No. 3 reservoir site of the Carlsbad Irrigation Project, New Mexico, with respect to water tightness: U. S. Geol. Survey Water-Supply Paper 580-A, pp. 6-7 and 13-15, 1926.

[14] Bates, R. L., Lateral gradation in the Seven Rivers formation, Rocky Arroyo, Eddy County, New Mexico: Bull. Amer. Assoc. Petrol. Geol., Vol. 26, No. 1, pp. 80-99, January 1942.

[15] DeFord, R. K., Wills, N. H., and Riggs, G. D., Road log of fall field trip, 1940, of West Texas Geological Society, in Eddy County, New Mexico: West Texas Geol. Soc. (mimeographed), Fig. 2, 1940.16

[16] DeFord, R. K., and Riggs, G. D., Tansill formation, west Texas and southeastern New Mexico: Bull. Amer. Assoc. Petrol. Geol., Vol. 25, No. 9, pp. 1713-1728, September 1941.

[17] Lang, W. B., Op. cit., pp. 855-863.

These formations are continuous over the entire West Texas-New Mexico region. (See cross section, Fig. 11.) The Salado of the back-reef area is similar to that of the Delaware Basin, but is only approximately one-half as thick (about 1,000 feet). The overlying Rustler and Dewey Lake formations are also similar to their extensions in the Delaware Basin. The three formations of the Ochoa series are all discussed at some length in oil-field papers under Southeast Area, pages 167 to 283.

The Salado is overlapped by younger beds in the Pecos Valley and does not crop out. The Rustler formation crops out in low hills immediately northeast of Carlsbad, where it consists of anhydrite, gray and brown dolomite, and redbeds. Dewey Lake redbeds are at the surface in the northern part of T. 21 S., R. 30 E., Eddy County, 20 miles east by north of Carlsbad. The contact with overlying Triassic beds can be seen in sec. 5 of that township.[18]

TRIASSIC SYSTEM

ROBERT L. BATES

GENERAL STATEMENT

Triassic rocks occupy large areas in northern New Mexico. The most extensive outcrops are in Guadalupe and Quay Counties; other wide belts are found in Rio Arriba County north of Coyote, and around the Zuni Mountains in Valencia and McKinley Counties. Triassic rocks are present in the Permian Basin in the southeast part of the State, where they are mostly covered by younger sediments. In the southwest quarter of the State, a short part of Triassic time may be represented by the Lobo formation.

Strata of Triassic age are in large part non-fossiliferous, and geologists are not in complete agreement as to their age and correlation. Further field study is likely to aid in solving many of the problems.

MOENKOPI FORMATION

Red shales and sandstones of Moenkopi age may be present in thin development in the vicinity of Ojo Caliente and Zuni Pueblo, southwest of the Zuni Mountains. Additional field work in this area is necessary before more definite statements can be made.

SHINARUMP CONGLOMERATE

It is doubtful whether the Shinarump formation is represented in New Mexico. Strata of Shinarump age may be present in the Ojo Caliente-Zuni Pueblo area, associated with Moenkopi beds mentioned in the preceding paragraph.

CHINLE FORMATION

The Chinle formation consists mainly of red and purplish shale, with subordinate amounts of sandstone. It is present in the Zuni Mountains, along the west side of the Nacimiento up-

[18] DeFord, R. K., Editorial footnote in King, P. B., Op. cit., p. 613.

lift, in the Chama Basin, in the central part of the State near Socorro, in the northeast, and in the subsurface of the Permian Basin on the southeast.

Subdivision and correlation of the Triassic beds in the northwest part of the State have been based largely on excellent exposures in the Zuni Mountains. As the interpretation given in this paper does not follow those of previous reports, the following notes on the Zuni Mountain section are added.

Strata previously designated Moenkopi.—Red, purple, and lavender shales, with small amounts of red and white sandstone, are found in the Zuni Mountains above the San Andres (Permian) limestone and below a 50- to 100-foot white sandstone. These purple shales, which are about 700 feet thick, were regarded by Darton[1] as representing the Moenkopi formation of the Grand Canyon region. Baker and Reeside[2] state that as the Moenkopi thins eastward from north central Arizona, it should be thin, if present at all, in the Zunis. They consider the beds in question to be Permian. In support of this interpretation they cite the presence at several localities of Permian vertebrates in redbeds in or above the Chupadera formation (now recognized as the Yeso, Glorieta, and San Andres formations).

However, the purple shales rest on a rough silicified San Andres surface which is plainly an unconformity. The lithology of the beds, furthermore, is strongly suggestive of the Chinle, and Reiche[3] believes that they belong in the lower part of the Chinle formation. He gives as evidence the presence of locally abundant petrified wood, and of a widely developed limestone conglomerate, both of which features are characteristic of the lower Chinle in other areas. Reiche's conclusion is regarded as correct.

Strata previously designated Shinarump.—The thick coarse cross-bedded sandstone which overlies the purple shales just discussed was termed Shinarump by Darton.[4] At best this correlation is open to some question, as the beds are separated from other exposures of the Shinarump. If, as is here postulated, the underlying shales are lower Chinle, the sandstone is a member of the Chinle. It is overlain by red and purple shales more than 1,000 feet thick, which constitute the upper part of the formation.

POLEO SANDSTONE

A massive sandstone 50 to 150 feet thick extends along the Nacimiento uplift and is well developed in the Chama Basin. It caps Poleo Mesa north of Coyote, in southern Rio Arriba County, and is called the Poleo sandstone. It is believed to be the equivalent of the Santa Rosa sandstone of the eastern part of the State.

[1] Darton, N. H., "Red Beds" etc.: U. S. Geol. Survey Bull. 794, p. 30, 1928.

[2] Baker, A. A., and Reeside, J. B., jr., Correlation of the Permian of southern Utah, northern Arizona, northwestern New Mexico, and southwestern Colorado: Bull. Amer. Assoc. Petrol. Geol., Vol. 13, No. 11, p. 1430, November 1929.

[3] Reiche, Parry, Personal communication, 1942.

[4] Darton, N. H., Op. cit., pp. 30-31.

DOCKUM GROUP[5]

Triassic rocks in the oil-field areas of southeastern New Mexico are included in the Dockum group of Upper Triassic age. Three formations are recognized.

Tecovas formation.—The Tecovas formation consists of red silts, sands, and shales. The thickness varies from about 200 feet over the structural highs to 450 feet in the intervening synclines. The Tecovas redbeds appear to be made up largely of re-worked material from the Upper Permian formations. Thus part of the Tecovas consists of orange-red sands with pebbles of dolomite, and lenses or concretions of limestone and gypsum. Beds of red shale and fine red sandstone are interstratified with these materials. Coarse polished quartz grains are in places abundant enough to form recognizable beds. Unless well-cuttings are exceptionally good, it is difficult to distinguish the poorly bedded loosely lithified Tecovas from the well stratified and lithified Upper Permian redbeds of the Dewey Lake formation. Over parts of southeastern New Mexico the Tecovas appears to rest unconformably on the eroded upper surface of the Permian Rustler formation. Tecovas beds are exposed across a wide belt east of the Pecos River, where they are partly obscured by caliche and sand dunes.

Santa Rosa sandstone.—Above the Tecovas lies coarse gray and red sand with layers of chert gravel and red shale. The coarse sands at the top of the Santa Rosa grade downward into an 80-foot zone of fine sand, silt, and shale. The total thickness of the formation is about 300 feet. The Santa Rosa sands form scarps and steep slopes along the west edge of the Llano Estacado.

Chinle formation.—The uppermost Triassic formation in southeastern New Mexico is a red shale from 600 to 800 feet thick. Thin beds of green and gray sand and silt are interstratified with the red shale. Over most of the area the Chinle is deeply weathered and is buried beneath a layer of caliche, windblown sand, or alluvium. The pure red shale carries a high colloidal content and is locally quarried for drilling mud.

LOBO FORMATION (TRIASSIC ?)[6]

Some red strata in Luna County have been separated as the Lobo formation and tentatively classed as Triassic (?) on account of their character and their position between Permian limestone below and the Sarten (Lower Cretaceous) sandstone above. The Lobo formation is found in the Florida Mountains and in southern spurs and outliers of the Cooks Range. The rocks are mainly reddish and gray shale and gray to pink impure limestone. The Lobo carries no fossils, and is bounded above and below by unconformities.

[5] Based extensively on notes by John Emery Adams, enclosed with personal communication of June 16, 1942.

[6] Based on Darton, N. H., "Red Beds" etc.: U. S. Geol. Survey Bull. 794, pp. 32-33, 1928.

JURASSIC SYSTEM

C. E. NEEDHAM[1]

Socorro, New Mexico

WINGATE SANDSTONE

This formation was named by Dutton[2] from exposures near Ft. Wingate in McKinley County, New Mexico. It is a massive compact moderately hard pale-red to buff sandstone that forms prominent cliffs in many places. It attains its maximum thickness, about 300 feet, near Thoreau in McKinley County. It is of rather wide distribution, being present in the Nacimiento Mountains, the Chama Valley, the hogbacks just west of Las Vegas, and the Canadian escarpment, where it is less than 100 feet thick. It has not been traced farther to the northeast than Ute Creek in northern Harding County.[3] Southward, it thins out in southern Valencia County.

TODILTO FORMATION

The Todilto was named by Gregory[4] from Todilto Park, McKinley County, New Mexico. At this locality it caps the Wingate sandstone, and consists of 10 feet of resistant compact blue-gray limestone separated into two parts by a few inches of red sandy shale. In other localities, it grades laterally into a sandy shale and becomes much thicker. East of Laguna, north of Abiquiu, and in La Bajada between Santa Fe and Albuquerque, the limestone is associated with a thick bed of gypsum, considered the upper member of the Todilto.

The Todilto, according to Darton,[5] is present in the Zuni, Lucero, and Nacimiento uplifts, the northern Sandia Mountains, the Las Vegas region, and the southern front of the Canadian escarpment nearly to longitude 104°. The southern margin is a few miles south of Acoma. Baker, Dane and Reeside[6] considered the Todilto to be the basal member of the Morrison formation; however, more recent work[7] has thrown doubt on this conclusion.

KAYENTA SANDSTONE

This formation of the Glen Canyon group was named by Baker, Dane, and McKnight.[8] The type locality is one mile north of Kayenta, Arizona. Baker, Dane, and Reeside[9] considered that the Kayenta feathered out from the west at Four Corners, and

[1] Formerly Director, State Bureau of Mines and Mineral Resources.

[2] Dutton, C. E., U. S. Geol. Survey: 6th Ann. Rept., Pl. 16, p. 136, 1885.

[3] Darton, N. H., "Red Beds" etc.: U. S. Geol. Survey Bull. 794, p. 34, 1928.

[4] Gregory, H. E., The Navajo country: U. S. Geol. Survey Water-Supply Paper 380, p. 79, Pl. XXI, 1916; Geology of the Navajo country: U. S. Geol. Survey Prof. Paper 93, pp. 55-56, 1917.

[5] Darton, N. H., "Red Beds" etc.: U. S. Geol. Survey Bull. 794, pp. 34-35, 1928.

Baker, A. A., Dane, C. H., and Reeside, J. B., jr., Correlation of the Jurassic formations of parts of Utah, Arizona, New Mexico, and Colorado: U. S. Geol. Survey Prof. Paper 183, 1936.

Goldman, M. I., and Spencer, A. C., Correlation of Cross' La Plata sandstone, southwestern Colorado: Bull. Amer. Assoc. Petrol. Geol., Vol. 25, pp. 1759-1762, 1941.

[8] Baker, A. A., Dane, C. H., and McKnight, E. T., U. S. Geol. Survey preliminary map showing geologic structure of parts of Grand and San Juan Counties, Utah, 1931.

[9] Op cit., p. 44.

hence was not present in New Mexico. Goldman and Spencer,[10] however, show that the formation probably is present as far south as Todilto Park and consists of 40 feet of soft red sandy beds.

NAVAJO SANDSTONE

This sandstone was named by Gregory[11] from the Navajo Indian Reservation in Arizona. A nearly complete section is exposed in Navajo Canyon. Baker, Dane, and Reeside[12] considered that the Navajo, like the Kayenta, wedged out from the west near Four Corners and was not present in New Mexico. Goldman and Spencer[13] believe that in Todilto Park the hard yellowish-brown and red sandstone 100 feet thick overlying the Kayenta formation is the Navajo sandstone.

CARMEL AND ENTRADA FORMATIONS

Both of these were named by Gilluly and Reeside,[14] the Carmel from Mount Carmel, Kane County, Utah, and the Entrada from Entrada Point in the north part of the San Rafael Swell, Utah.

In northwestern New Mexico these formations are reddish sandstones and shales. The Carmel barely extends into the State, where, at the most, it is only a few feet thick ; the Entrada is 30 to 40 feet thick. The Carmel overlies the Navajo, and the Entrada is overlain by the Pony Express limestone member of the Morrison formation.

MORRISON FORMATION

The term Morrison was first used by Eldridge[15] for green, drab, and gray marls well developed near Morrison, Colorado. In New Mexico the formation is present across the entire State from near Gallup eastward into Union County. It is not developed in the Socorro region, but it crops out in a number of places around Sierra Blanca in Lincoln County. The formation appears to reach its maximum thickness, over 300 feet, near Manuelito in McKinley County and also 20 miles northeast of Santa Rosa in Guadalupe County.[16] It thins toward the east.

The Morrison consists mainly of pale-green sandy clays and shales, gray sandstones and sandy shales, and red to orange-brown sandstones and sandy clays. Thin beds of limestone are also present, one prominent member being the basal Pony Express limestone found in parts of southwestern Colorado and northwestern New Mexico.

The Morrison is placed in the upper Jurassic. In northwest-

[10] Op. cit., p. 1762.

[11] Gregory, H. E., The igneous origin of the "glacial deposits" on the Navajo Reservation, Arizona and Utah: Amer. Jour. Science, 4th ser., Vol. 40, pp. 102 and 112, 1915.

[12] Op. cit., p. 44.

[13] Op. cit., p. 1761.

[14] Gilluly, J., and Reeside, J. B., jr., U. S. Geol. Survey Press Bull. 6064, 1926.

[15] Emmons, S. F., Cross, W., and Eldridge, G. H., Geology of the Denver Basin in Colorado: S. Geol. Survey Monograph 27, 1896.16

[16] Sellards, E. H., Adkins, W. S., and Plummer, F. B., Geology of Texas: Univ. Texas Bull. 3232, Vol. 1, pp. 258-259, 1932.

ern New Mexico it is overlain by the Dakota sandstone, and in the northeastern part by the Purgatoire formation. Strata formerly designated "McElmo formation" are now included in the Morrison.

LOWER CRETACEOUS (COMANCHEAN) SYSTEM

C. E. NEEDHAM[1]
Socorro, New Mexico

TRINITY GROUP

The oldest Cretaceous rocks in New Mexico are those named and described by Lasky[2] from the Little Hatchet Mountains in Grant and Hidalgo Counties. The rocks of the Trinity group in this range have an average thickness of 19,000 feet, of which 15,000 feet is correlated with the Glen Rose formation of Texas. The following summary of the formations is taken entirely from Lasky's paper.

Broken Jug limestone.—This limestone is named from Broken Jug Pass in the Sylvanite part of the Little Hatchet Mountains. The full thickness is not known, for the base is hidden beneath valley fill, but it may approach 5,000 feet in places. The formation consists of limestone with subordinate amounts of shale and sandstone. *Exogyra* and *Orbitolina* are abundant.

Ringbone shale.—This shale is named from the Ringbone Ranch and overlies the Broken Jug limestone conformably in some places and unconformably in others. A heavy basal conglomerate is present in places, but the formation is mainly dark shale, subordinate sandstone, and here and there a bed of black limestone. The upper 150 feet is composed of tuffaceous sandstone and shale containing two volcanic members. Some fresh-water shells and fossil wood have been collected from the formation. The maximum thickness of the Ringbone is 650 feet.

Hidalgo volcanics.—This formation is named from Hidalgo County, over which it seems to be widely distributed. It consists primarily of basaltic lava flows, although locally 200 feet of gray and red limestone, red and green shale, and conglomerate were deposited. The exposed thickness ranges from 900 to 5,000 feet, the wide range being due to disconformities at top and bottom.

Howells Ridge formation.—This formation takes its name from Howells Ridge in the Eureka section. In the lower part it consists of red beds of mudstone, shale, limestone, sandstone, and conglomerate. The top beds are massive and thin-bedded black limestone and massive creamy white limestone. *Exogyra* and *Orbitolina* are abundant. The thickness is 4,900 feet in the Sylvanite section.

[1] Formerly Director, State Bureau of Mines and Mineral Resources.

[2] Lasky, S. G., Newly discovered section of Trinity age in southwestern New Mexico : Bull. Amer. Assoc. Petrol. Geol., Vol. 22, pp. 524-540, 1938.

Corbett sandstone.—This is named from Corbett Ranch at Granite Pass. It rests conformably on the Howells Ridge formation and consists chiefly of black, brown, and white sandstone. Shale beds up to 15 feet thick alternate with the sandstone beds, and in places limestone beds are present. The limestones carry a marine gastropod and pelecypod fauna. The Corbett is 4,000 feet thick in the Sylvanite section.

Playas Peak formation.—This formation is named for Playas Peak in the Eureka half of the range. It consists of sandstone and shale underlain in the Eureka section by a basal conglomerate and capped by massive *Orbitolina*-bearing limestones. Freshwater shells and fragments of fossil wood have been collected from the sandstone-shale part of the Eureka section. The Playas Peak formation reaches a maximum thickness of between 3,000 and 3,500 feet in the Sylvanite section.

Skunk Ranch conglomerate.—This formation takes its name from Skunk Ranch in the Eureka section. It consists largely of coarse conglomerate of red boulders and pebbles of various rocks in a matrix of red sandstone and shale. Lateral gradations from the red bouldery conglomerate to gray fine-grained limestone conglomerate and to coarse-grained sandstone are exposed here and there. A 200-foot layer of augite basalt is exposed at one place. The maximum thickness is 3,400 feet, the topmost part being covered by Miocene (?) volcanic rocks.

FREDERICKSBURG GROUP

Representatives of the Fredericksburg group are present in Dona Ana County near the Mexican boundary, in the Cornudas Mountains in Otero County, near Deming in Luna County, and in Quay and Harding Counties in the northeastern part of the State. Böse[3] and Adkins[4] have described the outcrops in Cerro de Muleros just west of El Paso, Texas, where the total thickness of Comanchean rocks is nearly 1,000 feet. The following summary is largely taken from Adkins' paper.

Goodland formation.—Near the base of the section this formation is exposed to a thickness of about 90 feet. It consists mainly of limestone with interbedded shale.

Kiamichi formation.—Overlying the Goodland is shale 75 feet thick, with subordinate amounts of limestone. The Kiamichi is well exposed opposite the smelter at El Paso.

Sarten sandstone.—This formation was first described and named by Darton[5] from Sarten Ridge north of Deming, Luna County, New Mexico. There it is about 300 feet thick and con-

[3] Bose, Emil, Excursion au Cerro de Muleros : Tenth Int. Geol. Cong., Guidebook 20, 1906.

[4] Sellards, E. H., Adkins, W. S., and Plummer, F. B., The geology of Texas : Univ. Texas Bull. 3232, Vol. 1, pp. 272-400, 1932.

[5] Darton, N. H., Geology and underground water of Luna County, New Mexico : U. S. Geol. Survey Bull. 618, pp. 43-44, 1916.

sists almost entirely of light-gray massive sandstone, mostly hard and quartzitic. Some conglomerate is found in the base. The age of the Sarten is in question. Limy beds not far below the middle of the formation contain fossils that have been referred to the Washita group. Adkins,[6] however, refers these fossils to the Fredericksburg group.

Purgatoire formation.—In northeastern New Mexico are sandy fossiliferous clays referred to the Purgatoire formation. These beds are about 60 feet thick near Tucumcari in Quay County. Fossils show that the lower beds are of Fredericksburg age and the upper beds of Washita age.[7]

WASHITA GROUP

Beds of Washita age in New Mexico are exposed coextensively with those of Fredericksburg age. The best outcrops, near El Paso, Texas, have been described by Adkins,[8] from whose discussion the following notes are taken.

Duck Creek formation.—The Duck Creek is about 100 feet thick and consists of marls and limy shales.

Fort Worth-Denton formation.—This formation is marly nodular limestone about 50 feet thick.

Pawpaw-Weno formation.—This unit consists of blue clays and sandy marls 130 feet thick.

Main Street formation.—The Main Street formation is nearly 300 feet thick and consists of red sandstone and red-brown quartzite, with shaly layers in the upper part.

Grayson formation.—This unit is marly shale and clay about 75 feet thick.

Buda formation.—The topmost formation consists chiefly of fine-grained light-colored limestone. It is about 90 feet thick.

UPPER CRETACEOUS SYSTEM[1]

DAKOTA SANDSTONE

Throughout northeastern New Mexico the basal formation of the Upper Cretaceous succession is a hard gray massive sandstone supposed to be a southern extension of the Dakota sandstone. It constitutes much of the surface of the Canadian Plateau in Union and Mora Counties, which extends southward to the Canadian Escarpment. Outliers of this plateau south and west of Tucumcari are capped by this sandstone . . . , and a small area of it remains in the northern face of the Llano Estacado, in Quay County. It is well exhibited also in the basin of the Sierra Blanca region, in the western part of Lincoln County. It constitutes the surface of the plateaus on both sides of the Chama Valley, in the central part of Rio Arriba County, and is

[6] Sellards, Adkins, and Plummer, op. cit., p. 281.
[7] Ibid., pp. 280-281.
[8] Ibid. , pp. 272-400.
[1] Quoted extensively from Darton, N. H., "Red Beds" etc.: U. S. Geol. Survey Bull. 794, pp. 40-50, 1928.

conspicuous in the Lucero and Zuni uplifts. Its supposed representative crops out in a broad belt extending from Manuelito to Atarque, on the west side of the Zuni Basin, and it is also exposed in the valley of the San Juan in the northwest corner of the State. The thickness of the Dakota sandstone ranges in general from 80 to 100 feet. In Mora and Colfax Counties the sandstone passes beneath the shale of the Colorado group but is uplifted and exposed at intervals along the foot of the Rocky Mountain front range. In the western part of the State the Dakota (?) sandstone is immediately overlain by the Mancos shale. East of Gallup it overlaps from the Morrison formation directly onto the Navajo sandstone, which it caps in the areas from Zuni to Atarque and Ramah to El Moro. . . Farther south it lies on Chinle shale. Locally the Dakota sandstone contains conglomerate, especially at its base. In some places in the western part of the State this sandstone contains fossil *Exogyra,* which probably indicates either that the sandstone here is the basal member of the Mancos or that marine conditions began in Dakota time in that region .. .

In the Carthage-Tokay district, Socorro County, the Dakota is well exposed and has a thickness of about 40 feet.

COLORADO GROUP

In northeastern New Mexico the subdivisions of the Colorado group that have been recognized in eastern Colorado extend southward to the Las Vegas region, and they are also more or less evident in the Upper Cretaceous succession in the north-central and northwestern parts of the State, where they are grouped in the Mancos shale. The basal formation is the Graneros shale, a dark shale 150 to 160 feet thick, and next is the Greenhorn limestone, 50 to 80 feet thick, which is overlain by the Carlile shale, 150 to 250 feet thick. The Niobrara formation, consisting of the Timpas limestone, 50 feet thick, and the Apishapa shale, 500 feet thick, is also present. The Graneros shale is extensively exposed in the region east of Springer and Wagon Mound, where its base lies on the Dakota sandstone in the slopes near the edge of the canyon of Canadian River. The Greenhorn consists of a succession of thin beds of limestone separated by black shale, and many layers contain large numbers of the highly characteristic fossil *Inoceramus labiatus.* It is exposed along Cimarron River (Colfax County) a few miles southeast of Springer and thence extends southward along the west side of the Canadian Valley and is well exposed in the eastern part of Las Vegas. . . The overlying Carlile shale is a dark-gray shale containing numerous biscuit-shaped concretions carrying many characteristic fossils. . .

The Timpas limestone was formerly quarried near Springer, Colfax County, on the banks of Cimarron River, and it crops out on Ocate Creek a short distance east of Colmor. Next above the limestone is the Apishapa shale, which crops out along the Canadian Valley and is well exposed about Dorsey and southwest of Springer. The upper boundary of the Apishapa is very indefinite, as it appears to grade into the Pierre shale.

The strata of Colorado age in the Cerrillos coal field and east of Galisteo are a nearly uniform succession of the dark shale about 2,000 feet thick. The Greenhorn limestone . . . is well defined in the lower part of this succession. It is also conspicuous in the Nacimiento uplift and extends southward through the outcrop zone in the western parts of Bernalillo and Valencia Counties. . . Near the base of the Colorado succession in the Cerrillos Basin is a prominent bed of hard gray sandstone, possibly the Tres Her-manes sandstone member of Lee.

MANCOS SHALE

The Mancos shale comprises shale of the Colorado group as above described and probably also the lower part of the Pierre shale. Its outcrop skirts both sides of the Zuni uplift, occupies a broad area in the San Juan Valley in the northwest corner of San Juan County, and extends along the western margin of the Gallup coal basin. The formation is also exposed in the valley of Carrizo Creek in the Salt Lake region, Catron County. It underlies the Sierra Blanca, Cerrillos, and Tijeras coal basins and crops out along the east slope of the Sierra Caballo. There are small outcrops in the ridges east of Socorro, in the region north and northeast of Silver City, and on the south and east side of the Cooks Range, north of Deming.. .

The thickness of the Mancos shale ranges from 900 to 1,300 feet in most parts of the area above described, except where the upper beds have been removed by erosion. In the Tijeras region Lee[2] measured 1,550 feet. In places the formation includes sandstone associated with coal deposits, and where these occur it is difficult to separate the Mancos from the overlying Mesaverde formation. A notable occurrence of this sort is found in the basin south of La Jaya. In north-central New Mexico two included sandstones are the Punta de la Mesa and Tres Hermanos sandstone members. In the Puertecito region, where much of the Mancos shale has been separated by Winchester[3] as the Miguel formation, there are two included sandstones, known as the Bell Mountain and Gallego sandstone members. In the Tijeras coal field a 145-foot sandstone member 60 feet above the base has been regarded by Lee[4] as the Tres Hermanos member. An included sandstone in the northwestern part of the State has been called the Tocito sandstone lentil;[5] it attains a thickness of 35 feet near Tocito.

In the Gallup-Zuni basin Sears[6] found that the Mancos shale is from 700 to 950 feet thick, placing the upper limit at the bottom of the massive sandstone (Gallup sandstone member of the Mesaverde formation) that forms the west ridge of the hogback east of Gallup. The rocks are mainly dark-gray, somewhat sandy marine shale with sandy shale and slabby to shaly sandstone near and at the top. Near the base is a 10-foot bed of impure limestone . . . Sears states that in the Zuni Reservation there is only 425 feet of gray marine shale that can be assigned to the Mancos.

It is the opinion of Lee[7] that the coal measures at the north end of the Sierra Caballo (Engle field) are of Benton age. They are largely sandstones of gray to buff tint with beds of shale and shaly sandstones overlain unconformably by Tertiary deposits.

The Mancos and associated strata in the Chama Valley have been described by Lee,[8] who found the Mancos shale well developed, with a sandstone near the base regarded as a representative of the Tres Hermanos sandstone member. . . The Mancos strata extend to a massive sandstone regarded as the base of the Mesaverde, which forms a high ridge and walls of a deep canyon just east of Monero. . .

In the Carthage area, Socorro County, beds above the Graneros shale and below the Mesaverde formation are assigned to the Frontier and the Niobrara formations. The Frontier is alternating sandstone and sandy shale in the lower part and thick-bedded brown sandstone in the upper. It is 280 feet thick. The Niobrara is a soft shale 230 feet thick.

[2] Lee, W. T., The Tijeras coal field, Bernalillo County, N. Mex.: U. S. Geol. Survey Bull. 471, p. 575, 1912.

[3] Winchester, D. E., Geology of Alamosa Creek valley, Socorro County, N. Mex.: U. S. Geol. Survey Bull. 716, pp. 6-8, 1921.

[4] Lee, W. T., U. S. Geol. Survey Bull. 471, p. 571, 1912; Prof. Paper 101, p. 199, 1917; Stratigraphy of the coal fields of north-central New Mexico: Bull. Geol. Soc. Amer., Vol. 23, p. 631, 1912.

[5] Reeside, J. B., jr., Upper Cretaceous and Tertiary formations of the western part of the San Juan Basin, Colorado and New Mexico : U. S. Geol. Survey Prof. Paper 134, p. 9, 1924.

[6] Sears, J. D., Geology and coal resources of the Gallup-Zuni Basin, N. Mex.: U. S. Geol. Survey Bull. 767, pp. 14-15, 1925.

[7] Lee, W. T., The Engle coal field, N. Mex. : U. S. Geol. Survey Bull. 285, p. 240, 1906. See also U. S. G. S. Prof. Paper 95, p. 41 ; Prof. Paper 101, p. 33, 1917.

[8] Lee, W. T., Op. cit. (U. S. G. S. Prof. Paper 101), p. 189.

PIERRE SHALE

The upper half of the thick succession of shales of Upper Cretaceous age in north-central New Mexico is the Pierre shale, which extends southward from Colorado. It is considerably more than 2.000 feet thick in the Raton region and may be 1,800 feet thick in the vicinity of Las Vegas. It consists of dark shale with a few thin sandstone layers in its upper part and limy beds toward the base. Farther south and in the region west of the Sangre de Cristo Mountains, where the formation includes thick beds of sandstone, it is represented by the Mesaverde group, the Lewis shale, and probably the top of the Mancos shale.. .

TRINIDAD SANDSTONE

The Trinidad sandstone extends from the type locality in southern Colorado into New Mexico as part of the rim of the Raton coal basin. According to Lee[9] it is a moderately hard massive light-colored rock, appearing as a cliff above slopes of the Pierre shale. In most places it is about 100 feet thick, but locally the thickness diminishes to 50 feet or less. South of Dawson a lower sandstone member appears in the upper part of the Pierre shale, and thence southward it is the more conspicuous cliff-maker above the shale slope.. .

The age of the Trinidad is regarded as upper Montana, possibly equivalent to that of the lower part of the Fox Hills of the Rocky Mountain region.

VERMEJO FORMATION

Conformably above the Trinidad sandstone in the Raton coal field is the Vermejo formation, which consists of coal-bearing shale and sandstone. According to Lee[10] it has a maximum thickness of about 75 feet in and near Raton and thickens locally in the Koehler region to a maximum of about 200 feet. It thins out by erosion to the east at a point about 2 miles northeast of Raton. It is absent locally near Red River Peak and some other points. Its top is more or less eroded throughout the area. In the southern and western part of the coal basin it thickens to a maximum of nearly 400 feet, having a thickness of about 375 feet at Vermejo Park, the type locality. The principal material of the Vermejo formation is shale, most of it carbonaceous, and it contains several widespread coal beds, some of which attain a thickness of 15 feet. Irregular sandstone deposits are included at many places. Many fossil plants have been collected from the Vermejo and according to Knowlton[11] represent 108 species belonging to the Montana flora.

MESAVERDE GROUP

In most of New Mexico the upper part of the Upper Cretaceous consists of a succession of sandstone and shale with coal measures, but as the base of these sandy sediments is not at the same horizon throughout it is not possible to establish a uniform plane of separation. The sandstones that overlie the Mancos shale in the central and northwestern parts of the State are known as the Mesaverde group. According to Reeside,[12] in the western part of the San Juan Basin the group consists of the three formations into which it has been divided in southwestern Colorado. At the base is the Point Lookout sandstone, about 200 feet thick, capping slopes of the Mancos shale. Next above is the Menefee formation, consisting of 700 to 1,100 feet of gray to brown shale with lenticular sandstone members and coal beds. Some beds of this formation are of marine origin, and others were deposited in fresh water. At the top is the Cliff House sandstone, 300 to 750 feet

[9] Lee, W. T., Op. cit. (U. S. G. S. Prof. Paper 101), pp. 48-50. See also U. S. Geol. Survey, Geol. Atlas, Raton-Brilliant-Koehler Folio (No. 214), p. 6, 1922.

[10] Lee, W. T., Op. cit. (U. S. G. S. Prof. Paper 101), pp. 51-56. See also Folio 214, pp. 6-7, 1922.

[11] Knowlton, F. H., Fossil floras of the Vermejo and Raton formations of Colorado and New Mexico: U. S. Geol. Survey Prof. Paper 101, pp. 227-230, 1917.

[12] Reeside. J. B., jr., Op. cit. (U. S. G. S. Prof. Paper 134), pp. 13-16.

thick, consisting of a thick yellow to brown massive sandstone underlain and overlain by thin sandstone and shale, all of marine origin. According to Gardner,[13] on Arroyo Torrejon, on the eastern margin of the San Juan Basin, the Mesaverde group is 1,328 feet thick. The lower 70 feet may represent the Point Lookout sandstone, the middle 938 feet the Menefee formation, and the upper 320 feet the Cliff House sandstone.. .

According to Lee[14] the coal at Monero occurs above a westward-dipping sandstone classed as Mesaverde. . . The Mesaverde sandstones and shales crop out southward from this place along the east rim of the San Juan Basin, and their features and relations in that area have been described by Gardner.[15] There is much hard sandstone, which makes a prominent hogback ridge, and more or less coal is included. The thickness of the formation ranges from 214 to 719 feet in the sections measured, and in places the strata are covered by an overlap of Wasatch beds. Lee[16] has examined the outcrops farther south near Cabezon and Casa Salazar and recorded various details of their stratigraphy.

The wide area of Mesaverde strata in the Gallup-Zuni coal basin was studied by Shaler[17] in 1906 and in greater detail by Sears[18] in 1919 and 1920. The thickness of 1,800 feet comprises alternating beds of gray sandstone and drab clay shale, with coal beds that are extensively mined.. .

The formation extends southward to the Hagan or Una del Gato field [Sandoval Co.] where Lee[19] measured 1,854 feet of Mesaverde beds consisting of sandstone, sandy shale, and shale.

In the Tijeras coal field, a few miles east of Albuquerque, Lee[20] found Montana fossils in the coal-bearing rocks, which are classed as Mesaverde. The thickness of this formation is stated to be 1,197 feet, with a 115-foot bed of sandstone at the base, resting on 1,550 feet of the Mancos shale. Some shale above the coal measures suggests the presence of the Lewis shale.

The Mesaverde formation crops out in the vicinity of Carthage, where it carries commercial amounts of coal. About 900 feet is exposed; the upper part is concealed by Tertiary sandstones and conglomerates.

LEWIS SHALE

Overlying the Mesaverde group in northern and western New Mexico is a thick body of shale of Montana age named the Lewis shale, from Fort Lewis, in La Plata County, Colorado. Its outcrop zone extends around the San Juan Basin, varying in width from one to five miles in greater part. It forms a broad valley between Monero and Dulce. Although it consists essentially of shale, a few layers of limestone and sandy and concretionary beds occur in it. According to Reeside[21] its thickness is 1,100 feet at Navajo Springs, north of Kirtland, 475 feet on San Juan River, and 76 feet at Coal Creek. It is about 100 to 150 feet thick on the south side of the San Juan Basin, and according to Gardner[22] it is over 2,000 feet thick north of Gallina and only 250 feet at Arroyo Torrejon, 30 miles southwest of Cuba. The upper and lower contacts are indefinite, and probably where the formation is thick it is in part equivalent to upper Mesaverde strata. . .

The Lewis shale is believed to be equivalent to the upper and perhaps also the middle part of the Pierre shale east of the Rocky Mountains.

[13] Gardner, J. H., The coal field between San Mateo and Cuba, N. Mex.: U. S. Geol. Survey Bull. 381, pp. 470-471, 1910.

[14] Lee, W. T., Op. cit. (U. S. G. S. Prof. Paper 101), p. 189.15

[15] Gardner, J. H., Op. cit. (U. S. G. S. Bull. 341), pp. 338-339, 342-347.

[16] Lee, W. T., Op. cit. (U. S. G. S. Prof. Paper 101), pp. 192-195.17

[17] Shaler, M. K., A reconnaissance survey of the western part of the Durango-Gallup coal field of Colorado and New Mexico: U. S. Geol. Survey Bull. 316, pp. 379 and 380, 1907.

[18] Sears, J. D., Op. cit. (U. S. G. S. Bull. 767), pp. 15-18.19

[19] Lee, W. T., Op. cit. (U. S. G. S. Prof. Paper 101), pp. 201-202.

[20] Idem, pp. 198-200; Bull. 471, pp. 10-14, Pl. 59, 1912.

[21] Reeside, J. B., jr., Op. cit., p. 17.

[22] Gardner, J. H., Op. cit. (U. S. G. S. Bull. 341), p. 339.

PICTURED CLIFFS SANDSTONE

The sandstone overlying the Lewis shale in the San Juan Basin consists mainly of sandstone with interbedded gray sandy shale, all of marine origin. According to Reeside,[23] it is 281 feet thick on San Juan River, but it thins to the south, measuring only about 50 feet near the big bend to the north in Chaco River and thence eastward for some distance, finally thinning out near longitude 107°. Lee[24] suggests, however, that it may be represented in the 225 feet of sandstone and shale overlying the Lewis shale near Dulce. In the San Juan Basin it merges into adjoining formations. . .

FRUITLAND FORMATION

The Upper Cretaceous Fruitland formation is extensively exposed on the west side of the San Juan Basin except in a small area where it is overlapped by Tertiary formations. It is not recognized in the eastern rim of the basin or in other areas. According to Reeside[25] it consists of sandstones, shale, and coal deposits of brackish and fresh-water origin, in a succession that varies somewhat from place to place. It is 240 feet thick on San Juan River, 423 feet near La Plata, and 530 feet at the Colorado state line. In the southeastern part of San Juan County its thickness ranges from 194 to 328 feet. . .

Reeside[26] regards these two formations as late Montana, possibly equivalent to the latest part of the Pierre shale and part of the Fox Hills sandstone.

KIRTLAND SHALE

The Kirtland shale crops out in a wide belt around the western and southern margins of the San Juan Basin but has not been recognized east of longitude 107°. According to Reeside[27] it consists of three members, all of fresh-water origin. The lower member is mainly gray shale with dark layers and soft light-colored irregularly bedded sandstones. The middle part, the Farmington sandstone member, consists of many irregular lenses of sandstone, soft and light colored below but darker and harder above. The top member consists of shale and soft sandstone. The Farmington sandstone member thins out near the southeast corner of San Juan County but is conspicuous in the vicinity of San Juan River and northward, where its thickness is 480 feet. The total thickness of the formation varies considerably, being 1,065 feet at the Colorado state line, 800 feet on San Juan River, 1,180 feet on Hunter Wash, 700 feet on Escavado Wash, and 390 feet in the southwestern margin of Sandoval County, not far east of which it is overlapped by later formations. At its base the Kirtland shale grades into the Fruitland formation. The fossils collected from the Kirtland shale . . . indicate a fluviatile origin.

McDERMOTT FORMATION

In the San Juan Basin the Kirtland shale is succeeded by the McDermott formation, which is provisionally regarded as Cretaceous, according to Reeside,[28] because it seems to have much closer relations to the underlying strata than the overlying Tertiary deposits. It is included in the uppermost part of the Kirtland shale as described by Bauer, Gilmore, Stanton, and Knowlton. Its outcrop extends some distance along the western margin of the San Juan Basin, but it passes under the Ojo Alamo sandstone at a point about 12 miles due north of Pueblo Bonito (Putnam). In Colorado the formation consists of soft sandstone, tuffaceous shale, and coarse conglomerate in which some of the pebbles are andesite. Nearly all the finer-grained parts of the formation contain some volcanic debris, but the amount of this material is greatly diminished in its extension in New Mexico. At the Colorado state line the formation is 245 feet thick ; at San Juan River 30

[23] Reeside, J. B., jr., Op. cit., p. 18.
[24] Lee, W. T., Op. cit. (U. S. G. S. Prof. Paper 101), p. 183.
[25] Reeside, J. B., jr., Op. cit., pp. 20-21.
[26] Reeside, J. B., jr., Op. cit., pp. 20-21.
[27] Idem, pp. 21-24.
[28] Idem, pp. 27-28.

feet; and thence southward and eastward to the point where it disappears it ranges from 30 to 50 feet in greater part. South of San Juan River the formation is a thin assemblage of brown sandstone, grit, gray-white sandstone, and purple and gray shale. At San Juan River it is represented by thin irregular lenses of fine purple and green tuffaceous sandstone, coarse white sandstone with clay pellets, and purple and gray shale, in all 30 feet thick.

OJO ALAMO SANDSTONE

The Ojo Alamo sandstone crops out in central San Juan County in the vicinity of Ojo Alamo. It consists of sandstone and conglomerate, the latter containing pebbles of quartz and igneous rocks. Reptilian remains and silicified logs are abundant. The formation is 60 to 80 feet thick near the type locality. It rests unconformably on the McDermott formation and for a long time was provisionally considered as Tertiary in age. However, it is now regarded[29] as of Upper Cretaceous age.

TERTIARY SYSTEM

C. E. NEEDHAM[1]

Socorro, New Mexico

GENERAL FEATURES

Numerous sedimentary formations of Tertiary age, all of non-marine origin, are known in New Mexico. In the San Juan Basin an area of nearly 5,000 square miles lying mainly in San Juan, Rio Arriba, and Sandoval Counties, is occupied in ascending order by the Puerco, Torrejon, and Wasatch formations of Eocene age. The total thickness of these is over 2,000 feet.

Another extensive area is the Rio Grande depression from the Colorado state line to El Paso, Texas. In the north part the El Rito, Abiquiu, and Santa Fe formations of Miocene (?) to Pliocene age have been described; in the Socorro area, the Popotosa and Santa Fe formations. The Santa Fe is exposed in many places between Socorro and El Paso, and it is probably present in a number of the desert basins, under a blanket of caliche and sand.

In Raton Mesa and along the Rocky Mountain front in Colfax County, the Raton formation of Eocene age covers nearly 900 square miles.

Stretching across the Great Plains from Union County on the north to the southern limits of Lea County on the south is an area of nearly 10,000 square miles underlain by the Ogallala formation of Miocene-Pliocene age.

Numerous scattered smaller areas of Tertiary sediments are found over the State. In one of these, in Santa Fe County, the Galisteo formation of Oligocene age is exposed.

[29] Dane, C. H., Notes on the Puerco and Torrejon formations, San Juan Basin, New Mexico: Wash. Acad. Sci., Jour., Vol. 22, No. 14, pp. 406-411, 1932.1

[1] Formerly Director, State Bureau of Mines and Mineral Resources.

PUERCO FORMATION

Cope[2] first applied the term *Puerco marls* to a succession of non-marine green and black soapy marls about 500 feet thick, cropping out along the upper Rio Puerco near Cuba, Sandoval County, New Mexico. No fossils were found in these beds, but numerous fossils were later found in beds west of the Rio Puerco, in eastern San Juan County; Cope believed these fossils to have come from the equivalent of his Puerco formation. As now defined by its fauna, the Puerco is known only in the southeastern part of San Juan County, although Dane[3] states that the Puerco may be present along the Rio Puerco even though its distinctive fauna has not been found there.

The formation, as shown by its vertebrate fauna, is Eocene in age. It increases in thickness toward the northwest to about 1,200 feet on the east side of the Animas River.

The Puerco rests unconformably on the Ojo Alamo sandstone of Upper Cretaceous age and is overlain by the Torrejon formation.

TORREJON FORMATION

The Puerco beds were reported by Wortman[4] to contain two distinct faunas, no species being common to both, and only three or four genera passing from the lower Puerco into the upper. The name Puerco was retained for the lower beds and the term Torrejon formation given to the upper.

The Torrejon is 275 feet thick at the type locality on Arroyo Torrejon in Sandoval County, New Mexico, and consists of variegated shale and soft coarse-grained sandstone of white, gray, and tan colors. It rests with probable unconformity on the Puerco formation and is overlain unconformably by the Wasatch formation. Its age is Eocene. It can be traced northwestward almost to the Colorado state line.[5]

WASATCH FORMATION

Hayden[6] named this formation from exposures in Echo and Weber Canyons, Wasatch Mountains, Utah. In New Mexico it is found at the surface over a considerable part of the central and eastern San Juan Basin, extending as far east as the Nacimiento Mountains. In places it is about 1,000 feet thick. Reeside[7] describes excellent exposures along Blanco and lower Largo Canyons, where "the lower 300 feet or so seems to be one continuous sandstone bed. Elsewhere there is a succession of sandstone and shale beds, the sandstones mostly red-brown and resistant, the

[2] Cope, E. D., Ann. Rept. Chief Engrs. U. S. Army: Rept. Sec. War to 44th Cong., Vol. 2, Pt. 2, pp. 1008-1017, 1875.

[3] Dane, C. H., Notes on the Puerco and Torrejon formations, San Juan Basin, New Mexico: Wash. Acad. Sci., Jour., Vol. 22, pp. 406-411. 1932.

[4] Wortman, J. L., reported by G. N. Calkins: Science, n. s., Vol. 6, p. 852, 1897.

[5] Reeside, J. B., Jr., Upper Cretaceous and Tertiary formations of the western part of the San Juan Basin, Colorado and New Mexico : U. S. Geol. Survey Prof. Paper 134, pp. 3944, 1924.

[6] Hayden, F. V., U. S. Geol. and Geog. Survey Terr.: 3rd Ann. Rept., 1869, p. 191 of 1873 editon.

[7] Reeside, J. B., jr., Op. cit., pp. 45-46.

shales gray and red with layers of soft white sandstone irregularly intermingled." The age of the Wasatch is Eocene.

TOHATCHI SHALE AND CHUSKA SANDSTONE

Both these formations were named by Gregory,[8] the Tohatchi for the Tohatchi Indian School, 25 miles north of Gallup in McKinley County, New Mexico, and the Chuska for Chuska Peak, also in McKinley County.

The Tohatchi is 200 to 1,100 feet thick and consists of dark-brown and white shale, with subordinate amounts of sandstone. It rests unconformably on Upper Cretaceous beds and is overlain by the Chuska sandstone. The Chuska, which is 700 to 900 feet thick, consists of white and gray porous cross-bedded sandstone. It is overlain by lava flows.

The Tohatchi and Chuska are probably of Eocene age they may have their equivalents in the Puerco, Torrejon, and Wasatch formations of the San Juan Basin.

RATON FORMATION

Hayden[9] used the term *Raton Hills group* to indicate all coal-bearing rocks examined by him in Raton Mesa, Colfax County, New Mexico. Lee[10] found that this group really consisted of two formations separated by an unconformity. The upper, of Eocene age, was called the Raton, and the lower, of Cretaceous age, the Vermejo formation.

In Raton Mesa the Raton formation reaches a maximum thickness of some 2,000 feet, and consists of coal, carbonaceous shale, sandy shale, sandstone, and conglomerate. Toward the west the conglomerate at the base is several hundred feet thick and contains much arkose. The formation contains several commercial coal beds, one of the best being the Sugarite seam.

The Raton is older Eocene in age and correlates with the Denver and Arapahoe formations of the Denver Basin. The Raton in Colorado is overlain by the Poison Canyon formation.

GALISTEO FORMATION

Hayden[11] applied the term *Gallisteo sand group* to a great thickness of varicolored sands, sandstones, and conglomerates exposed along the valley of Galisteo creek in Santa Fe County, New Mexico. The formation rests unconformably on Mesaverde beds of Upper Cretaceous age, and is overlain by the Santa Fe formation. Lee [12] assigned a thickness of 3,790 feet to the Galisteo at the Hagan coal field in Sandoval County.

[8] Gregory, H. E., The Navajo country : U. S. Geol. Survey Water-Supply Paper 380, 1916.

[9] Hayden, F. V., U. S. Geol. Survey of Colorado and New Mexico: 3rd Ann. Rept., pp. 89-91. 1869.

[10] Lee, W. T., Recent discoveries of dinosaurs in the Tertiary : Amer. Jour. Science, 4th ser., Vol. 35, p. 531, 1913.

[11] Hayden, F. V., U. S. Geol. and Geog. Survey Terr., 3rd Ann. Rept.: pp. 40, 67, and 90, 1869.

[12] Lee, W. T., The Cerrillos coal field, Santa Fe County, New Mexico : U. S. Geol. Survey Bull. 531, pp. 286-297, 1913.

Mr. C. E. Stearns of Harvard University has recently done considerable work on the Galisteo, and, according to Bryan,[13] he has found sufficient fossils in two localities to indicate that the top of the main part of the formation is of Oligocene age.

EL RITO FORMATION

This Tertiary formation was first distinguished and described by Smith,[14] presumably from the lower reaches of El Rito Creek in Rio Arriba County, New Mexico. It rests unconformably on rocks ranging from pre-Cambrian to Jurassic, and is overlain unconformably by the Abiquiu tuff. The formation reaches a maximum thickness of about 200 feet, and consists of sandstones, conglomerates, and breccias, all brick-red in color. Quartzite makes most of the pebbles; volcanic material is absent. The formation is believed to have been deposited by streams flowing from the north. Remnants are found as far southeast as Santa Fe. These were mapped by Cabot[15] in his Picuris formation, which term, however, was preoccupied by Just[16] in 1937 for a pre-Cambrian series of basalts in Taos County. The El Rito formation may be about the same age as the Popotosa formation of Socorro County.

POPOTOSA FORMATION

Unconformably underlying the Pliocene Santa Fe formation on the east side of the Sierra Ladron in Socorro County is a basin deposit believed to be at least 3,000 and possibly 5,000 feet thick. It was first described by Denny[17] and named the Popotosa formation from Arroyo Popotosa in T. 1 N., R. 1 W., Socorro County. The formation consists of heavy conglomerate, gravels, sandstones, silts, clays, and tuffs, with some gypsum. Colors include red, gray, and pink. The pebbles and boulders are angular and are composed of various types of volcanic rocks and pre-Cambrian crystalline rocks.

Denny believes that the coarse sediments in the Popotosa were laid down as alluvial-fan deposits derived from highlands to the west and northwest, and that the silts and clays were formed in the center of a basin, which was at times a playa and at other times a lake.

The Popotosa is tentatively assigned to late Miocene time. It rests unconformably on volcanic rocks supposedly of Miocene age.

ABIQUIU TUFF

This formation was first described by Smith[18] from typical exposures near the village of Abiquiu in Rio Arriba County. It

[13] Bryan, Kirk, Personal communication, February 1942.

[14] Smith, H. T. U., Tertiary geology of the Abiquiu quadrangle, New Mexico: Jour. Geology, Vol. 46, pp. 940-944, 1938.

[15] Cabot, E. C., Fault border of the Sangre de Cristo Mountains north of Santa Fe, New Mexico: Jour. Geology, Vol. 46, pp. 88-105, 1938.

[16] Just, Evan, Geology and economic features of the pegmatites of Taos and Rio Arriba Counties, New Mexico: N. Mex. Bur. Mines Bull. 13, pp. 23-24, 1937.

[17] Denny, C. S., Tertiary geology of the San Acacia area, New Mexico: Jour. Geology, Vol. 48, pp. 77-84, 1940.

[18] Smith, H. T. U., Op. cit., pp. 944-952.

rests unconformably on the El Rito formation and is overlain by the Santa Fe formation. It is at least 1,200 feet thick a short distance west of Abiquiu. It consists of stream-laid tuffs and volcanic conglomerates, with arkosic gravels near the base, and interbedded lava flows at a few localities. West of Abiquiu, a five-to ten-foot bed of light buff limestone is found, and on the slopes of Cerro Pedernal is a five-foot bed of flint. The Abiquiu is easily recognized in the field by its pure white to light gray color, and by its characteristically abrupt and angular topographic forms. The formation is interpreted as a broad irregular piedmont fan deposit with its apex in the central or west-central part of the Tusas quadrangle, eastern Rio Arriba County.

SANTA FE FORMATION

This formation was named by Hayden[19] from the numerous exposures of unconsolidated alluvial deposits north of Santa Fe, New Mexico. Early workers interpreted the formation as lacustrine in origin, but it is now recognized to be of fluvial origin. The formation is widespread. According to Bryan[20] "the main body of sedimentary deposits of the Rio Grande depression, from the north end of the San Luis Valley to and beyond El Paso, is considered to be of the same general age and to belong to the Santa Fe formation." Denny[21] states that the total thickness of the formation in the type region cannot be accurately estimated, but that it is probably at least 2,000 feet and may be 3,000 to 4,000 feet. He describes the formation as including alluvial fan and river gravel, sand, silt, clay, volcanic ash, intraformational breccias, and lava flows. Colors are variable, but pink and salmon are common. The sediments were laid down as coalescing alluvial fans in a number of contiguous basins, extending from southern Colorado across New Mexico. In the middle of some of the basins, gypsiferous silts and clays of playa origin are found. The climate of Santa Fe time was probably semi-arid to humid.

Vertebrate remains have been collected in some quantity from Santa Fe beds in the Rio Grande depression. Near Santa Fe, the fossils indicate the age of the formation to be late Miocene or early Pliocene. North of Socorro the fossils suggest that the age is medial to late Pliocene.[22] The Santa Fe formation probably correlates for the most part with the Gila conglomerate of Arizona.

OGALLALA FORMATION

Darton[23] first applied the term Ogallala to a succession of gravels and coarse sands, sandy clays, and marly limestones exposed around Ogallala, Keith County, Nebraska. The formation

[19] Hayden, F. V., U. S. Geol. and Geog. Survey Tern : 3rd Ann. Rept., pp. 66 and 90, 1869.

[20] Bryan, Kirk, Geology and ground water conditions of the Rio Grande depression in Colorado and New Mexico: Regional Planning, Part VI, Rio Grande Joint Investigation in the Upper Rio Grande Basin; National Resources Committee, Vol. 1, Part II, p. 205, 1938.

[21] Denny, C. S., Op. cit., pp. 93-94, 1940.

[22] Denny, C. S., idem.

[23] Darton, N. H., U. S. Geol. Survey, 19th Ann. Rept., Pt. 4, pp. 732-742, 1898.

mantles the surface over a vast extent of western Nebraska and Kansas, eastern Colorado, and northwestern Texas, and extends westward into New Mexico as far as Santa Fe County. Vertebrate remains from Nebraska and Texas show its age to be late Miocene and Pliocene. There is little question that the Ogallala of New Mexico is equivalent to the Santa Fe formation of the Rio Grande Valley.

PALOMAS GRAVEL

This formation was named by Gordon[24] from exposures along Palomas Creek, Sierra County, New Mexico, and was stated to be Pleistocene in age. Its thickness was given as 1,500 to 2,000 feet in Sierra and Grant Counties. The writer has not visited the type locality, but after examining many other exposures of supposed Palomas gravel in Sierra County, he believes that the formation is merely the Santa Fe formation of the Rio Grande Valley, capped by a few feet of Pleistocene alluvium.

GILA CONGLOMERATE

This series of valley beds was named by Gilbert[25] from exposures along the gorges of the upper Gila river and its tributaries. These beds are widely distributed in southwestern New Mexico. The formation has been considered Pleistocene in age by many geologists, but recent work by Knechtel[26] leaves no doubt that at least a part of it is Upper Pliocene, as is most, if not all, of the Santa Fe formation in the Middle Rio Grande Valley. Knechtel also shows that the Gila along the margins of some of the basins is a fanglomerate, which grades basinward into lacustrine clays, silts, thin limestones, and diatomite beds.

It appears certain that Gilbert included Pleistocene pediment gravels and other alluvium in his original definition of the Gila conglomerate.

QUATERNARY SYSTEM

The following paragraphs on bolson and saline deposits, dune sands, and glacial deposits are quoted from Darton.[1]

BOLSON DEPOSITS

> The products of Quaternary time in New Mexico are mainly sand, gravel, and clay, which constitute the thick and extensive valley fills. There are also lavas and other igneous materials derived from volcanic eruptions. Wide valleys, such as those of the Tularosa Desert, the Jornada del Muerto, the Rio Grande, and the Florida Plains contain a vast amount of detrital material, largely of Quaternary age but possibly in part late Tertiary. Deep borings have shown that in places these deposits of sand, gravel, and clay have a thickness of more than 1,500 feet, but the amount is probably variable, and in some of the valleys the deposit is thin and even discontinuous. Thick deposits of Quaternary sand crop out in high banks along the west side of the valley of the Rio Grande opposite Las Cruces and farther south.

[24] Gordon, C. H., New Mexico geology: Science, n. s., Vol. 22, pp. 824-825, 1907.

[25] Gilbert, G. K., U. S. Geog. and Geol. Survey, 100th Meridian, Vol. 3, pp. 540-541, 1875.

[26] Knechtel, M. M., Geologic relations of the Gila conglomerate in southeastern Arizona: Amer. Jour. Science, 5th ser., Vol. 31, pp. 81-92, 1936.

[1] Darton, N. H., "Red Beds" etc.: U. S. Geol. Survey Bull. 794, pp. 58-59, 1928.

In the slopes northwest of El Paso 200 feet of this material is exposed, underlying the wide plain that extends westward to and beyond Deming. There are also notable exposures of similar beds in the slopes west and northwest of Rincon, but it seems probable that some of the lower strata in these thick deposits may be of late Tertiary age. Alluvial deposits occur along most of the streams all over the State except where rock canyons are being cut, and large amounts of wash and talus accumulate on the slopes.

SALINE DEPOSITS

There are many inclosed basins in New Mexico, in several of which saline deposits have been in the course of accumulation for a long time. Some of the most notable of these are in Estancia and Tularosa Valleys, which have been described by Meinzer.[2] The deposits in the valleys of Hidalgo County have been described by Schwennesen.[3]

DUNE SANDS

On the east side of the Pecos Valley in southern New Mexico there are very extensive sand hills formed of deposits known as the "Mescalero Sands," which are doubtless of Quaternary age and may represent deposits of an early stage of Pecos River that have been more or less rearranged by the wind.

A most remarkable accumulation of dune sand is the large deposit of gypsum sand that constitutes the White Sands west of Alamogordo. These sands occupy an irregular area about 27 miles long by 10 to 13 miles wide, and at the ends of this area they merge into dune sands consisting mainly of quartz grains. The gypsum has been brought to the surface by a seepage of water, probably from underlying Chupadera [Yeso] beds, and deposited on the surface in crusts, which have crumbled to sand and in the course of many centuries have been piled by wind into great dunes covering many square miles.

GLACIAL DEPOSITS

Deposits of rock debris on some of the higher parts of the Sangre de Cristo Mountains are probably glacial moraines. They have not been mapped. One of the most notable deposits according to Stevenson,[4] covers the pass between Vermejo and Costilla Creeks at an altitude of about 10,150 feet. Its surface is hummocky, with many irregular depressions, some of which are occupied by ponds. Distinct moraines occur along the east side of Costilla Park on the headwaters of Costilla Creek.

GATUNA FORMATION

The name Gatuña formation was applied by Lang[5] to valley fill in the Pecos Valley. Lang describes the formation in part as follows:

> The dominant material . . . is fine red sand. However the material is largely of local derivation and therefore the character of the source of the material has had a controlling influence on the composition and color of the resulting deposits. Conglomerates, stream gravels, gypsum, and limestone, as well as bedded and unconsolidated sands and silts, comprise this formation.

The name is taken from Gatuña Canyon in northeastern Eddy County. The formation is of Quaternary age.

[2] Meinzer, 0. E., Geology and ground-water resources of Estancia Valley, N. Mex.: U. S. Geol. Survey Water-Supply Paper 275, 1911 ; Geology and water resources of the Tularosa Basin, N. Mex.: U. S. Geol. Survey Water-Supply Paper 343, 1915.

[3] Schwennesen, A. T., Ground water in the Animas, Playas, Hachita, and San Luis Basins, N. Mex.: U. S. Geol. Survey Water-Supply Paper 422, 1918.

[4] Stevenson, J. J., Report upon geological examinations in southern Colorado and northern New Mexico during the years 1878 and 1879: U. S. Geog. Surveys W. 100th Mer. Rept. Vol. 3, Suppl., pp. 177-178, 1881.

[5] Lang, W. B., Geology of the Pecos Riper between Laguna Grande de la Sal and Pierce Canyon: Twelfth and Thirteenth Biennial Reports of the State Engineer of New Mexico, pp. 84-85, 1938.

IGNEOUS ROCKS[6]

There are extensive masses of igneous rocks in most parts of New Mexico, comprising intrusive dikes, sills, and stocks, mostly of pre-Cambrian, late Cretaceous, Tertiary, and Quaternary age, and volcanic rocks of late Cretaceous, Tertiary, and Quaternary age. Most of these rocks have riot been studied or mapped in detail, but many scattered facts regarding them, especially in certain mining districts, are on record.

INTRUSIVE ROCKS

The pre-Cambrian granites are intrusive and in many places they are exposed cutting gneiss, schist, quartzite, and other pre-Cambrian rocks, and there are also syenite, amphibolite, porphyry, and other pre-Cambrian intrusive rocks, some of which cut granite. In many districts sedimentary rocks ranging from Cambrian to Cretaceous are cut by porphyry and other intrusive rocks of various kinds in stocks, dikes, or sills. No intrusive rocks of Paleozoic age have been observed. In all parts of the State there are dikes of diabase and other similar rocks, . . . some of them cutting Tertiary strata and Quaternary gravel and sand. Most of these dikes are feeders of Quaternary lava flows.. .

VOLCANIC ROCKS

A large area in New Mexico is covered by products of volcanic eruptions that occurred mainly in Tertiary and Quaternary time. There were, however, flows of considerable extent in late Cretaceous time in the southwestern part of the State, but it is difficult to separate the lavas of that period from later ones. In Tertiary time many different lavas were erupted and much volcanic fragmental material was deposited between the flows, together with sand and gravel in some areas. No widespread regularity in the sequence of eruptions has yet been established, and outflows of similar lava appear to have taken place at different times. In general it has not been possible to separate the later Tertiary outflows from those of earlier Quaternary time, especially the basalts capping high mesas. Most of the tilted flows are regarded as pre-Quaternary.

The largest areas of volcanic rocks are in the west-central part of the State, where the Tertiary lava flows cover many thousands of square miles and probably have great aggregate thickness. They present considerable variety, including latite, andesite, rhyolite, basalt, and various fragmental volcanic products such as agglomerate, tuff and ash. In places they have been uplifted and faulted extensively. In most areas the succession and relations of these volcanic rocks have not been studied in detail. . .

[6] Quoted from Darton, N. H., "Red Beds" etc.: U. S. Geol. Survey Bull. 794, pp. 60-62, 1928.

GENERAL GEOLOGY OF OIL AND GAS[1]

Oil and gas are products derived from organic materials which were included in sediments at the time of their deposition. Later these organic materials were subjected to decay and alteration, and by the aid of pressure and heat certain constituents were converted into liquid oil and gas. These mobile products moved through the porous beds and accumulated in places, forming "pools" from which they are being liberated through holes drilled into the reservoir rocks by man.

The geologist, in his scientific studies connected with the search for commercial deposits of oil and gas, first considers whether or not the rocks which are known or assumed to underlie a particular area contain the mother materials from which oil or gas might, under proper conditions, have been formed. If such materials are present in the rocks of the area, his next interest is in the question whether or not there are porous beds in the geologic section through which the oil and gas might move in order to accumulate in commercial amounts in favorable localities. Having determined these two factors to be favorable, the geologist studies the geologic structure of the rocks to see if conditions are present which would cause the oil and gas to accumulate into "pools".

When water, oil, and gas are contained in a porous rock, the difference in specific gravity causes the oil and gas to rise into the higher part of the porous bed, while the water accumulates in the lower part. If oil, gas, and water are contained in a porous sand, the upper surface of which is horizontal, the gas will segregate as a horizontal layer at the top of the bed, and the oil will form a layer between the gas and the water below. In this instance the movement of the various substances will be essentially vertical. If the upper surface of the porous bed is irregular some lateral movement will take place to allow the gas to accumulate in the highest portion of the bed, while the oil and water will accumulate at successively lower levels.

Although practically all sedimentary beds were laid down in a horizontal or nearly horizontal position, they have in most areas been tilted, folded, or faulted, with the result that the strata are no longer horizontal. In these disturbed strata, gas will tend to rise to the highest part of a porous bed and the oil to follow just below it. The oil and gas will migrate up the dip of the porous bed, and in the absence of an obstruction they will finally come to the surface at the outcrop of the bed. Oil oozing from a rock outcrop is called a seep.

If oil and gas in their migration up the dip of a stratum encounter an obstruction—reversal in dip, closed fault, or some

[1] Quoted from Winchester, Dean E.. The oil and gas resources of New Mexico: N. Mex. Bur. Mines Bull. 9, pp. 55-56, 1933.

other obstruction—they accumulate against that obstruction, and if the amount is sufficiently large a commercial "pool" forms. The geologist searches for reversals in dip (anticlines), faults, etc., as the most logical places to find oil or gas accumulations, and hence the best places to drill for production.

The migration of oil and gas up the dip of a porous stratum may be stopped by the wedging out of the stratum or by a decrease in its porosity, and under these conditions valuable accumulations may result. "Pools" formed in this way give no surface indication of their presence and their discovery is largely accidental.

Until a few years ago the geologist, in his attempts to locate places favorable for oil and gas accumulation, was limited to the study of the rocks which were exposed or which were known to be present beneath the surface through evidence resulting from drilling operations. This essentially limited his studies to areas where the rocks were visible and made impossible the interpretation of conditions in great areas where rock formations which might be expected to contain oil and gas were covered by soil, sand, or other unconformable rock formations. Recent advances in the science of geophysics and the improvement of geophysical instruments have made it possible for the geologist to enter these areas and by the determination of certain physical properties of rocks of the area get a picture of the structural conditions prevailing beneath the surface.

GEOPHYSICS AND GEOCHEMISTRY

B. I. ROUTH[1]

Socorro, New Mexico

GENERAL STATEMENT

The Drake well, drilled in Pennsylvania in 1859, probably started organized prospecting for oil. The first method was to drill near oil and gas seepages, and according to one reliable source[2] this method has probably been the greatest single means of oil finding. Such indications of oil and gas in an area were soon tested and other means of locating petroleum were needed. Surface geology was used, then examination of cores and cuttings (subsurface geology), and in the early twenties geophysics was introduced. Geochemistry started in the early twenties, also, but was not recognized as a probable effective petroleum-finding tool until much later. It has been applied in the last few years and may become the next useful means of exploration.

The general opinion is that no radically different methods of exploration will be introduced in the near future, but that im-

[1] Formerly Head of the Department of Petroleum Engineering, New Mexico School of Mines; now with Chemical Construction Corp., Etter, Texas.

[2] DeGolyer, E., Future position of petroleum geology in the oil industry : Bull. Amer. Assoc. Petrol. Geol., Vol. 24, p. 1397, 1940.

provements will be made in present types of apparatus, field methods, and interpretations. It is considered quite possible that several fields may be discovered from data already on file, when proper interpretation can be made from a better understanding of certain anomalies.

New Mexico's rapid rise among the oil-producing states may be credited in some measure to geophysical work. Over vast areas in New Mexico, surface exposures are totally inadequate for an interpretation of the geology. Particularly is this true of the southeastern part of the State. However, with the aid of geophysics it has been possible to make wise selections of drilling sites, and prophecies as to probable depth. Drilling in the Hobbs area was started because a magnetometer survey by the Midwest Refining Co. indicated a structure worth testing. Doubtless other mantled areas in the State have good prospects of being productive.

Geophysical and geochemical methods may be divided into direct and indirect methods. Direct methods measure natural phenomena, whereas indirect methods measure artificial phenomena.

I. Methods measuring natural earth forces and properties of the earth's field; forces over which man has no control.

A. Gravimetric methods.
B. Magnetic methods.
C. Hydrocarbon analysis methods.
D. Water analysis methods.
E. Geothermal methods.
F. Radioactivity methods.

II. Methods measuring the reaction of the earth's substances to artificially created forces.

A. Seismic methods.
B. Electric methods (except self-potential).

GRAVIMETRIC METHODS

Gravimetric methods are used to measure variations in the earth's gravitational field. Newton's law of universal gravitation states that every particle in the universe attracts every other particle with a force directly proportional to the product of the two masses and inversely as the square of the distance between them. Likewise, the pull of gravity at any point on the earth's surface depends upon the weight and distribution of masses underlying and surrounding that point. A concentration of heavy material or a decrease in distance between the heavy material and the measuring point will give a positive reading, whereas a concentration of light material or an increase in distance between the light material and the measuring point will give a negative reading. Thus, heavy ore bodies, buried granite ridges, structural uplifts or basins, salt domes, and other geologic features cause variations in the pull of gravity which may be measured by gravity instruments. In general, positive anomalies are obtained over anticlines or uplifts and negative anomalies over synclines or basins. As anticlines are possible oil-bearing structures, oil pools may sometimes be found by locating places where heavy basement rocks have been forced up, causing the sedimentary rocks above to be folded. Positive anomalies do not always mean that uplifts are present, nor do negative anomalies always indicate the location of synclines. A salt dome may be indicated by either a positive or a negative anomaly, depending upon its depth and the extent and density of the cap rock. It is essential, therefore, that the interpreter of gravity surveys know something of the geology of the area, the type of structures predominant, and the specific gravity of the subsurface formations.

There are three types of instruments available for making gravitational investigations, namely, torsion balance, pendulum, and gravity meter or gravimeter. The torsion balance measures the rate of change of the gravitational field and the warping of the equipotential surface of gravity. The pendulum and gravimeter measure relative gravity. The pendulum, which may also be used to measure absolute gravity, has been used extensively for geodetic and other scientific purposes but to a rather limited extent for commercial geophysical prospecting. The torsion balance has been extensively used in petroleum geophysical exploration, and, with the faster instruments, readings at a single station can be completed in about two hours. One party can, however, operate more than one instrument.

The gravimeter has practically displaced the other two instruments in petroleum exploration work. The commercial gravimeter is essentially a mass supported by a spring with very sensitive arrangements for measuring the change in length of the spring. These instruments have been developed to the point where they are able to detect a difference of about one ten-millionth part of the pull of gravity. Most commercial gravimeters may be set up and read in ten minutes or less, giving a great advantage in speed over the torsion balance.

Some inference may be made from a gravity or torsion balance survey as to size and depth of mass anomalies, if shape and densities are known or assumed. For this reason, the more that is known about a particular area the more accurate the interpretation of gravity work is likely to be.

Differences in the pull of gravity, as observed from station to station, may be due to the general shape and rotation of the earth, differences in elevations of stations, masses between station levels, and terrain; these differences may be allowed for by certain corrections to the field readings. The above named factors may influence gravity sufficiently to mask completely a local anomaly due to some subsurface mass, if the corrections are not applied.

MAGNETIC METHODS

Magnetic methods of geophysical exploration are used to determine anomalies in the earth's magnetic field that are caused by magnetic minerals in the earth. Magnetite is by far the most common and most magnetic of these minerals, and is probably the mineral that gives most rocks their magnetic properties. Igneous rocks contain more magnetite than the average sedimentary rock. One writer[3] has given the average values of 0.90 percent magnetite in granites to 4.76 percent in basalts, as compared with 0.07 percent in the average sedimentary rock. Magnetic instruments measure a natural force, so they cannot be selective with regard to depth. Therefore, it is generally considered that magnetic methods in reality map the surface of the basement floor and any magnetic contrasts that may occur below that surface. Since folds in sedimentary rocks are often controlled by the topography of the basement surface, magnetic surveys are useful to the petroleum geologist.

In some areas where thick ferruginous beds, granite wash, etc., are present, the magnetic effect of the sediments may predominate. These beds would show highs where they are present on top of a structure, but a structure would be represented by a magnetic low if the magnetic sediment had been eroded from the upper part of the structure. Similar relations might also indicate faults. Changing characteristics of sediments and the lack of uniformity in the basement rocks may add difficulty to interpretations or even make the magnetic methods unfit for certain areas. In any event, the more geological information available to the interpreter, the better are his possibilities of arriving at correct conclusions.

The magnetic instrument commonly used in petroleum geophysical exploration is the magnetometer. Vertical and horizontal instruments are made, but the vertical type is more popular for petroleum geophysics. The vertical magnetometer measures the vertical intensity of the magnetic field. The magnetometer may be operated with considerable speed; a skilled operator can set up an instrument and make a reading in five minutes. The apparatus is easily portable, and costs of magnetometer surveys are low.

Objects and structures such as railroads, pipe lines, concrete highways with steel reinforcing, cars, and magnetic material on the operator's person, as well as magnetic storms, etc., must be guarded against when choosing stations and when making readings. All readings must be corrected for regional influences, diurnal variations, temperature variations, etc. The magnetic expression of structures that may accumulate oil is

[3] Stearn, N. H., A background for the application of geomagnetics to exploration: Geophysical Prospecting, Am. Inst. Min. Met. Engineers Trans., Vol. 81, pp. 315-344, 1929.

commonly very weak, and careful corrections have to be made to give as clear a picture as possible.

HYDROCARBON ANALYSIS

Methods used for the detection of hydrocarbons and associated inorganic compounds have been commercially developed only in the past few years. They would seem to be a natural sequel to our earliest method of locating oil and gas accumulations by their seepages at the surface. The larger and more conspicuous seeps were exhausted first and those that were not so apparent were drilled later. It seems quite logical, then, that there are seepages not visible to the unaided eye that might be identified by other means. Hydrocarbon analysis is an attempt to locate these seepages by chemical methods.

Hydrocarbon surveys may be divided into two fundamental groups, gas detection and soil analysis. The gas detection method is used to determine the concentration of combustible gases in the interstitial soil air. In this method air is withdrawn from a shallow borehole and passed through a portable hot-filament type detector. These detectors make no differentiation among hydrocarbons. The soil analysis method, which is more widely used at present, includes two procedures. In one procedure the concentration of volatile components is determined, and in the other the amount of extractable organic liquids and solids and the inorganic constituents. In the soil analysis method samples are taken in the field and sent to the laboratory in airtight glass containers. The sampling procedure varies with the method of running the soil analysis. Some investigators take samples at the surface, while others take them five feet or more below the surface, preferably below the water table. Undisturbed areas, away from levees, road beds, borrow pits, etc., are preferable for the collection of samples. An analysis for volatile hydrocarbons usually shows hydrogen, methane, ethane to butane inclusive, pentanes plus, and total hydrocarbons.

The second procedure extracts liquids and solids, which may be oxidized or polymerized hydrocarbons or other compounds. Those compounds that are not true hydrocarbons are sometimes called "pseudo" hydrocarbons. Some of the processes are being patented at the present time and details remain a secret.

Surveys over productive oil pools have shown that imperceptible seepage is going on over many fields, and that data may possibly be collected and plotted to locate new oil pools. It seems from experimental work that the areas of highest hydrocarbon concentration very often are found surrounding the productive limits of a pool. These concentrations have been referred to as "halos". Actually, a full halo or complete encircling of an oil pool is seldom found. The present explanation for the concentration of hydrocarbons over the edge of a pool is that the top of the structure has been partly cemented by percolating ground waters which, with certain chemical processes associated with migrating gas, have tended to reduce the permeability of the overlying strata, so that the escaping gas comes predominantly from the edge of the pool.

Soil analysis is practically the only exploration method that will give direct surface indication of petroleum deposits, and as yet it is not thoroughly tested. All other methods are used to locate structural conditions favorable to the accumulation of oil. Soil analysis methods should prove valuable in the location of oil and gas in stratigraphic traps which do not show the usual structural features.

A further application of soil analysis is used in geochemical well logging.[4] Cuttings are analyzed during routine drilling, and a log of hydrocarbons and various inorganic constituents is made. Logs of typical producing wells show a low concentration of hydrocarbons in the upper portion of the hole, increasing to a maximum at the productive sand. It is claimed that substantial increases of the hydrocarbons have been noticed as much as 1,000 feet above the productive zone in some cases, while in other wells no increase at all was recorded. The magnitude and distance of increased hydrocarbon content, in the strata above an oil accumulation, may depend to a certain extent upon the gravity of the oil—e.g., distillate reservoirs seem to give better indications than do those containing oil of lower gravity. Logs of nonproductive wells show relatively small concentrations of hydrocarbons from top to bottom. Thus geochemical logging under favorable conditions seems to allow the prediction of oil which may be as much as 1,000 feet below the bit. The lateral distance over which geochemical logging is influenced by the presence of an oil pool seems to be limited to less than one mile.

On the other hand, surface soil analysis gives a lateral investigation without regard to depth. A strong surface indication does not necessarily mean a shallow pool, nor does a weak indication mean a deep pool. Methane gas may come from sources other than petroleum, and pronounced evidence of this gas does not necessarily mean that oil or even gas accumulations are in any way involved.

WATER ANALYSIS METHODS

These methods involve the determination of certain chemical elements, radicals, and compounds that are present in water. The routine analysis, which is usually reported by the Palmer method, consists of determinations for calcium, magnesium, chloride, sulfate, carbonate, bicarbonate, and sodium and potassium calculated by difference. The specific gravity is usually taken, the presence of hydrogen sulfide or iron noted, and in certain areas qualitative tests are made for barium, strontium, or

[4] Rosaire, E. E., Geochemical prospecting for petroleum: Bull. Amer. Assoc. Petrol. Geo., Vol. 24, p 1415, 1940.

some other very characteristic element. The Palmer method[5] of reporting analyses in the ionic form, showing parts per million and reactive values in percent, is the most widely used, and makes it easy to recognize the same water with varying degrees of dilution or concentration.[6] From an analysis, the salinity and alkalinity[7] of a water may also be determined, and in turn used for correlative work. Waters from the different formations in an area usually vary sufficiently to be individually recognized, and very often one or more properties, such as specific gravity, chlorides, sulfates, etc., which may be quickly determined, will definitely correlate or identify the water in question.

Analysis of ground waters has led to the discovery of oil fields,[8] and some structures, such as salt domes, are indicated by characteristic anomalies.[9] Water analyses have been used considerably in correlation work and consequently are useful in drilling and production practice.

Analyses of waters encountered in drilling wildcat wells or in developing a field may frequently be used for correlation of formations over short distances, and quite often over very large areas. Water samples are easy to obtain on cable-tool wells, but are not so readily obtainable on rotary wells. However, the more samples obtained, analyzed, and placed on file, the greater the value of this method in development and production work.

Water analysis methods have proved useful in completion work, where the waters up the hole have been sampled. For instance, a well being drilled-in starts making water near the top of the "pay" bed, and upon analysis this water is found to be from a formation up the hole. The water may then be shut off and the well deepened for an increase in potential production, whereas if the water had been considered as bottom water, the well might have been plugged back or completed as a producer with a water cut.

Again, in a field where the wells are making a small percentage of water, a sudden increase in water could mean an increase in bottom or edge water, a casing leak, or a poor or damaged cement job. An analysis of this water should be checked against analyses made when the well was drilled, or if no samples were taken during drilling, the water should be checked against the present water being produced from offset wells. The latter method is often used on rotary-drilled wells, as water samples probably were not taken during drilling. The first appearance of water in a well within a field will, of course, have to be checked with analyses on file. If no water samples were taken in the im-

[5] Palmer, C., The geochemical interpretation of water analyses: U. S. Geol. Survey Bull. 479, p. 9, 1911.

[6] Typical water analyses are given in this bulletin on pages 105, 114, and 115. Also note the correlation made between these two waters, p. 104.

[7] Palmer, C. Op. cit., p. 11.

[8] Deussen, C., Two decades in the progress of oil finding: Bull. Amer. Assoc. Petrol. Geol., Vol. 18, p. 943, 1934.

[9] Minor, H. E., Oil-field waters of the Gulf Coastal Plain: Bull. Amer. Assoc. Petrol. Geol., Problems of Petroleum Geology, p. 893, 1934.

mediate area during drilling, the water, when it is from the producing formation, can usually be correlated with the water from an edge well.

These methods are used by some companies to advantage in development and production work as shown above, and are applied in numerous other ways depending upon the knowledge and ingenuity of the men in charge.

GEOTHERMAL METHOD

This method consists in the determination of temperature changes in the rock formations. Wherever wells or mines have penetrated the earth, an increase in temperature with depth has been noted. This geothermal gradient is quite variable from place to place. A well in the Maljamar area of southeastern New Mexico,[10] sec. 34, T. 17 S., R. 33 E., recorded a temperature of 103.06° F. at 5,200 feet. A deep well in the Rattlesnake field in northwestern New Mexico, in sec. 2, T. 29 N., R. 19 W., showed a temperature of 141° F. at 7,400 feet.[11]

Several possibilities have been suggested as a cause of the gradient variation: character of the rock formation, thickness of sediments, circulation of ground water, chemical reaction, radioactivity, and presence of oil. In certain areas, as in the Salt Creek oil field in Wyoming,[12] and in shallow salt domes along the Gulf Coast,[13] there appears to be a definite relation between the geothermal gradient and the geologic structure. That a high geothermal gradient is indicative of oil seems to be disproved by these facts: (1) high gradients are known over structures where no oil is present; (2) oil is found where no abnormal gradients can be detected; and (3) temperature surveys in wells with thick oil-bearing strata show no abnormal temperature increase through those strata. It appears, therefore, that geothermal gradients are of no value in the direct location of oil but may be of use in structural studies.

Well temperatures are taken by maximum-reading thermometers and by electrical-resistance thermometers. The maximum-reading thermometer is cheap and simple in operation, the thermometer being run into a well in a suitable container on a wire line. Its main disadvantage is that a round trip is necessary for each reading taken. The electrical-resistance thermometer, although it is more expensive and not so simple in operation, has been developed to give a continuous temperature log. This type of thermometer must be run on an electric cable.

Temperature surveys have found considerable economic use in the completion of oil and gas wells. Flows of gas, oil, or water into a well will disrupt the normal well gradient and consequently

[10] Hawtof, E. M., Results of deep well temperature measurements in Texas : Amer. Petrol. Inst. Production Bull. 205, p. 107, October 1930.

[11] Continental Oil Co., Personal communication. 1941.

[12] Van Orstrand, C. E., Some evidence on the variation of temperature with geologic structure in California and Wyoming oil districts: Econ. Geology, Vol. XXI, p. 145, 1926.

[13] Hawtof, E. M., Op. cit., p. 76.

show up on a temperature log. Such changes in temperature may be used in locating productive zones or in picking contact points between the reservoir components (gas, oil, and water). Another application is the determination of the position of cement behind a cemented string of casing. The heat generated in the setting of cement raises the temperature of the well fluid and the change may be recorded by a temperature survey. The log will show a decided "kick" at the depth corresponding to the top of the cement.

RADIOACTIVITY METHODS

Radioactivity is the spontaneous change of one element into another element. During this transformation, the radioactive material gives off three types of rays, which are known as alpha, beta, and gamma rays. The gamma rays, which are somewhat like X-rays, have a shorter wave length than X-rays and are even more penetrating. Some of the better known radioactive elements are uranium, radium, thorium, radon, and potassium.

The radioactivity methods are concerned with the location of concentrations or contrasts of radioactive material. Shallow faults may be located from the surface because radon, which is absorbed quite readily by water, may have been concentrated in the ground water circulating in the fault zone. Although oil has a high absorption power for radon, it cannot be detected from the surface because the sediments act as an effective shield against the alpha and beta radiations, and oil sands have not been found to give gamma radiation.

Two methods of measurement may be used in radioactivity exploration: (1) soil samples are taken to the laboratory for analysis, or (2) determinations of the activity of the formations in place are made with portable ionization chambers. The second method may determine (1) the entire radiation with an open bottom ionization chamber, (2) the radiation due to radon by analyzing the soil air, and (3) the penetrating gamma radiation by shielding an ionization chamber against alpha and beta rays.

Radioactivity logging has been developed in the past few years and is now being used in the petroleum industry. It is based on the fact that measurable quantities of radioactive materials are disseminated through all rocks. Lithologic changes show radioactive contrasts, which if measured will show changes of formations in a well. These logs do not differentiate between sandstone and limestone nor do they indicate permeability or fluid content. They differentiate shale from sandstone and limestone, because shale shows a high radioactivity compared with the other two types. The radioactivity log may be used in conjunction with a sample log to identify zones of low activity. The chief advantage of radioactivity surveys is the fact that they may be made in cased holes, because of the penetrating power of the gamma ray.

Operators allowed many old wells to be drilled to an objective sand without recording upper oil and gas shows, and sometimes without saving cuttings. On rotary wells, if samples were taken, the lag of cuttings with respect to the drilling depth might have been sufficient to introduce considerable guesswork when perforating upper pay beds. If a geologist is familiar with the geologic column, he will probably be able to pick the more promising horizons from a radioactivity survey on a cased hole. Such procedure may account for considerable additional production from wells which otherwise would have been plugged on depletion of lower productive strata. Radioactivity logs may also be used for correlative purposes on cased or uncased wells, -and show sufficient similarity to electric logs to be correlated with them.

The radioactive mineral[14] carnotite has been placed in the first portion of a cement slurry used in casing jobs, and a gamma ray survey later run to pick the top of the cement. An advantage of this method of locating cement is that the survey may be run at any time after the well is completed, and does not have to be run while the cement is setting.

Radioactive logging, in measuring the radiation of the penetrating gamma ray, utilizes an ionization chamber. This type of apparatus has a gas-filled chamber connected in an electric circuit. The ionization of the gas in the chamber, which decreases its resistance and allows a flow of the electric current, is proportional to the gamma radiation to which it is subjected.

SEISMIC METHODS

The seismograph, first used to record natural earthquakes, was used during the first World War to locate enemy guns, and soon after the war it was applied to the study of geology. Seismic methods depend upon the fact that vibrations or seismic waves may be produced in rocks, that these waves travel with different speeds in the various types of rocks, and that they are refracted and reflected much the same as light waves. The wave speed in a rock depends upon the rock's elastic properties, rigidity, and density. Hard, well-cemented rocks give greater speeds than loose, unconsolidated rocks. Usually, the deeper the rocks are buried, and the older they are, the more compact and cemented they become. For this reason the wave speed generally increases with depth. In general, crystalline and metamorphic rocks—salt, granite, gneiss, etc.—give higher velocities than do the other types.

The essentials for seismic exploration are:

1. A source of vibrations (usually a dynamite explosion).
2. The detectors which pick up the vibrations.
3. The amplifier-filter-recorder system (seismograph) for registering the vibrations.
4. A method for marking the shot moment on the record.

[14] Howell, L. G., and Frosch, A., Detection of radioactive cement in cased wells: Am. Inst. Min. Met. Engineers Trans., Vol. 136, pp.71-78, 1940.

5. A method of marking small time intervals on the seismogram (usually 0.01 second or less).

The explosives used in seismic work are usually placed in shallow drill-holes in order to get below the low-speed, weathered surface zone. These holes are drilled by light rotary drills mounted on trucks. The shot moment is transmitted to the recorder by wire or radio communication. The detector "spread"[15] varies in the effort to obtain the best possible record under the prevailing conditions, and is connected to the seismograph which may be mounted in a truck. Sometimes several groups of detectors instead of single detectors are connected to the elements on a seismograph in order to cancel certain disturbing waves. The vibrations caused by the shot are picked up by the detector and passed to the seismograph where the disturbances are transmitted to a sensitive photographic paper. Time-interval lines are also made on the photographic paper so that the time of arrival of any vibration may be determined. (See Fig. 1).

To determine the wave velocity in surface formations, the seismograph is placed rather close to the explosion. The distance being known, and the time of the shot and the time of the wave arrival being shown on the seismogram, it is a simple matter to calculate the speed of the waves through the geologic formations. If the surface formation is underlain by a high-speed formation, the waves may travel along the high-speed bed and up through the overlying lower-speed beds, arriving at the seismograph before the wave front traveling through the slow-velocity upper formation has arrived.

In the refraction method of seismic work, the times of travel of the first impulses are used to determine the depth to a high-speed marker bed. Determinations of beds at greater depth are made by increasing the distance between the shot and the seismograph, the strength of the explosion being necessarily increased. Depths to beds giving increased speed can be computed both at the point of explosion and at the location of the seismograph. With these depths known, it is possible for the geologist to make an accurate subsurface map of the structure, as indicated by the relative elevations of a given bed or formation at different points.

The "fan shooting" method has been used very successfully in prospecting for salt domes. In practice, a number of detectors are spaced some distance[16] from a single shot hole, the shot point and detectors forming a fan pattern. When a salt dome is between the shot point and any of the detectors, the impulses reach these detectors ahead of the regular travel time, because the impulses travel faster through the salt. The differences in time of arrival for the faster traveling waves as compared with normal travel are called "time leads" and are indicative of a

[15] General arrangement of detectors with respect to each other and the shot point.
[16] The distance between shot point and detectors may be as much as ten miles.

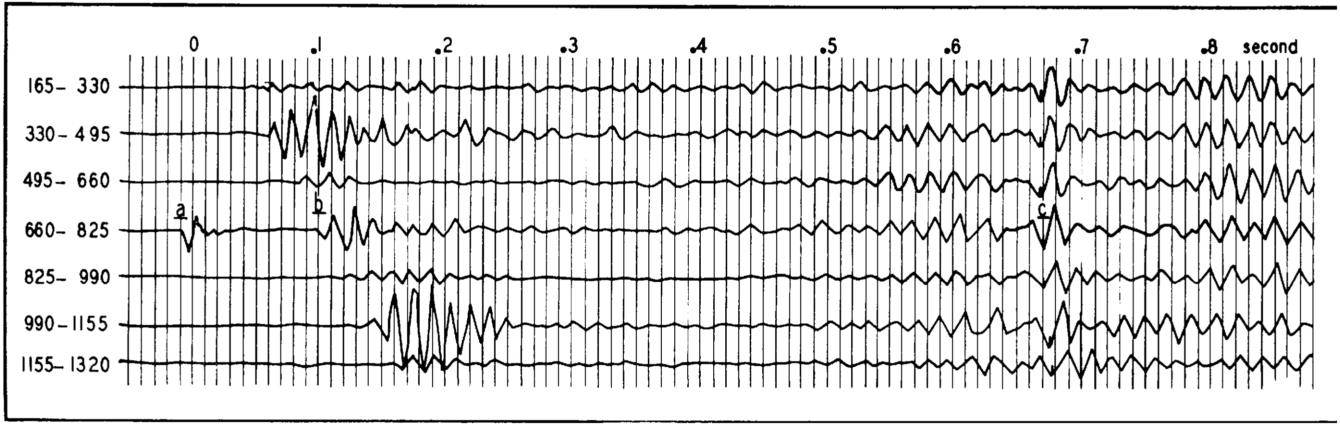


FIGURE 1.—Seismogram showing shot moment a, refracted waves b, and reflected waves *c*. Figures at left show the distance in feet between the detector spreads and the shot point.

change in medium (salt dome) between the shot point and detectors. By cross shooting, the approximate center of a dome can be located.

In the reflection method the shot point is close[17] to the receiver, and the results depend upon the reflection of waves from contact surfaces between geologic beds of different speeds. By this method, it is possible to determine several contacts from a single shot and a single seismogram, as well as their depths, by considering impulses recorded after the first ones are received. The reflection method may be used for depths in excess of those reached by the modern rotary drill.

Although expensive, seismic methods give details of actual depths at given points, which is an advantage over other methods, and consequently they may be used to outline geologic structures and to determine contours on certain marker beds. The reflection method, which is used more than any other seismic method, has been used in all parts of the world.

ELECTRIC METHODS

The electric methods are limited to electric logging.[18] This method measures the resistivities and spontaneous potentials of the formations in an uncased hole. They are measured by lowering an electrode system, suspended on an electric steel-shrouded cable, into the well at an approximate rate of 1,000 feet per hour. The cable, which runs over a measuring pulley, is raised or lowered by a winch mounted in a recording truck. The resistivity and spontaneous potential are recorded as continuous curves on a log together with depth of the electrodes. An electric current is used to measure the resistivity.

The rock-forming minerals, with the exception of a few metallic minerals, are better insulators than conductors, and formations transmit electric currents only because of the electrolytic conductivity of the contained fluids. Because of the difference in mineral content of formation waters and the variation in porosity, the resistivity will vary from bed to bed a porous rock containing concentrated salt water will show a low resistivity, one containing fresh water a higher resistivity, and one having gas or oil a still greater resistivity.

The spontaneous potential (also called self or natural potential) is closely related to the permeability of the formations and is due (1) to the movement of fluids through the formation into or from the well, and (2) to the differences in concentration between the formation and drilling fluids. The first factor seems to be predominant, and is usually due to the infiltration of the drilling fluid because of the greater hydrostatic head maintained in the well. The potential curve gives relative rather than actual per-

[17] The distance from shot point to the farthest detector is usually less than one-half mile.
[18] The Eltran (electrical transient) method is claimed to be useful in surface exploration, but no field discoveries have been credited to it.

meability, with the permeability proportional to the potential reading.

In general, the combinations of resistivity and potential may be interpreted as follows :

1. Low potential and low resistivity—a formation with low permeability but sufficient salt water to be conductive—shale.
2. Low potential and high resistivity—a formation with low permeability and practically no conductive fluid—dense limestone, gypsum.
3. High potential and low resistivity—a formation with good permeability and a conductive fluid, such as salt water—sand or lime.
4. High potential and high resistivity—a formation with good permeability and little or no conducting fluid—sand or lime containing either gas, or oil, or both.

Experience is needed in the interpretation of electric logs, as conditions may vary. A productive oil sand may contain sufficient connate water to make the sand conductive to some extent, hence it may possibly be overlooked.

An original electric log in an area is best used in conjunction with a sample log and paleontology, but subsequent logs can usually be correlated without added information. The electric log gives sharp formation contacts, and shows the depth and thickness of breaks in a formation, e.g., shale breaks in sand. Detection of these breaks would be practically impossible with cuttings, because of sample lag, mixing of cuttings, and caving. The electric log also shows the presence of faulting where parts of formations are faulted out. It has an advantage over mechanical coring, in that it gives a continuous log at a fraction of the cost of continuous mechanical coring. Useful information for well completion is also obtained, e.g., casing points, zones opposite which casing may be perforated for production, oil-water contact, and actual depth of set casing. The method is widely used and has been successful in most cases.

GENERAL FEATURES OF OIL AND GAS ACCUMULATIONS IN NEW MEXICO

ROBERT L. BATES

STRUCTURE AND STRATIGRAPHY

Exploration for oil and gas in New Mexico has shown that their accumulation in commercial amounts is due primarily to one of two geologic factors: favorable geologic structure, or lenticular porosity of the reservoir beds. The greater part of the oil has come from anticlinal structures, such as Hobbs, Monument, Rattlesnake, and Hospah; however, good commercial production has also been developed on structural noses with little or no closure and on monoclines without reversal, as in the Artesia-Vacuum trend, the Cooper-Jal area, and the Bloomfield and Kutz Canyon gas fields.

Oil or gas, or both, have been found in New Mexico in strata of Pennsylvanian, Permian, Triassic, and Cretaceous ages. In the southeastern part of the State, oil and gas are produced from sandstones and porous limestones belonging to the Whitehorse group, and also from the underlying San Andres limestone, both of Permian age. In the northwestern part, the Dakota sandstone (Upper Cretaceous) is the chief producer. Pennsylvanian and Cretaceous rocks have been proved to contain commercial accumulations only in the northwestern part. Carbon dioxide gas is found in and beneath the Triassic rocks in the northeastern part of the State.

The Oil and Gas Map of New Mexico, Plate 4, shows the axes of most of the known anticlinal folds, together with the locations and total depths of wildcat wells, the oil and gas fields, refineries, and pipe lines. Detailed maps of many areas within the State are given in connection with the discussions of those areas.

For description of the structural features and the development of oil and gas, the State is divided into five "areas": Northwest Area, Northeast Area, Southeast Area, Median Area, and Southwest Area. The boundaries of these areas are indicated on the State map, Plate 5. In general, each area has structural and stratigraphic features which distinguish it from the others.

SUMMARY OF OIL AND GAS POSSIBILITIES

In the words of Winchester,[1]

> The development of new oil and gas production in New Mexico will follow two general lines: (1) the location and drilling of new structures, and (2) the drilling of formations below those already tested on known

[1] Winchester, D. E., The oil and gas resources of New Mexico: N. Mex. Bur. Mines Bull. 9, p. 57, 1933.

structures. Geologists have already made rather complete surveys of the areas where rocks are well exposed, and it is safe to say that very few additional folds will be located in this manner. In large areas, however, subsurface geologic conditions are obscure, and in these areas geophysical investigations will probably be of great assistance in determining structural conditions.

In the Southeast Area, where bedrock exposures are scarce or absent, wildcat drilling and geophysical surveying have delineated most of the structures. It is believed that in this section of the State considerably more future production will be forthcoming from deeper zones on known structures than from depths now exploited on structures yet to be found. Commercial amounts of oil have been found in Pennsylvanian rocks at depths in the vicinity of 7,000 feet in wildcat wells within a few miles of the east line of the State. These wells are located on the Central Basin Platform (see map, Fig. 10), and there is little reason to doubt that the reservoirs tapped in Texas extend into New Mexico. It seems especially likely that large reserves exist under such major structures as Hobbs and Eunice-Monument.

The Delaware Basin does not offer good possibilities. It has been thought that oil might be found in the uppermost Delaware Mountain sandstones, where they lap up against the Capitan Reef along the edge of the Basin, forming stratigraphic traps; but wells drilled in this zone have secured only negligible amounts of oil.

The following paragraphs from Winchester[2] well summarize the possibilities in other parts of the State.

Many of the anticlinal folds in the State have been drilled to depths which at the time of drilling were considered sufficient to constitute a complete test of the reservoir beds thought to be good possibilities for commercial accumulations. Because of the subsequent development of commercial production in formations deeper than those tested, a number of these structures deserve additional testing with the drill. This is especially true in the San Juan Basin, where, until recently, drilling to test the formations below the Dakota (Cretaceous) sandstone was considered unduly hazardous and economically unjustified. The completion of the first deep test on the Rattlesnake dome and its production from the deep Pennsylvanian sands have greatly increased the attractiveness of this formation, and a number of wells sufficiently deep to test the Pennsylvanian rocks will doubtless be drilled in the Northwest Area as soon as market conditions in the oil industry become more favorable.

Similar though perhaps less attractive geologic conditions for oil and gas accumulation occur in the deeper rocks of the Northeast Area, where numerous wells have been drilled. It is thought that few if any of these wells have reached the pre-Cambrian granite, in which of course no oil or gas can be expected. Probably most if not all of the granite reported in wells in northeastern New Mexico is "granite wash" or arkose, composed almost wholly of fragments of granite, which have been but little altered during erosion and deposition as a true sedimentary rock. Recent studies of outcropping formations, as well as cuttings from borings, have proved that beds of arkose exist in the Permian and Pennsylvanian sedimentary formations above as well as below beds of shale and limestone rich in organic

[2] Winchester, D. E., Op. cit., p. 58.

material.... Associated sands ... should constitute good reservoir rocks for oil and gas which might originate in the shale and limestone. Deeper drilling, therefore, is warranted on many of the anticlinal folds in northeastern New Mexico. Until tested, the deep formations below the arkose beds are prospective sources of commercial production of oil and gas. Suggestions for deeper drilling are given in connection with the detailed discussion of the anticlinal folds of this area.

In general, the Median Area and the Southwest Area are not promising for commercial accumulations of oil and gas, but in certain areas testing with the drill may be justified.

Brief discussions of future oil and gas possibilities in northern New Mexico are given in the symposium on Possible Future Oil Provinces of the United States and Canada.[3]

DEVELOPMENT AND PRODUCTION

Since 1924 New Mexico has been a consistent producer of oil and gas. Production in 1941 totalled more than 39,000,000 barrels and placed the State seventh among oil-producing states. The total number of well completions in the State in 1941 was 402, of which 301 were oil wells, 19 gas wells, and 82 dry holes. At the end of 1941 there were in the State 3,664 wells producing oil and 136 wells producing gas.

The table below gives the production of petroleum, natural gas, and natural gasoline for the period from 1924 to 1941.

Production of Petroleum, Natural Gas, and Natural Gasoline in New Mexico[1]

Year	Petroleum, barrels	Natural Gas, cubic feet	Natural Gasoline, gallons
1924	98,000	---------------	------------
1925	1,060,000		
1926	1,666,000	-----------------	1,488,000
1927	1,226,000	-----------------	1,827,000
1928	943,000	838,000,000	1,506,000
1929	1,830,000	3,054,000,000	1,077,000
1930	10,189,000	9,496,777,000	3,633,000
1931	15,227,000	19,354,000,000	17,775,000
1932	12,455,000	17,604,000,000	17,507,000
1933	14,116,000	19,148,000,000	19,149,000
1934	16,864,000	24,075,000,000	21,748,000
1935	20,483,000	27,931,000,000	19,563,000
1936	27,223,000	33,928,000,000	28,921,000
1937	38,854,000	46,337,000,000	38,253,000
1938	35,759,000	50,706,000,000	49,596,000
1939	37,323,000	60,284,000,000	54,555,000
1940	38,904,466	63,990,000,000	55,713,000
1941	39,369,000	-----------------	61,633,000

[1] Figures by U. S. Bureau of Mines

[3] Bull. Amer. Assoc. Petrol. Geol., Vol. 25, No. 8, August 1941. On the San Juan Basin (Northwest Area) : pp. 1504-1507. On the Northeast Area : pp. 1491-1496 and pp. 1527-1529.

NORTHWEST AREA

B. I. ROUTH[1]
Socorro, New Mexico

A considerable part of the section on the Northwest Area has been taken from the earlier bulletin on New Mexico oil and gas by Dean E. Winchester. Other parts have been rewritten following Winchester's general outline, and still other sections are new contributions.

John A. Frost, of the Farmington office of the U. S. Geological Survey, furnished much valuable information, as well as a number of analyses of gas, oil, and water. Cooperation on the part of the following persons is also gratefully acknowledged: C. H. Rankin, Continental Oil Co.; E. T. Barker, Petroleum Products Corp.; O. B. Peacore, New Mexico Natural Gas Co.; and field employees of the Continental, Stanolind, and Southern Union Production companies.

GEOGRAPHY AND GEOLOGY

The Northwest Area (see Plate 5) includes that part of the State north of the Datil Mountains in Socorro and Catron Counties, and west of the Nacimiento Mountains in Sandoval County and the Ladron Mountains in Socorro County. Within the area are included the great San Juan Basin, the Zuni Basin to the southwest, the Acoma Basin to the southeast, and the Chama Basin to the northeast. The Zuni Mountains in Valencia and McKinley Counties separate the Zuni Basin from the Acoma Basin. In this report the Chama Basin is considered as part of the San Juan Basin. Sedimentary formations ranging in age from Pennsylvanian to Recent are exposed in the area, and limited areas of granite occur in the Zuni, Nacimiento, and Ladron Mountains. Folding has produced numerous anticlines and domes, and in places these are faulted to considerable extent. Intrusions of basaltic rock take the form of plugs and dikes which resist erosion and in places stand out as conspicuous landmarks. Lava caps many high mesas, particularly in the Zuni and Acoma Basins, whereas more recent extrusions of lava have in some places followed present drainage channels where they form the floors of the valleys.

OIL AND GAS

Geologic exploration has outlined many anticlinal structures within the area, and wells have been drilled on a number of the structures. Commercial oil fields have been developed on the Rattlesnake, Hogback, Table Mesa, and Hospah structures and in

[1]Formerly Head of the Department of Petroleum Engineering, New Mexico School of Mines ; now with Chemical Construction Corp., Etter, Texas.

the Bloomfield area, and non-commercial oil has been found on the Red Mountain and Stoney Buttes structures and in the Seven Lakes area. Commercial gas has been developed on the Barker and Southern Ute domes and in the Kutz Canyon, Fulcher Basin, and Blanco areas. The Southern Ute dome supplies Durango, Colorado, with gas, and the town of Aztec receives its gas from the Blanco area. The Southern Ute dome, Fulcher Basin, and Kutz Canyon fields are connected by pipe line and furnish gas to Albuquerque, Santa Fe, Belen, and intermediate points. Farmington is served by a gas line from the Kutz Canyon field. Commercial oil is produced from the Farmington, Hospah, and Dakota sands, all of Cretaceous age, and also from Pennsylvanian rocks. Gas is produced from the Farmington, Pictured Cliffs, and Dakota sands and from sands in the Mesaverde formation.

SAN JUAN BASIN

GEOGRAPHY AND GEOLOGY

A large part of northwestern New Mexico, together with a narrow area to the north in southwestern Colorado, is occupied by the broad relatively shallow San Juan Basin. This great structural basin is bounded on the south by the Zuni Mountains, on the east by Brazos Peak northeast of Tierra Amarilla and the Nacimiento Mountains near Cuba, on the north in Colorado by the San Juan Mountains, and on the west by the Defiance uplift in northeastern Arizona. With the exception of the extreme eastern and southern edges, the basin is drained through the San Juan River and its tributaries into the Colorado River and the Pacific Ocean.

The central part of the basin is floored with Eocene beds. Surrounding them are strata ranging in age from Cretaceous to Pennsylvanian. It is estimated that in the deepest part of the basin the total thickness of sediments is between 12,000 and 15,000 feet. The accompanying cross section, Fig. 2, shows the structural conditions as revealed by the drill across the basin from east to west, approximately through the town of Farmington. As shown by this cross section, the formations in the heart of the basin are relatively flat, with beds of the Mesaverde formation abruptly upturned on both the eastern and western edges. Beyond the outcrop of the Mesaverde on both the east and west sides of the basin are one, two, or three lines of gentle folds.

A cross section from north to south would show somewhat different structural conditions. On the north in Colorado the Mesaverde and older formations are steeply upturned against the San Juan Mountains, whereas on the south the Mesaverde dips gently into the basin. On the south beyond the outcrop of the Mesaverde the older formations down to the Permian are more steeply upturned adjacent to the granite core of the Zuni Mountains. No Pennsylvanian or older beds are exposed around

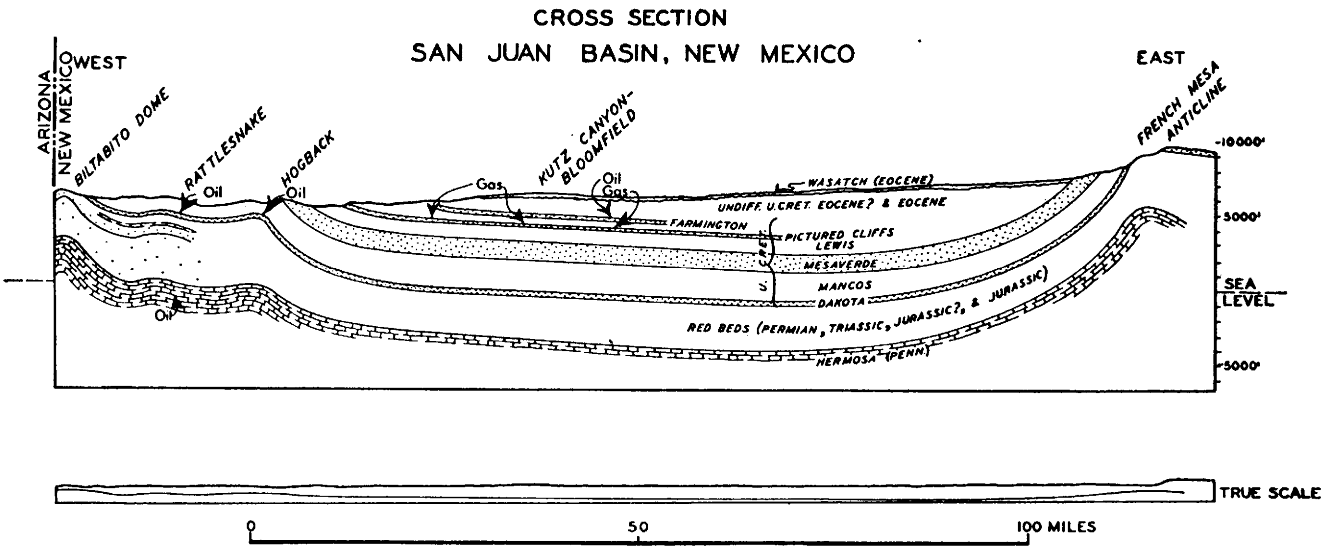


FIGURE 2.— (From Bull. Amer. Assoc. Petrol. Geol., Vol. 25, No. 8, Fig. 27, August 1941; after Winchester, D. E., N. Mex. Bur. Mines Bull. 9, Plate XV, 1933.)

these mountains, but as they are present in the northern and eastern parts of the basin, and have been encountered in deep wells on the Rattlesnake structure, it is assumed that they are present beneath the Permian beds at points not far north of the Zuni Mountains. No wells have so far been drilled sufficiently deep in the San Juan Basin to reach granite; one well in the Rattlesnake field was drilled to the Ignacio quartzite of Cambrian age.

Darton and others have given the name Chama Basin to a small area northeast of the Nacimiento Mountains and the line of structures to the north—French Mesa, Gallina Mountain, and El Vado anticlines—which is here included in the San Juan Basin. This area is drained by the Chama River and its tributaries. East of the arch north of the Nacimiento Mountains, Cretaceous and older formations dip gently toward the heart of this local basin but are steeply tilted and faulted near Abiquiu on its eastern side. Near Coyote, in the southern part of the Chama Basin, three small anticlines appear in beds of Triassic or Permian age. Several other anticlines are located on the western edge of the basin, between the El Vado anticline and the Colorado-New Mexico state line (see map, Plate 6).

Prominent igneous plugs and dikes are numerous in the San Juan Basin, but in no place do such intrusions occur in the heart of an anticlinal fold. (See Plate 7.) Ship Rock, one of the most conspicuous of the igneous plugs, rises to an altitude of approximately 1,850 feet above the surrounding country. (See Plates 1 and 10A.) These intrusions probably have had little or no effect on the accumulation of the oil and gas.

OIL AND GAS

The accumulation of oil and gas in the San Juan Basin appears to have been controlled by anticlinal folding, except in the area near Aztec in the north-central part of the basin and in the Seven Lakes area to the south. In these areas anticlinal folding is absent, and the production appears to be controlled by lenticular sand conditions in essentially flat-lying beds. Much detailed mapping of structures has been done by various geologists, and probably most of the anticlinal folds around the edges of the basin have been studied. It is possible, however, that geophysics may locate buried structures in the central part of the basin. Nearly all the favorable structures in the basin have been tested to the Dakota sand at the base of the Cretaceous, but only one—the Rattlesnake dome near Shiprock—has been drilled sufficiently deep to test the lower formations.

In the San Juan Basin, the principal oil-producing formation to date has been the Dakota, from which a total of 7,642,306 barrels of oil had been produced up to December 31, 1941. The oil from this sandstone has the unusually high gravity of 55° to 76° A. P. I.

The Pennsylvanian production from the Rattlesnake dome, which is the only such production in the basin, amounted to 489,629 barrels up to December 31, 1941.

The major gas-producing horizon to date has been the Pictured Cliffs sandstone of the Cretaceous, which up to December 31, 1941, had produced 13,898,000,000 cubic feet. The Dakota production from the Southern Ute dome until the end of 1941 totaled 7,379,000,000 cubic feet, and there is a proved Dakota gas reserve on the Barker dome.

Many of the structures on the east as well as on the west side of the San Juan Basin are considered good prospects for production from the Pennsylvanian when market conditions justify the large expense of drilling to the necessary depths. Such structures as Beautiful Mountain, Biltabito, El Vado, French Mesa, Gallina Mountain, Hogback, Table Mesa, and Tocito (see maps, Plates 6 and 7) are well worth testing for Pennsylvanian production. In 1938 the Standard Oil Co. of California, Continental Oil Co., and Stanolind Oil and Gas Co. tried without success to obtain leases from the Navajo Indians on the Chimney Rock, Biltabito, and Beautiful Mountain structures. These companies were acting as a joint operator.

The possibilities of Pennsylvanian production on structures in the southern part of the basin depend upon whether or not Pennsylvanian rocks are present beneath the structures. Along the north side of the Zuni Mountains Pennsylvanian rocks are absent, and younger formations lie directly against the granite. It is thought, however, that this condition holds for only a relatively short distance out into the basin and in the future a deep test may be justified on one of the stronger structures, perhaps the Walker dome, to determine whether or not the Pennsylvanian is present and whether or not it contains valuable oil or gas accumulations.

Two tables on the following pages summarize the results of drilling in the San Juan Basin, and a third lists structures not yet drilled.

AZTEC GAS FIELD

The town of Aztec, San Juan County, during the 1920's received its gas supply from wells drilled a short distance south of town. (See map, Plate 8.) All wells in this vicinity had been plugged previous to 1942.

The wells produced from the Farmington sand member of the Kirtland shale. The lenticularity of the sand seems to have been the controlling factor in accumulation, as no structure has been determined.

The initial production of individual wells ranged from a few thousand up to 4,000,000 cubic feet per day. The best well, Aztec Oil Syndicate No. 1, in the SW¼SE¼SW¼ sec. 16, T. 30 N., R. 11 W., was reported as making 4,000,000 cubic feet of gas

Drilled Structures in the San Juan Basin

Name	Surface Formation	Lowest Formation Penetrated	Total Depth of Well, Feet	Remarks
Ambrosia	Mancos	(?)	1,720	Dry. Dakota topped at 700 feet; Navajo at 780 feet. Remnant of Morrison at 780 feet.
Azotea	Mancos	(?) (Redbeds)	2,300	Show of oil at 1,060 feet in Dakota.
Barker	Mesaverde	Morrison	3,365	Commercial gas production in Dakota.
Beautiful Mountain	Mancos	Chinle	3,290	Show of 40° A. P. I. oil in Wingate.
Bonita	Mesaverde	Mancos	3,275	Dry.
Carica	Mesaverde	Morrison	3,190	Dry.
Chavez	Mesaverde	Morrison	2,154	Dry.
Chico	Chico	Dakota	1,807	Dry.
Chimney Rock	Mancos	Morrison	2,002	Show of gas in Tocito; water in Dakota.
Chromo	Mancos	Dakota	725	Dry.
Dulce	Mesaverde	Dakota	2,536	Dry.
French Mesa	Poleo	Pennsylvanian	3,355	Incomplete test of Pennsylvanian.
Hogback	Tocito	Wingate (?)	1,965	Commercial production in Dakota, 63° A. P. I. gravity oil.
Horse Lake	Redbeds	(?)	1,785	Dry.

Hospah	Mesaverde	Morrison (?)	3,282	Commercial production in Mesaverde (Hospah sand), 30° A. P. I. gravity oil.
Lagunitas	Mancos	Pre-Cambrian	6,220	P. & A. schist.
La Ventana	Mancos	Morrison	2003,	Questionable closure; one well dry. Morrison topped at 1,925 feet.
Monero	Mancos	Dakota	1,515	Dry.
Rattlesnake	Tocito	Ignacio	7,397	Commercial production in Dakota, 70-76° A. P. I. gravity oil. Commercial production in Pennsylvanian, 40-43° gravity oil.
Red Mountain	Mesaverde	Mesaverde (?)	665	Small production of 40-43° A. P. I. gravity oil from sands in Mesaverde.
Rio Salado	Chinle	Pennsylvanian	2,008	Faulted; one well dry. Pennsylvanian topped at 1,880 feet.
San Mateo	Mancos	Morrison	1,320	Dry.
Stoney Buttes	Mesaverde	Mancos	3,060	Non-commercial production in Mesaverde, 35° A. P. I. gravity oil.
Table Mesa	Mancos	Chinle	3010	Commercial oil in Dakota, 56-58° A.P. I. gravity.
Tocito	Tocito	Chinle	3,022	Water in all sands drilled.
Ute	Mesaverde	Dakota	2,428	Commercial production in Dakota.
Vogt	Mesaverde	Dakota	2,350	Dry.
Walker	Mancos	Morrison	1,460	Show of oil in Dakota.
Willow Creek	Redbeds	Granite	2,054	Dry.

Drilled Stratigraphic Traps in the San Juan Basin

Name	Surface Formation	Lowest Formation Drilled	Total Depth of Well, Feet	Remarks
Aztec	Puerco and Torrejon			Small gas production from Farmington ; now abandoned. Gas shows in Pictured Cliffs.
Blanco	Puerco and Torrejon	Mesaverde (?)	4,550	Small gas production from Mesaverde and Pictured Cliffs, now supplying town of Aztec.
Bloomfield	Puerco and Torrejon			Small oil and gas production from Farmington; 57° A. P. I. oil. Gas shows in Pictured Cliffs.
Fulcher Basin	Puerco, Torrejon and Ojo Alamo	Lewis	2,035	Commercial gas production from Pictured Cliffs. Non-commercial oil in Farmington.
Kutz Canyon	and Puerco an Torrejon	Mesaverde (?)	4,400	Commercial gas production from Pictured Cliffs.
Oswell	Puerco and	Kirtland		Small oil and gas production from Farmington; 57° A .P. I. oil.
Seven Lakes	Mesaverde			Small amount of oil from Mesaverde sands. Abandoned.

Untested Structures in the San Juan Basin

Name	Location			Surface Formation	Remarks
	T. - N.	R.	County		
Agua Zarca	22-23	2E.	Rio Arriba	Triassic	
Biltabito	12-13	5W.	San Juan	Wingate	Navajo Meridian and Navajo Base Line.
Cabezon	16	2W.	Sandoval	Mancos	
Canada de las Milpas	15	1E.	Sandoval	Jurassic	
Coyote	22-23	3E.	Rio Arriba	Permian	
El Vado			Rio Arriba	Dakota	Unsurveyed.
Garcia	30	1E.	Rio Arriba	Mesaverde	
Gallina Mountain	26	2E.	Rio Arriba	Pennsylvanian	
Guadalupe	15	3W.	Sandoval	Mancos	
Mariano Lake	15	13W.	McKinley	Mancos	
McGaffey	13	17W.	McKinley	Triassic (?)	
North Horse Lake	30	1E.	Rio Arriba	Mesaverde	
Olguin	17-18	1W.	Sandoval	Mancos	
Poleo Creek	22-23	2-3E.	Rio Arriba	Permian	
Rio Puerco	12-13	1-2W.	Sandoval	Mancos	Faulted; two highs.
Tierra Amarilla	15	1E.	Sandoval	Jurassic (?)	

per day, with a rock pressure of 285 pounds per square inch at a plugged-back depth of 985 feet. The well was drilled to 1,750 feet and encountered several oil shows, as did other wells in this field.

The following analysis shows the character of the gas.

Analysis of Gas from Aztec No. 2 Well
Sec. 16, T. 30 N., R. 11 W.

Component	Percent
Carbon dioxide	0.52
Oxygen	3.30
Methane	63.53
Ethane	20.49
Nitrogen	12.16
	100.00

BARKER DOME AND SOUTHERN UTE DOME

The Barker and Southern Ute domes are located on the Southern Ute Indian Reservation near the north line of the State and west of the great hogback. (See map, Plate 7.) They lie about 19 miles north-northwest of Farmington. The surface rocks of the area belong to the Mesaverde formation and consist of beds of massive sandstone interbedded with shale and coal. The topography of the area is exceedingly rugged, with surface elevations ranging from 6,500 to 7,500 feet above sea level.

Barker dome, on the state line, has its crest in secs. 15 and 16, T. 32 N., R. 14 W. The dome has a structural closure of at least 300 feet with 19 or 20 square miles within the closing contour, of which approximately one-half is located in New Mexico, the rest in Colorado. The axis of the dome trends northeast and is crossed by one major fault just south of the crest.

A lease to acreage on the Barker dome was sold to the Gypsy Oil Co. (now Gulf Oil Corp., Gypsy Division) , which in 1925 completed a well on top of the structure through the Dakota to a total depth of 3,365 feet. The well found the top of the Dakota at 3,123 feet and was rated at 30,000,000 cubic feet of gas per day. Due to the lack of a market, the well was plugged in July, 1925, and the lease returned to the Ute Indians. A lease granted in 1930 to the Southern Union Gas Co. was also allowed to revert to the Indians.

A lease to the Southern Union Production Co. for 4,960 acres on the Barker dome was approved in November, 1941. A well was spudded in the same month in the NW$^1/_4$NW$^1/_4$ sec. 21, T. 32 N., R. 14 W., and drilled to a total depth of 2,495 feet. This well had an initial production of 15,000,000 cubic feet of gas per day from the Dakota sandstone, which was topped at 2,390 feet. At the total depth of 2,495 feet, water was encountered in the Dakota. From the data on this well, there seems to be about 250 feet of closure in the Dakota sandstone above the water level.

Southern Ute dome, located immediately southeast of the Barker dome, is crossed by several faults of considerable magnitude as shown by the accompanying map, Plate 7. The axis of this dome is essentially parallel to that of the Barker dome. The crest is located in secs. 35 and 36, T. 32 N., R. 14 W., and in secs. 1 and 2, T. 31 N., R. 14 W. Gas in large quantity has been proved by three wells drilled on top of the structure.

The Midwest Refining Co. (now Stanolind Oil and Gas Co.) in 1921 obtained a lease on certain lands on the Southern Ute dome from the Indians, and in October, 1921, completed its first well in the Dakota sand at 2,325 feet. This well was not properly completed, but was rated at 4,000,000 cubic feet of gas per day. Well No. 2, located in sec. 36, T. 32 N., R. 14 W., a short distance east of well No. 1, was completed in June, 1922, making 37,000,000 cubic feet of gas per day at a total depth of 2,428 feet. The Producers & Refiners Corp., drilling in the northwest corner of sec. 1, T. 31 N., R. 14 W., offsetting the Midwest No. 2 well to the south, completed a well at a total depth of 2,385 feet. This well tested 70,000,000 cubic feet of gas with a rock pressure of 700 pounds per square inch.

The Southern Ute wells were shut in until June, 1929, when the Southern Union Gas Co. completed a 32-mile, 6-inch pipe line from the field to Durango, Colorado. In November, 1932, the Southern Ute dome was connected with the Kutz Canyon field with 25 miles of 6-inch line, to help supply the Santa Fe-Albuquerque-Belen market. In 1941 nine miles of the Southern Ute-Kutz Canyon line was replaced by 8-inch pipe on the Kutz Canyon end, and the rest of the line was looped with 6-inch pipe.

Other wells will have to be drilled on the Southern Ute dome to determine whether the faulting has restricted the movement of gas through the structure. At the beginning of 1941 the field pressure was approximately 570 pounds per square inch.

Following are analyses of gas from the Southern Ute dome.

Analyses of Gas from Dakota Sandstone, Southern Ute Dome

Component	Midwest Refining Co. Well No. 1 Interval: 2190-2325 feet. (Percent)	Midwest Refining Co. Well No. 2. Interval: 2340-2428 feet. (Percent)
Methane	84.10	90.79
Ethane and heavier	14.97	8.18
Carbon dioxide	0.32	0.44
Oxygen	0.22	0.44
Nitrogen	0.38	0.20
Totals	99.99	100.05

The cumulative gas production from the Southern Ute dome through 1941 amounted to 7,379,000,000 cubic feet. The 1941 production was 910,000,000 cubic feet.

BEAUTIFUL MOUNTAIN ANTICLINE

The Beautiful Mountain anticline is located on the Navajo Indian Reservation in San Juan County, approximately 25 miles southwest of the town of Shiprock and six miles west of the Tocito dome. The structure is a long, relatively narrow anticlinal fold with its axis trending northerly. (See map, Plate 7.) The maximum closure probably does not exceed 150 feet. Along the axis there are apparently two high points separated by a low saddle, with the top of the Dakota sandstone exposed by erosion on the north high. The north high is located in secs. 28, 29, 32, and 33, T. 27 N., R. 19 W., and the south high in secs. 4 and 9, T. 25 N., R. 19 W. The axis bends slightly to the west between the two crests. The heart of the anticline is in a topographic basin, which is bounded on all sides by cliffs of the Tocito sandstone.

An exploratory lease on approximately 4,800 acres located on the south end of the structure was sold at Santa Fe, New Mexico, in October, 1923. The Navajo Co. was organized to develop the lease, and in 1925 this company completed a test to a depth of 3,290 feet near the south quarter corner of sec. 4, T. 25 N., R. 19 W. The well, which was located on the crest of the south high, penetrated the top of the Dakota, carrying fresh soft water, at 275 feet. At 1,727 feet the well had a fair showing of oil which had a gravity of 40° A. P. I., but no commercial oil or gas was developed. The hole was sold to the Navajo Indians as a water well. It flows unrestricted, with a few small globules of oil rising to the surface. The oil is thought to come from the 1,727-foot horizon.

In 1938 three major oil companies, acting as a unit, asked for a lease on this structure, but the Navajo Tribal Council did not grant the lease.

BILTABITO DOME

Biltabito dome, named after the Indian trading post on the northern rim of the structure, is in San Juan County near the west line of the State, about 46 miles nearly due west of Farmington. Biltabito is a Navajo Indian word meaning "spring under a rock."

The structure is a slightly elongated dome with a closure of about 400 feet to the syncline at the southwest. (See map, Plate 7.) The dome includes approximately 2,500 acres within the lowest closing contour. The crest of the structure is located in secs. 12 and 13, T. 30 N., R. 20 W. On all sides except the west, Morrison shale is exposed in the outcrops, with successively lower formations consisting of the Navajo, Todilto, and Wingate exposed towards the apex of the structure, where the base of the Wingate appears. It is estimated that the horizon in the Pennsylvanian which is productive on the Rattlesnake structure to the east can be reached on the Biltabito dome at a depth of approximately 4,150 feet, and that the sand which yielded a small amount of oil and gas in the Boundary Butte (Utah) well, some 30 miles to the northwest, should be reached at 1,000 to 1,200 feet.

Lands on the Biltabito dome are owned by the Navajo Indians, who in 1926 sold an exploratory lease of 3,120 acres on the structure to Eugene A. Stephenson for $5,100.00. No drilling has been done. A lease on the dome was sought in 1938 by three oil companies (Standard of California, Continental, and Stanolind) acting as a joint lessee, but the Tribal Council did not grant a lease. The structure deserves a test of the Pennsylvanian section.

BLANCO GAS FIELD

Several wells have been drilled in the vicinity of Blanco, about 10 miles east of Bloomfield in eastern San Juan County (see map, Plate 8), and small gas production has been developed. In 1925-27 (?) the Huntington Park Oil Co. drilled their No. 1 Goede in the NE¼SE¼SE¼ sec. 29, T. 30 N., R. 9 W., to 4,550 feet. This well encountered 200,000 cubic feet of gas per day in the Pictured Cliffs sandstone at 2,220-45 and 2,515-55 feet, and 600,000 cubic feet from the Mesaverde at 4,152-57 feet. The reservoir pressure of the Mesaverde gas zone was 1,200 pounds per square inch. Since 1929, gas from this well has supplied the town of Aztec through approximately 12 miles of 4-inch pipe line. Gas is taken from the Mesaverde pay in the winter and from the Pictured Cliffs during the summer.

In 1926-28 the Union Oil & Mining Co. completed their No. 2 Pine in SE¼SW¼ sec. 8, T. 29 N., R. 9 W., for 540,000 cubic feet of gas from the Mesaverde formation at 3,145-75 feet, after drilling to a total depth of 4,289 feet. Gas was also encountered in the Pictured Cliffs sandstone at 1,980-85 and 2,100-05 feet.

In 1932-33 Governador Drilling Co. completed their No. 1 Likins in the SW¼SE¼SW¼, sec. 33, T. 30 N., R. 9 W., for 215,000 cubic feet of gas from the Pictured Cliffs at 2,350-57 feet. The reservoir pressure was 720 pounds per square inch.

The following analysis shows the character of the gas.

Analysis of Mesaverde Gas from Huntington Park Oil Syndicate No. 1 Goede, Sec. 29, T. 30 N., R. 9 W.

Component	Percent
Carbon dioxide	0.39
Oxygen	0.93
Methane	69.80
Ethane	17.66
Nitrogen	11.22
	100.00

The gas production to the end of 1941 was 305,000,000 cubic feet, and 1941 production was 44,000,000 cubic feet. A small amount of oil has been produced from the Farmington sand in the Huntington Park well.

BLOOMFIELD POOL

The Bloomfield pool is in San Juan County in the broad valley of the San Juan River. (See map, Plate 8.) It surrounds the small town of Bloomfield, which is about 10 miles south of Aztec, the nearest railroad point, and 13 miles east of Farmington, the principal town of the San Juan Basin and the terminus of the Denver & Rio Grande Western narrow-gauge railroad from Durango, Colorado. The highways to these towns and to Albuquerque, New Mexico, are all good.

The surface rocks of the area belong to the Puerco and Torrejon formations, of Tertiary age. Production of both oil and gas is obtained from the Farmington sandstone member of the Kirtland shale of Upper Cretaceous age. This member, which is composed of lenses of sandstone and shale, is of fluviatile origin, and hence is quite variable in both composition and thickness. Although the member is persistent as a unit for several miles along its outcrop, many individual sandstone beds pass into shale within a few hundred feet.

The discovery well was completed by the Bloomfield Oil & Gas Co. in July, 1924, in the NW¼SW¼ sec. 14, T. 29 N., R. 11 W., and made three barrels of high-gravity oil daily at 719-37 feet. Since then some 30 small producers have been completed out of approximately 60 wells drilled to the Farmington sand. One well was completed for an initial production of 30 barrels per day, but most wells make only one to five barrels. Small amounts of gas occur in some of the oil wells, and one gas well was completed in the Farmington sand for 2,000,000 cubic feet.

It seems probable that the occurrence of oil and gas in the Bloomfield area is due to shale-sealed lenses of sand in the Farmington sandstone, as neither surface nor subsurface data indicate sufficient folding to explain the accumulation. According to Boyer and Hanson,[1]

> Where oil has been found in quantities sufficient for production, the drill has commonly released first gas, then oil, and finally salt water. Attempts to shut off the salt water have resulted in either shutting off the oil or diminishing its yield, and operation has shown that where the sand contains oil, it also carries salt water. Where wells have passed through the producing zone and have not found oil, salt water is also absent.

Some of the oil was originally used as a motor fuel as it came from the wells, but for the past few years a topping plant, with a daily capacity of 100 barrels, has been operated in the field. Gasoline produced by this plant is marketed in the surrounding area. The 1941 production was approximately one barrel per day from each of seven wells. The following analysis of a representative sample of crude oil is by the U. S. Bureau of Mines.

[1] Boyer, W. W., and Hanson, E. A., The Bloomfield Mesa oil and gas field: S. Geol. Survey Press Notice 4548, January 8, 1926.

Analysis of Bloomfield Crude Oil
Sample Number 25507

Harry E. Kauns No. 1	New Mexico.
West Coast Gasoline Co.	San Juan County.
700-712 ft.	Section 20, T. 29 N., R. 11 W.

General Characteristics

Specific gravity 0.751	A. P. I. gravity 56.9°
Percent sulfur less than 0.1	Pour point below 5° F.
Saybolt Universal viscosity at 100° F.,	Less than 32 sec.

Distillation, Bureau of Mines Hempel Method

Dry Distillation Barometer 740 mm. First drop: 48° C. (118° F.)

Temperature °C.	Per cent cut	Sum per cent	Sp. gr. of cut	°A. P. I. of cut	Viscosity at 100° F.	Cloud test °F.	Temperature °F.
Up to 50	---	---	---	----			
50 -75	3.3	3.3	0.686	74.8			
75 - 100	29.4	32.7	.720	65.0			
100 - 125	31.0	63.7	.744	58.7			
125 - 150	10.5	74.2	.760	54.7			
150 - 175	4.5	78.7	.770	52.3			
175 - 200	2.1	80.8	.778	50.4			
200 - 225	2.7	83.5	.784	49.0			
225 - 250	2.4	85.9	.794	46.7			
250 - 275	3.0	88.9	.807	43.8			

Carbon residue of residuum 4.8 per cent. Carbon residue of crude 0.1 per cent.

Approximate Summary

	Per cent	Sp. gr.	°A. P. I.	Viscosity
Light gasoline	32.7	0.717	65.9	
Total gasoline and naphtha	80.8	0.737	60.5	
Kerosene distillate	8.1	0.795	46.5	
Gas oil	---	----	---	
Nonviscous lubricating distillate	---	----	---	50-100
Medium lubricating distillate	---	----	---	100-200
Viscous lubricating distillate	---	----	---	Above 200
Residuum	10.4	0.928	21.0	
Distillation loss	0.7	----	---	---

An analysis of the gas follows.

Analysis of Gas from Bloomfield Oil & Gas Co.
No. 6 Chrisman, Bloomfield Poole

Component	Percent
Methane	69.90
Ethane	28.20
Oxygen	0.44
Carbon dioxide	0.59
Nitrogen	0.87
Total	100.00

[2] Initial production of this well was 1,000,000 cubic feet of gas and five barrels of oil per day.

BONITA (CATHEDRAL ROCK) ANTICLINE

The Bonita anticline is a relatively small dome-like structure located in the southwest part of T. 20 N., R. 10 W., McKinley County, some 10 miles south of Pueblo Bonita. The surface rocks belong to the Mesaverde formation, and they show a closure of approximately 50 feet with an area of nearly 1,000 acres inside the lowest closing contour. The structure is slightly elongated in an east-west direction and unfaulted. The highest point of the structure is located near the center of sec. 29, T. 20 N., R. 10 W.

In 1926-27, the Pittsburg Oil Development Co. (Benedum and Trees) drilled a well in the SW¼ sec. 30 to a total depth of 3,275 feet without obtaining commercial production. According to the log, a show of oil was encountered at 3,265-68 feet in sandy shale, and drilling was stopped in a hard sandy stratum at 3,275 feet without testing the Dakota.

CARICA ANTICLINE

The Carica anticline, in McKinley County, is a small east-west anticline formed in rocks of Mesaverde age and located in the center of T. 17 N., R. 7 W., nine miles east of the Hospah field. (See Plate 9.) The structure has a closure of a little over 50 feet, with its high point near the SW cor. sec. 9, T. 17 N., R. 7 W., and an area of approximately 400 acres within the lowest closing contour.

In 1927-28 the Continental Oil Co. drilled a test well to a total depth of 3,190 feet without finding oil or gas.

CHAVEZ (MIGUEL CREEK) ANTICLINE

The Chavez anticline is located on the Chavez and Tafoya grants in Tps. 15 and 16 N., R. 6 W., McKinley County, about 15 miles northeast of San Mateo village and 35 miles northeast of Grants. (See map, Plate 9.)

The structure has a closure of some 500 feet with approximately 13,000 acres inside the lowest closing contour. The axis extends in a general northeast direction from sec. 18, T. 15 N., R. 6 W., to the high point located in the NE¼ sec. 4 of the same township, then turns to the northwest through secs. 33 and 29, T. 16 N., R. 6 W. South of the crest of the anticline the structure is cut by a series of transverse faults of considerable magnitude. Sandstones and shales of the Mesaverde formation are the outcropping beds.

Prior to 1923 a test was drilled by Milholland et al. in the SE¼ sec. 8, T. 15 N., R. 6 W., to 1,540 feet. At this depth it was in the Dakota. In 1923 the Midwest Refining Co. drilled their No. 1 Chavez Grant in the NE cor. sec. 4, T. 15 N., R. 6 W., to a total depth of 2,154 feet. A show of oil was recorded at 725 feet. The Dakota, which was topped at 1,725 feet, carried water.

A third Dakota test was drilled in 1926 by the Marland Oil

Co. and Prairie Oil and Gas Co. in the SE¼NE¼SE¼ sec. 4, T. 15 N., R. 6 W., to a total depth of 1,772 feet. An oil show was encountered at 880 feet, and the Dakota, topped at 1,768 feet, was found to contain water.

CHIMNEY ROCK DOME

The Chimney Rock dome is located on the Navajo Indian Reservation, San Juan County, about 10 miles north of the San Juan River and approximately 25 miles northwest of Farmington. The structure is a much-faulted elongate dome with a closure of more than 100 feet. (See map, Plate 7.) The south end of the dome is truncated by a fault having a displacement of 50 to 80 feet. The Mancos shale, which is the surface formation, includes few marker beds, so that considerable difficulty was encountered in mapping the structure.

A lease on the Chimney Rock dome was purchased at the second sale of Navajo Indian leases in June, 1926, by the Marland Oil Co., which contracted with the Continental Oil Co. to drill a test well. This well, located in the SW¼SE¼ sec. 34, T. 31 N., R. 17 W., found the top of the Tocito sandstone at 605 feet, with a small flow of gas (estimated at 50,000 cubic feet) at 625 to 640 feet. The Dakota, which was topped at 1,425 feet, contained only sulfur water. In January, 1927, the well was abandoned at 2,002 feet without a showing of oil.

Because of the location of the well with reference to known faults, it is possible that additional holes will ultimately be drilled before this dome is finally abandoned.

In 1938 three companies, Standard of California, Continental, and Stanolind, tried to obtain a lease on this dome as a joint lessee, but the lease was not granted by the Navajo Tribal Council.

DULCE AND MONERO DOMES

In the vicinity of Dulce and Monero, Rio Arriba County, the sedimentary beds are folded and faulted, forming two rounded structures separated from each other by a faulted syncline. (See map, Plate 6.) The west dome, known as the Dulce dome, has a structural closure independent of the fault of more than 250 feet, while the east or Monero dome shows less than 100 feet of closure. The crest of the Dulce dome is located near the NE cor. sec. 22, T. 31 N., R. 1 W., and the highest point on the Monero dome is near the SE cor. sec. 13 of the same township.

Sandstones of the Mesaverde formation occur at the surface over the entire Dulce dome, and the Mancos shale below the Mesaverde is exposed on the Monero dome.

In 1925 Paul S. Ache drilled a test well in the NE¼NE¼ sec. 13, T. 31 N., R. 1 W., near the top of the Monero dome and found the top of the Dakota sandstone at 1,385 feet. The well was drilled to 1,515 feet and abandoned as a dry hole. In 1926

Ache and Co. drilled a second well to the Dakota near the fault on the east side of the Monero dome in the SW¼SW¼ sec. 17, T. 31 N., R. 1 E., without favorable results. The well was abandoned at 1,472 feet. These two wells constitute an adequate test of the oil possibilities of the Dakota sandstone on the Monero dome, but the lower formations are still untested.

In 1930 Jarvis Bennett et al. drilled a test on the northwest flank of the Dulce dome to a total depth of 2,536 feet, at which depth the well is believed to have been at the top of the "second Dakota." No production was secured. The well was located in the NE¼SW¼ sec. 8, T. 31 N., R 1 W.

The Dulce dome was tested near its crest in 1940 by L. M. Hughes and the Continental Oil Co. The well was located on the Jicarilla Indian Reservation at the center of the south line of the SE¼NE¼ sec. 22, T. 31 N., R. 1 W. The base of the Mesaverde was reported at 430 feet, and the top of the Dakota at 2,340 feet. The Dakota was found to carry water, and the well was abandoned at 2,373 feet.

EL VADO ANTICLINE

The El Vado anticline is located on the Tierra Amarilla Grant just east of the old lumber camp of El Vado and about 10 miles west of the town of Tierra Amarilla. Chama, 20 miles to the northeast on the Denver and Rio Grande Western narrow-gauge railroad, is the nearest rail shipping point. A good highway connects Chama with Tierra Amarilla and extends westward to the site of the El Vado dam of the Middle Rio Grande Conservancy District on the Chama River, near the south end of the structure.

Along the axis of the anticline are two rounded domes separated by a deep saddle (see map, Plate 6). Each dome is represented by a hill whose shape and size correspond to the configuration of the dome. Chama River cuts through the north dome in a narrow canyon, which is 400 to 500 feet deep at the axis of the structure. To the west of the anticline is a wide shale valley through which the Chama River flows after coming out of the canyon. The effective closure of the anticline is at least 500 feet, and the bottom of the saddle is about 400 feet below the apex of the north dome.

The Dakota sandstone outcrops over the crest of each dome, and the Mancos shale is exposed on all sides. In Chama Canyon, lower Dakota and underlying beds are exposed. Small faults were seen at a number of points cutting the Dakota, but none are of sufficient magnitude to affect the structure.

No wells have yet been drilled on the El Vado anticline, and the possibilities of finding commercial production are considered good. Possible producing sands include the Wingate, which contains oil at its outcrop five miles east of Chama and which yielded a small amount of oil of 40° A. P. I. gravity in the Beautiful

Mountain well on the west side of the San Juan Basin; the Poleo sandstone, probable equivalent of the Santa Rosa sandstone, which was found to be oil-bearing in the Boundary Butte well just west of the northwest corner of the State; and the Pennsylvanian, from which good commercial production of 40° A. P. I. gravity crude was obtained in the deep test on the Rattlesnake dome on the opposite side of the San Juan Basin. It is estimated that a well 6,000 feet deep would adequately test all of the formations which have oil and gas possibilities.

FRENCH MESA ANTICLINE

French Mesa anticline (see map, Plate 6) is an L-shaped structure located on the east rim of the San Juan Basin in Rio Arriba County northeast of Gallina post office and store. The area covered by the structure is exceedingly rough, with narrow hogback ridges on the west and high mesas cut by deep canyons on the east. Gallina River flows north along the west side of the anticline, and thence eastward around the north end to join the Chama River beyond the structure to the east. Topographic elevations range from 7,100 feet above sea level on Gallina River west of the anticline to over 9,000 feet on the high mesa just east of the axis and 6,300 feet on Chama River farther to the east.

The surface formations of the area include the Mesaverde, Mancos, Dakota, Morrison, Todilto, Wingate, Chinle, Poleo and underlying redbeds. The redbeds, which are of Permian age, are exposed in the deep canyon cutting nearly to the axis of the anticline from the west. The Dakota forms a steeply-dipping hogback on the west side of the structure near the Gallina River, caps the very high mesa east of the axis, and forms the long dip slope extending nearly to the Chama River to the east.

From the high point in sec. 26, T. 24 N., R. 1 E., the axis of the French Mesa anticline trends southwestward, and is represented by a fault having a displacement of approximately 1,000 feet where it crosses the outcrop of the Dakota sandstone. Northward from the apex the axis plunges to the Gallina River, which crosses the axis of folding in the saddle separating the French Mesa anticline from the Gallina Mountain anticline to the north. The French Mesa anticline has a closure of at least 800 feet and includes approximately 19,000 acres within the lowest closing contour.

In 1925-26 the Rio Chama Co. and the Continental Oil Co. drilled a well in sec. 25, T. 24 N., R. 1 E., to a depth of 3,355 feet. This well was located just east of the crest of the anticline and was started a few feet above the top of the Poleo sandstone. The well was abandoned because of mechanical difficulties before the Pennsylvanian series was penetrated sufficiently far to reach the horizon which was later found to contain commercial oil on the Rattlesnake dome to the west.

French Mesa anticline cannot be considered as having been completely tested until at least 1,000 feet of additional strata are penetrated by the drill. It is thought that the structure has good possibilities of commercial production from the Pennsylvanian horizon equivalent to that found in the Rattlesnake deep tests.

FULCHER BASIN FIELD

The Fulcher Basin gas field is located in the northeast part of T. 29 N., R. 12 W., four and one-half miles directly northwest of the Kutz Canyon gas field. (See map, Plate 8.) The field is two miles from the Southern Ute Dome-Kutz Canyon gas line, to which it is connected by a 3-inch line. The topography is rugged. Beds of the Puerco and Torrejon formations are at the surface over most of the area; however, on the western edge of the field the Ojo Alamo sandstone is exposed.

The discovery well, Fred Barrett et al. No. 1 Hart, in the SW¼NW¼SW¼ sec. 11, T. 29 N., R. 12 W., was completed in 1934. Initial production was 800,000 cubic feet of gas per day from the Pictured Cliffs sandstone at 1,709 to 1,740 feet. A total of seven wells has been completed, four of which were drilled in 1941. (See table, page 103.) A total of 580 acres has been proved productive.

In the fall of 1941, Carroll and Cornell No. 5 Santa Fe, located in the NE¼NE¼ sec. 13, T. 29 N., R. 12 W., was completed as the field's only oil well. It produced from the Farmington sandstone at 940 to 980 feet, the initial production being estimated at 25 barrels per day. In six months the production had declined to three or four barrels per day.

A summary of wells drilled in the Fulcher Basin field is given on the opposite page.

Samples below a depth of 400 feet have been examined from the Southern Union Production Co. No. 4 Santa Fe. The section from the surface to 400 feet is believed to include the Puerco and Torrejon formations and the upper part of the Ojo Alamo. The lower Ojo Alamo is shown by the cuttings to consist of conglomeratic sandstone with some pyrite, chert, and arkosic material, and a small amount of green shale.

The McDermott formation, next below, is represented by 50 feet of gray, light green, and purple shale, with considerable sandstone in the upper half.

A series of sandstones and shales makes up the Kirtland formation, which is 770 feet thick. Four major sand bodies are present, ranging from 80 to 150 feet in thickness. They carry considerable green shale and are cemented with calcareous material. The sand is angular and grades from fine to medium. The Farmington sandstone member, which occurs near the middle of the formation and carries oil in some areas, was not recognized in cuttings from the No. 4 Santa Fe. The shale throughout the

Wells Drilled in the Fulcher Basin Field

Company	Well	Location, ¼, Sec., T.-N., R.-W.	Elevation, Feet	Total Depth, Feet	Sand Interval	Initial Pressure, Lbs. per Sq. in.	Initial Production, Thousands Cu. Ft.	Date of Completion,
Carroll & Cornell	No. 1	NE-11-29-12	5,772	1,989	1,855-1,989	576	1,100	10-5-40
Carroll & Cornell	No. 2	NW-12-29-12	5,804	2,035	1,925-2,005	575	1,500	4-23-41
Carroll & Cornell	No. 5	NE-13-29-12	5,676	990	940-980[1]		25[2]	Fall 1941
Fred Barrett et al.	No. 1 Hart	SW-11-29-12	5,626 (Approx)	1,970	1,709-1,740	575[3]	800	4-5-34 (Discovery)
Southern Union Prod. Co.	No. 1 Reid	SE-13-29-12	5,572	1,766	1,665-1,675	584	496	10-27-40
Southern Union Prod. Co.	No. 2 Reid	NE-13-29-12	5,630	1,802	1,733-1,773	583	4,000	8-22-41
Southern Union Prod. Co.	No. 3 Reid	SW-12-29-12	5,718[4]	1,886	1,822-1,852	592	1,300	2-21-41
Southern Union Prod. Co.	No. 4 Reid	SW-12-29-12		1,954	1,875-1,915		2,300	7-30-41
Southern Union Prod. Co.	No. 1 McDaniels	NE-19-29-11	5,523	1,820	1,675-1,689	575	1,070	10-15-41
Summit Oil Co.	No. 3 Government	SE-20-29-11	5,540	1,825	1,685-1,705		1,000[5]	12-19-41

[1] Farmington sandstone.
[2] Estimated production of oil in barrels.
[3] Pressure taken December 9, 1937.
[4] Derrick floor.
[5] Estimated production.

Kirtland is predominantly green, except at the base where some gray to black shale, with streaks of coal, is present.

The Fruitland formation, about 400 feet thick, consists chiefly of gray, green, and black shales, with a 100-foot sandy zone near the middle of the section. Coal is present in thin beds throughout the formation. Commercial coal is obtained from the Fruitland outcrop west of the town of Farmington.

Samples of only the upper 20 feet of the Pictured Cliffs sandstone were obtained. They show friable sandstone consisting of angular grains of medium size.

No structure other than a gentle dip to the northeast has been determined. The reservoir seems to be a stratigraphic trap similar to that at the Kutz Canyon field and is along the strike of the formations from that field. The area between the Fulcher Basin and Kutz Canyon fields has not been tested to the Pictured Cliffs sandstone. However, development in the latter part of 1941 proved Pictured Cliffs gas production in secs. 19 and 20, T. 29 N., R. 11 W. showing a two-mile southeast extension of the Fulcher Basin field. This leaves an undrilled gap of a little over two miles between the two fields. Drilling and production practice at Fulcher Basin has been similar to that at Kutz Canyon. The average initial casinghead pressure is 580 pounds per square inch. The initial daily production ranges from 500,000 to 4,000,000 cubic feet. The production to the close of 1941 amounted to 635,000,000 cubic feet, and 1941 production was 418,000,000 cubic feet. An analysis of the gas follows.

Analysis of Gas from Pictured Cliffs Sandstone, Fred Barrett et al. No. 1 Hart, Fulcher Basin Field

Component	Percent
Methane	62.7
Ethane	21.4
Nitrogen	15.9
Carbon dioxide	0.0
Oxygen	0.0
	100.0

The basal Fruitland formation carries salt water immediately below the lowest coal bed and just above the gas pay, as it does at Kutz Canyon. This water correlates with the water from the Kutz Canyon field, but shows about fifty percent dilution. The following water analysis may be compared with the analysis given on p. 114.

Analysis of Water from Basal Fruitland Formation,
Southern Union Production Co. No. 3 Reid, Fulcher Basin Field

Substance	Parts per Million	Reacting Value	Percent Reacting Value
Na	11,608	504.96	47.32
Ca	355	17.72	1.66
Mg	132	10.85	1.02
SO_4	0	0	0
Cl	18,603	524.67	49.17
CO_3	37	1.23	0.11
HCO_3	465	7.63	0.72
Totals	31,200		100.00

GALLINA MOUNTAIN ANTICLINE

The Gallina Mountain anticline is situated in T. 26 N., R. 2 E., Rio Arriba County, between the El Vado anticline on the north and the French Mesa anticline on the south. (See map, Plate 6.) The structure is a rather long narrow uplift with its axis passing just east of Gallina Mountain at the north end. The area is exceedingly rough, and no detailed structure map is known to have been made. The Dakota sandstone and overlying formations which surround the anticline have very steep dips, especially on the west side. It has been reported that the top of the Pennsylvanian limestone series is exposed in the heart of the anticline. This fact would make possible a complete test by drilling a well approximately 2,500 feet deep. The construction of a road several miles long to a proper drilling site would be quite expensive.

HOGBACK FIELD

The Hogback field, in San Juan County, is located in secs. 18 and 19, T. 29 N., R. 16 W., near the eastern edge of the Navajo Indian Reservation and on the crest of a pronounced structure known as the Hogback dome. (See map, Plate 7.) The field proper lies south of the San Juan River and west of the ridge known as the hogback. In an air line the field is approximately 22 miles west of Farmington, the terminus of the Denver & Rio Grande Western railway. The field is reached by a road from Shiprock, about 10 miles to the northwest.

The Midwest Refining Co., after negotiating a lease on certain lands on the Hogback dome with the Tribal Council of the Navajo Indians, spudded-in the first well on August 25, 1922. Drilling was completed on September 25, 1922, at 796 feet, where a flow of 375 barrels of high-gravity oil was found in the Dakota sand. Following this discovery 15 additional wells were drilled, which included 12 by the Midwest Refining Co., two by R. D. Compton, and one by the Santa Fe Mutual Co.

The table, page 106, taken from the report by K. B. Nowels,[1] gives a summary of drilling operations on the Hogback dome.

[1] Nowels, K. B., Development and relation of oil accumulation to structure in the Shiprock district of the Navajo Indian Reservation, New Mexico: Bull. Amer. Assoc. Petrol. Geol., Vol. 13, No. 2, p. 123, February 1929.

Summary of Drilling, Hogback Field

Well No.	Location, ¼, Sec., T.-N., R.-W.	Elevation, Feet.	Depth to Top of Sand, Feet.	Total Depth, Feet.	Production, Barrels.
			Midwest Refining Co.		
1	NE 19-29-16	5,133	722	988	375 oil. Pay cemented off; using as water well.
2	NW 19-29-16	5,132	785	795	1, 276 oil.
3	NW 20-29-16	5,061	1,003	1,225	3,000 sulfur water from Dakota. P. & A.
4	NW 19-29-16	5,132	837	842	1,200 sulfur water when drilled; now capable of making 5 to 10 oil.
5	SE 19-29-16	5,125	760	763	Estimated 1,200 oil when drilled; now producing a little water.
6	SE 19-29-16	5,126	771	783	Estimated 60 oil, 300 water; P. & A.
7	NE 19-29-16	5,003	647	657	1,200 oil.
8	SE 18-29-16	5,029	679	684	500 oil.
9	NE 19-29-16	5,004	633	647	212 oil.
10	NE 19-29-16	5,008	650	664	20 oil. P. & A.
11	NE 19-29-16	5,035	668	677	110 oil.
12	NE 19-29-16	5,134	774	776	656 oil. Small amount water.
13	19-29-16		773	997	100 water.
			R. D. Compton		
1	NE 30-29-16	5,125	892	925	500 water.
2	SE 13-29-17	5,081	776	799	Sulfur water. P. & A.
			Santa Fe Mutual Co.		
1	NE 13-29-17	5,090	823	1,965	Big flow sulfur water, from Dakota. P. & A.

To January 1, 1942, the Hogback field had produced 2,097,982 barrels of oil, representing a recovery of 13,112 barrels per acre from the 160 acres proved productive. In 1924 the Midwest Refining Co. completed a 3-inch welded pipe line from the Hogback field to Farmington, where the oil was loaded into tank cars for shipment to the refinery of the Utah Oil Refining Co., at Salt Lake City, Utah. However, at present the entire production is being processed in the Continental Oil Co.'s refinery at Farmington.

The Mesaverde formation is exposed in the hogback east of the structure, where it consists of resistant sandstones, shale, and coal. This formation dips steeply into the San Juan Basin.

The Mancos shale, having a total thickness of approximately 2,000 feet, forms the surface of the Hogback dome. The Mancos is composed essentially of drab shale with a few thin limestone beds and one thick sand zone about 750 feet above its base. This sand, known as the Tocito sand, forms the surface over the heart of the structure except where eroded through by the Chaco River, which crosses the structure from east to west just north of the high point.

The Dakota, from which production is obtained, is composed of alternating beds of sand and shale with some coal seams, and has a total thickness of approximately 200 feet.

Below the Dakota is the Morrison formation, largely shale, which has been reached in only two wells on the Hogback dome. Drilling has not explored the formations below the top of the Morrison.

The configuration of the Hogback dome, as shown by detailed mapping of the surface beds, is shown on the accompanying map, Plate 7. The dome is asymmetric, with very steep dips to the east into the San Juan Basin and moderate dips in all other directions. The structure has an area of about 20,000 acres within the closing contour, of which only approximately 160 acres has proved productive. The total closure is about 200 feet.

A single fault has been mapped. This is shown in the canyon wall near the No. 1 well, where a small displacement is visible in the Tocito sand.

Very high-grade oil, having an average gravity of 63° A. P. I., is obtained from the Dakota sand, but no gas accompanies the oil. Pressure is entirely hydrostatic, and the oil comes to the surface and flows gently over the top of the casing. Some of the wells, if allowed to flow unrestricted, make small quantities of water, and hence a back pressure is held on the wells. The No. 4 well originally found only bitter sulfur water in the Dakota, but after being allowed to flow unrestricted for several months it began producing up to 10 barrels of oil per day with the water. The present withdrawals have been closely regulated to maintain flowing pressures. When a shut-in well that had gone to water was recently allowed to flow unrestricted for a few days, the hydrostatic pressure was sufficiently reduced to cause a sharp drop in the oil production.

An analysis of the oil is given below.

Analysis of Crude Oil from the Hogback Field

Gravity	60.0° A. P. I.
Pour point	Below 5° F.
Color	Green
Saybolt Universal viscosity at 100° F.	30 sec.
Base	Less than 0.1 percent
Sulfur	Paraffin

Distillation

First drop -- 82.4° F.

Fraction	Percent
Gasoline and naphtha	74.5
Kerosene	13.3
Gas oil	6.0
Nonviscous lubricating distillate	4.4
Residuum	1.7
Distillation loss	0.1
	100.0

In wells in the Hogback field, three joints of conductor pipe are cemented through the Tocito sand. The oil string is cemented on top of the Dakota.

HOSPAH DOME

The Hospah field is located in sec. 1, T. 17 N., R. 9 W., and sec. 36, T. 18 N., R. 9 W., McKinley County. (See map, Plate 9.) It lies 38 miles north of the town of Prewitt, from which it can be reached by a graded road. The field is on the Continental Divide at an elevation of approximately 6,700 feet, and is typical of the high semi-arid Rocky Mountain region.

In 1925-26, Hurst, Welch et al. drilled their No. 1 Santa Fe (or No. 1 Hurst) in sec. 1, T. 17 N. R. 9 W., to 1,405 feet. This well was taken over in 1927 by the N., Refining Co., carried to a total depth of 1,610 feet, and completed for eight barrels of oil per day at 1,573 to 1,590 feet.

Two other oil wells were completed in the fall of 1927. One of these, the Midwest Refining Co. No. 2 Santa Fe (or No. 1 Hancock), was drilled to 3,282 feet. The Dakota, which was topped at 2,990 feet, carried water. The well was plugged back to 1,564 feet and completed for an initial production of 161 barrels of oil per day.

After completing three oil wells, the Midwest Refining Co. suspended development of the field. The present operating company is the Petroleum Products Corp. It was organized in 1938 and purchased the leases on the Hospah dome held by the Stanolind Oil and Gas Co. (formerly Midwest Refining Co.). These leases are on land owned by the State of New Mexico and the Santa Fe Pacific Railroad Co. The Petroleum Products Corp. had completed 24 wells by June, 1942. The three original wells are still producing.

Early in 1940 the Petroleum Products Refinery Co. completed a refinery at Prewitt to handle the Hospah crude oil. This refinery is a combination skimming and cracking plant with a daily capacity of 1,500 barrels.

The surface of the Hospah dome is underlain by the Mesaverde formation, and the producing zone, which is known as the Hospah sand, is a member of the same formation. The Dakota, which has been reached in one well, is the lowest formation that has been tested.

The Hospah structure is an elongated anticline, with its high point in the south central part of sec. 36, T. 18 N., R. 9 W., and the north central part of sec. 1, T. 17 N., R. 9 W. (See map, Fig. 3.) It has a closure of approximately 50 feet over an area of about 350 acres. A major fault trending in a northeast direction cuts the south end of the structure. The fault is about one-half mile southeast of present production, and evidently does not cut the Hospah sand within its present productive area.

Development has shown the producing sand on the top of the structure to have a thickness of approximately 40 feet. The upper 25 feet or more is a solid sand body, while the lower 15 feet carries shale. Well No. 9 indicated the presence of considerable shale in the productive zone in the southeast part of the field. The oil sand is uniform, clean, medium- to fine-grained, firm, and well saturated. Tests show 30 to 40 percent oil, 50 percent connate water, and 10 to 20 percent loss which probably represents the lighter fractions of the oil plus shrinkage.

Analyses of Cores from Petroleum Products Corp.
No. 11 Santa Fe, Hospah Field

Sample Number.	Depth, feet.	Porosity, percent.	Saturation, percent. Water.	Oil.	Permeability, Millidarcys. Horizontal	Vertical
1[1]	1,525	27.2	4.1	40.7	180	210
2	1,528	31.1		28.5	56	48
3	1,531	24.8		38.4	33	33
4	1,533	27.1		55.5[2]	615	697
5[3]	1,543	20.5	52.6	39.07	398	152

The above core analyses were made on a representative core of the sand body. The samples used were from a complete core recovery, but about 10 percent of the core, which represented bleeding "soft spots," was not included.

All wells except the first three have been drilled with a combination drilling machine. One joint of surface pipe is set, and a 7-inch oil string is cemented at the top of the sand. The present practice is to equip each well with a small pumping unit.

Originally the fluid in the wells stood at the ground level. Due to heavy withdrawals by a water well from the producing sand below the edgewater line, the fluid level has been lowered. Only a small amount of water has been produced, and no sand trouble has been experienced. A small amount of paraffin accumulates but has given no serious trouble.

[1] Tests on samples 1 to 4 made by the Petroleum Engineering Department, University of Texas.
[2] The sample was extremely difficult to handle, and this figure may be unreliable.
[3] Tests made by Grayden Oliver Laboratory, Los Angeles, California.

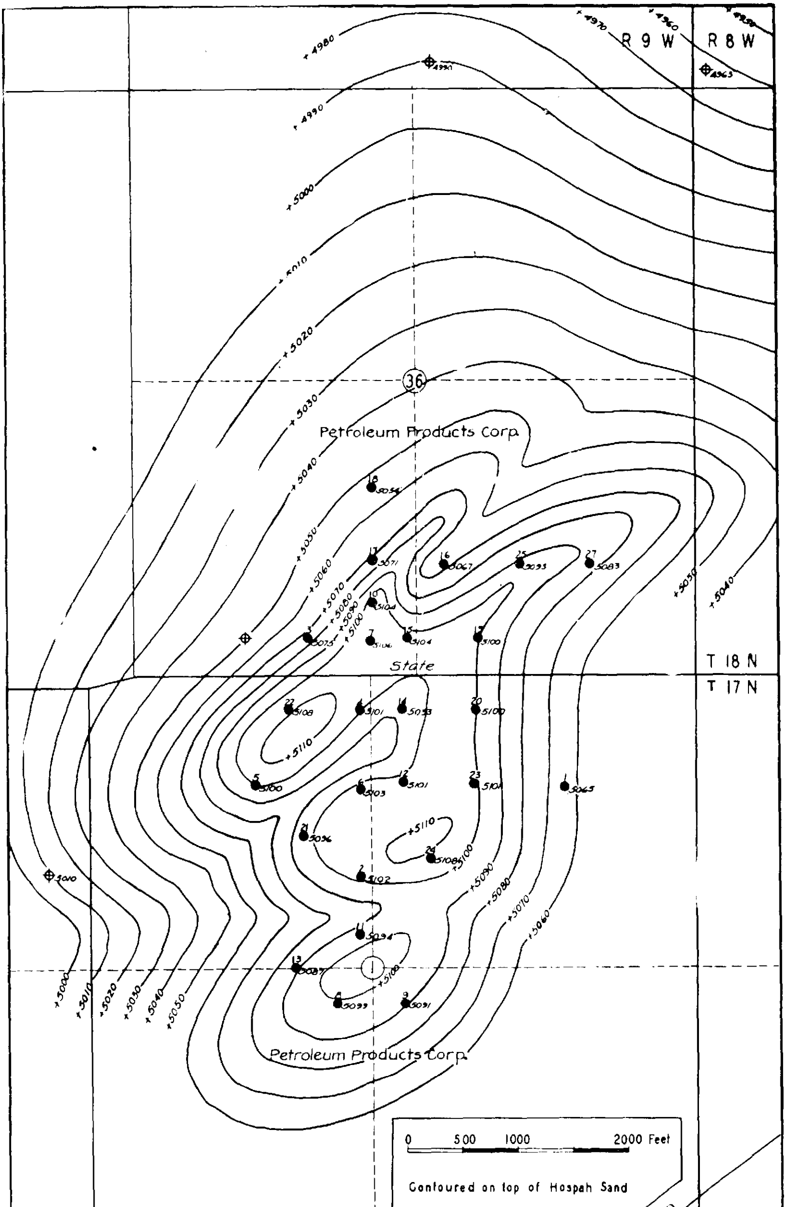


Figure 3.-Subsurface contour map of the Hospah dome, McKinley County

The wells produce very little gas with the oil the quantity is insufficient for a dependable lease fuel. An analysis of the oil is given below.

Analysis of Crude Oil[4] from the Hospah Sand, Hospah Field

Gravity	30.2° A. P. I.
Pour point	20° F.
Color	Green
Sulfur	0.25 percent
Saybolt Universal viscosity at 100° F.	67 sec.
Base	Intermediate

Distillation

First drop	142° F.

Fraction	Percent
Gasoline and naphtha	18.5
Kerosene	3.7
Gas oil	17.0
Nonviscous lubricating distillate	12.3
Medium lubricating distillate	10.1
Residuum	38.2
Loss	0.2
Total	100.0

Hospah field production to the end of 1941 is as follows:

Production from the Hospah Field

Year	Production in Barrels Yearly	Cumulative
1937	5,407[5] 2,704[6]	8,111
1938	4,388	12,499
1939	19,708	32,207
1940	163,781	195,988
1941	194,133	390,121

Lease storage consists of two 5,000-barrel bolted steel tanks and two 10,000-barrel welded tanks. The oil was at first transported by trucks to the refinery at Prewitt. However, at the end of 1941 the Petroleum Products Pipe Line Co. completed 32 miles of 4-inch pipe line to connect the Hospah field with the refinery. This line operates at a pressure of 450 pounds per square inch at the field end and has a daily capacity of 1,000 to 1,500 barrels.

KUTZ CANYON FIELD

The Kutz Canyon gas field, in San Juan County, is located south of Bloomfield and across the San Juan River. (See map, Plate 8.) The original Kutz Canyon wells, which were drilled

[4] Sampled in 1933.
[5] In storage on October 1, 1937.
[6] Production for November and December, 1937.

about two miles south of Bloomfield, mark the northwestern edge of the field. Development has been to the southeast until the field is over four miles long, and about a mile wide through the central part. The field derives its name from Kutz Canyon which enters the valley of the San Juan River just below Bloomfield. The topography is rugged, and elevations range from 5,500 to 6,000 feet. The Puerco and Torrejon formations form the surface beds and the productive formation is the Pictured Cliffs sandstone of Cretaceous age.

The discovery well was completed in 1927 by the Congress Oil Co. in sec. 34, T. 29 N., R. 11 W., at a depth of 1,910 feet for 1,500,000 cubic feet of gas. Up to July 1, 1941, 20 wells had been completed in the field either as producers or as dry holes with shows.

The table on page 113 gives the wells drilled to the Pictured Cliffs formation in and adjacent to the Kutz Canyon gas field and shows some data on each.

An initial production of 4,000,000 cubic feet per day, which would not be considered large in many gas areas, is about the maximum for the Kutz Canyon field. This low initial production rate indicates low permeability, as does the fact that wells drilled only one-half mile from wells that have been producing for three or four years show approximately the original gas pressure. Evidence as to porosity and permeability is necessarily indirect, as no cores have been obtained.

There is no evidence of a closed structure on the top of the gas sand, and only a gentle north-northeast dip. The Pictured Cliffs sandstone, which has a total thickness of 150 to 200 feet over the area, is composed of several sand members separated by shale. The lack of closure makes it necessary to assume that the accumulation is caused by a stratigraphic trap. The trap may be due to large sand lenses, sealed by shale, or to differential permeability within a continuous sand body. Numerous scattered wells in the basin have recorded gas shows in the Pictured Cliffs sandstone, and it may be necessary to find only a permeable zone in order to complete a commercial gas well in this formation. No reversal in the dip of the sand is known to exist between the field and the Pictured Cliffs outcrop on the San Juan River some 30 miles to the west; to date, no water has been reported in the sand.

Most of the wells have been drilled with cable tools, and 30 days is considered good completion time. The formations are not hard to drill, but some of the shales have a tendency to cave. When caving develops, a temporary string of casing is usually run to hold the shale. The casing program generally requires four strings, two of which are pulled upon completion of the well. This leaves surface pipe and pay string; the latter is usually 6¼-or $6^5/_8$-inch. A salt-water sand in the lower Fruitland formation is separated from the Pictured Cliffs gas pay by a shale break, and a good cement job must be obtained to shut off this water.

Wells Drilled to the Pictured Cliffs Sandstone in the Kutz Canyon Area

Company.	Well No.	Lease.	Location ¼, Sec. T.-N., R.-W	Elevation, Feet.	Total Depth, Feet.	Sand.	Initial Pressure, Lbs. per Sq. In.	Initial Production, Thousands Cu. Ft.	Completion Date and Remarks
Congress Oil Co.	1		SE 34-29-11	5,628	1,910	1,728-1,910	560	1,500	11-25-27
Congress Oil Co.	2		SE 34-29-11	5,619	1,794	1,725-1,736	555	3,210	5-15-31
Congress Oil Co.	2	Lachman	NW 18-28-10	5,809	2,015	1,904-2,012	569	439	11-9-39
Summit Oil Co.	1		SW 34-29-11	5,658	2,002	1,750-1,930	560	3,000	7-28-28
Summit Oil Co.	2		NW 34-29-11	5,622	1,860	1,725-1,745+	570	1,250	6-2-31
Angels Peak Oil Co.	2-S		Lt 1 11-28-11	5,732	3,057	1,820-1,967		Show gas	3-6-30; P. & A.
Angels Peak Oil Co.	3		Lt 1 11-28-11	5,732	1,973	1,827-1,973	54	1 500	3-19-30
Angels Peak Oil Co.	4		SE 11-28-11	5,688	1,880	1,786-1,880	555	4,000	11-25-30
Angels Peak Oil Co.	5		Lt 3 11-28-11	5,690	1,895	1,782-1,880	555	2,000	12-20-30
Angels Peak Oil Co.	6		Lt 2 11-28-11	5,676	2,340				P. & A.
Angels Peak Oil Co.	8		SW 13-28-11	5,841	1,955	1,888-1,940	513	1,800	11-25-39
Angels Peak Oil Co.	9-B		NW 24-28-11	5,787	1,893	1,814-1,875	520	3,150	3-8-40
Angels Peak Oil Co.	10-B		SE 24-28-11	5,834	2,074	1,849-1,872	545	1,580	4-24-40
Angels Peak Oil Co.	11-B		SE 25-28-11	5,854	2,060	1,884-1,888	573	94	6-29-40; P. & A.
Kutz Canyon 0. & G. Co.	1		SW 20-28-10	6,008	4,400	1,991-2,063	525	475[1]	11-12-36
Southern Union Prod. Co.	3		NW 14-28-11	5,522	1,725	1,596-1,658	600	500	6-24-30
Southern Union Prod. Co.	4		NE 14-28-11	5,740	1,940	1,780-1,940	517	4,030	12-23-35
Southern Union Prod. Co.	5		NE 14-28-11	5,761	1,973	1,815-1,884	500	2,500	8-10-36
Southern Union Prod. Co.	6		SE 14-28-11	5,819	1,882	1,833-1,865	495	1,580	12-20-39
Southern Union Prod. Co.	2	Brink	NW 19-28-10	5,890	2,065	1,925-1,972	575	880	6-20-36
Milwaukee N. M. Synd.	1		NE 30-28-11	5,960	2,005	1,765-1,870		250	8-24-35; P. & A.

[1] Test December, 1937.

The wells are completed with one-inch tubing running to bottom so that they may be blown dry of condensate that accumulates.

A typical analysis of the water found in the Fruitland formation is given below.

Analysis of Water from. Base of Fruitland Formation, Kutz Canyon Gas Field

Substance	Parts per Million	Reacting Value	Percent Reacting Value
Na	21,067	916.39	44.69
Ca	1.404	70.08	3.42
Mg	472	38.81	1.89
SO_4	49	1.02	0.05
Cl	36,180	1,020.57	49.77
HCO_3	225	3.69	0.18
Total	59,397		100.00

Following is a fractional analysis of the gas:

Fractional Distillation of Gas from the Kutz Canyon Field[1]

Component	Mol Percent	Weight Percent	Gasoline Gal. per Thousand Cu. Ft.
Non-condensable nitrogen	0.15	0.22	
Methane	89.74	78.06	
Ethane	6.17	10.07	
Propane	2.18	5.21	
Iso-butane	0.41	1.28	0.132
Normal butane	0.65	2.05	0.205
Pentanes and heavier	0.70	3.11	0.282
Total	100.00	100.00	0.619[2]

At the end of 1941 the cumulative gas production amounted to 12,958,000,000 cubic feet and the reservoir pressure was approximately 420 pounds per square inch. The production during 1941 was 1,983,000,000 cubic feet.

A 10- and 12-inch gas line runs from the Kutz Canyon field to Albuquerque, with an 8-inch side line to Santa Fe and a 5½-inch extension to Belen. A 4-inch line from the field serves the town of Farmington.

A booster station with a 400-horsepower compressor unit was installed in the Kutz Canyon field in 1938. In the late summer of 1939 a second 400-horsepower unit was installed, and in the summer of 1941 a 600-horsepower Clark unit was added. The gas is discharged from the booster station at 300 to 500 pounds per square inch into a diethylene glycol dehydrator to remove moisture before the gas passes into the main line. Considerable "drip" gasoline is recovered from drip tanks placed in the gas line. During one month in the spring of 1941, 16,000 gallons of "drip" gasoline was recovered.

[1] Analysis made by C. F. Braun & Co., Inc., Alhambra, California.

[2] Finished product will run less due to light fractions.

OSWELL FIELD

Several wells have been drilled by R. C. Oswell (Anna Oil Corp.) on the west side of the NW¼ sec. 34, T. 30 N., R. 11 W. (see map, Plate 8), and a small amount of 55-57° A. P. I. crude has been produced. This area, locally known as the Oswell field, is west of the Aztec-Bloomfield road about four miles south of Aztec. The first production was obtained in 1931 in the R. C. Oswell No. 2 well, which was bottomed at 1,455 feet in sand and made 25 barrels of oil per day.

The productive zone is in the Farmington sandstone. It is very lenticular, and offset wells may produce from different levels. Three oil wells have been brought in, at initial productions of about 25 barrels per day. One well also showed 800,000 cubic feet of gas. A small gas well in the south part of sec. 34, and another in the southwest corner of sec. 27, limit present production on the north and south sides of the field.

Water and oil analyses follow.

Analysis of Water from Farmington Sand in R. C. Oswell No. 2 Well, Sec. 34, T. 30 N., R. 11 W.[1]

Substance	Parts per Million	Reacting Value	Percent Reacting
HCO_3	7,272	316.32	42.66
Na	1,032	51.51	6.95
Ca	35	2.88	0.39
Mg	None	None	None
SO_4	13,122	370.14	49.92
Cl	35	0.57	0.08
Totals	21,496		100.00

Analysis of Crude Oil from the Oswell Field

Gravity --57.4° A. P. I.
Pour point ---------------------------------------Below 5° F.
Color ---Green
Base --Paraffin
Sulfur --Less than 0.1 percent
Saybolt Universal viscosity at 100° F. ------31 seconds

Distillation

First drop ---------------------------78.8° F.

Fraction	Percent
Gasoline and naphtha	85.5
Kerosene	6.3
Residuum (gravity 34.0° A. P. I.)	7.5
Distillation loss	0.7
Total	100.0

[1] Initial production, 25 barrels of oil and five barrels of water. Production at time of sampling, trace of oil and 50 barrels of water.

RATTLESNAKE FIELD

LOCATION

The Rattlesnake field is located on the Navajo Indian Reservation about eight miles west and a little south of the town of Shiprock. The conspicuous landmark known as Ship Rock is approximately three miles southwest of the field. (See maps, Plate 7 and Fig. 4.) Farmington, the nearest railroad point, is about 40 miles to the east at the terminus of the Denver & Rio Grande Western narrow-gauge line. Gallup, on the main line of the Atchison, Topeka & Santa Fe Railway, is approximately 100 miles to the south. A paved highway extends from Gallup to Shiprock.

HISTORY

A reconnaissance survey of the Rattlesnake structure was made several years before the lands were made available for drilling through the action of the Navajo Indian Tribal Council. On October 15, 1923, an exploratory lease amounting to 4,080 acres was offered for sale at public auction held at Santa Fe, New Mexico. After having been passed without a bid in the forenoon, the lease was again offered in the afternoon and purchased by S. C. Munoz for $1,000.00. Mr. Munoz organized the Santa Fe Co. for the development of the property, with Dean E. Winchester acting as consulting geologist. Arrangements were made with the Producers & Refiners Corp. to drill four wells to test the Dakota sand before starting a deep test called for by the terms of the lease. All drilling materials, casing, camp equipment, etc., had to be hauled from Gallup over 100 miles of road which was next to impassable at times. As far as possible Indian laborers and teams were used in transporting casing and materials. The first well, using standard derrick and equipment as demanded by the lease, was completed as a small producer on February 27, 1924, just a little over five months after the lease sale and only 37 days after the drilling contract was signed with the Producers & Refiners Corp. Late in the fall of 1924 the Continental Oil Co. acquired an interest in the property and has since been in charge of its operation. Prior to January 1, 1942, 106 wells had been drilled to test the shallow Dakota sands, and three deep tests to the Pennsylvanian had been completed. On June 25, 1941, the Continental Oil Co. obtained a lease on an additional 3,720 acres from the Navajo Indians. A bonus of one dollar per acre was paid for the lease with yearly rentals of $1.25 per acre. The lease was taken after considerable geophysical work had been completed over the Rattlesnake structure. A fourth deep test is to be drilled on the new acreage.

Early in 1925 a 2-inch pipe line was laid 13 miles to connect with the Midwest Refining Co.'s 3-inch line from the Hogback field to Farmington, and a 750-barrel refinery was built at Farmington. During the summer of 1926 a 4-inch pipe line 96 miles long was built to Gallup, where the oil was delivered to standard-gauge tank cars for transportation to refineries. Deliveries through the pipe line to Gallup were suspended in July, 1940, due to insufficient crude-oil production. However, the pipe line has been maintained, and may be placed in service again if production from this part of the San Juan Basin should increase in the future. Oil now produced from the Rattlesnake field is delivered to the Continental Oil Co.'s refinery at Farmington.

STRATIGRAPHY

CRETACEOUS

Mancos formation.—At the surface is the Tocito sandstone member of the Mancos formation. The sandstone, which is 60 to 80 feet thick, is shaly and contains shale partings. The remainder of the Mancos below the Tocito consists of drab shale, with a few thin limestones, to a thickness of 750 feet.

Dakota sandstone.—This well-known and widely distributed formation is 215 to 225 feet thick at Rattlesnake. It contains three sandstone units separated by beds of shale. Any one or all three of the sandstones may contain oil or water. In some places coal is present in the shale zones.

PRE-CRETACEOUS

JURASSIC

Morrison formation.—The upper part of the Morrison contains dark-gray sandy shale and fine argillaceous sandstone. A white and buff sugary sandstone, with considerable greenish shale, makes up the middle part of the formation. The lower 200 feet contains some sandy red shale and fine red sandstone. Small amounts of dense sandy limestone at the base may represent the Pony Express limestone of southwestern Colorado. Total thickness of the Morrison is about 600 feet.

San Rafael group.—A section of red shale and dark-gray micaceous shale 60 feet thick is thought to represent the Entrada and Carmel formations, which crop out on the San Rafael Swell in southeastern Utah and have a regional distribution.

Navajo sandstone.—Buff coarse sandstone, with subordinate amounts of dark fissile gray shale and fine red sandstone, makes up the Navajo formation. It is 70 feet thick.

Kayenta formation.—This formation contains dark red sandy shale and dark gray shale to a thickness of 70 feet.

Wingate sandstone.—The dominant constituent of the Wingate is bright red and orange sandstone which varies from fine

[1] This discussion, by C. E. Needham and Robert L. Bates, is based on a study of cuttings from the Continental Oil Co. No. 100 Navajo, 7,407-foot test in the northern part of the field.

to coarse. Minor amounts of dark red and gray sandy shale are present. A thickness of 570 feet is assigned to the Wingate.

TRIASSIC

Chinle formation.—This formation, which is 1,400 feet thick, consists chiefly of red shale, most of which is dark and sandy. Some gray and green shale and fine orange sandstone are present.

In the upper half of the formation is a 300-foot zone of pink and red dense argillaceous limestone and pink calcareous shale. Although this is a prominent feature of the upper redbed section in the Continental No. 100 Navajo, it apparently has received no name and is not known at the surface. It may be a nodular freshwater limestone of the type found in Triassic redbeds in other parts of New Mexico. That such beds are present is indicated by the finding of a thin bed of pink calcareous conglomerate in the red shale 200 feet below the base of the thick limestone.

PERMIAN

Coconino sandstone.—This formation of the Colorado Plateau region may be represented by abundant frosted quartz grains which are very large, loose, yellow, and subangular to round. They occur through a thickness of 150 feet. Evidence as to their mode of occurrence was afforded by a fragment of buff medium-grained sandstone in which one of the very large frosted quartz grains was embedded. Other evidence as to host rock or cementing material is lacking. The quartz grains are accompanied by much gray and red shale.

Cutler formation.—Red shale and fine red micaceous sandstone are the chief constituents of the Cutler formation. Considerable gray sandy shale is found in the upper half. In the lower half are traces of anhydrite intergrown with red shale, and small amounts of brown dense limestone with anhydrite inclusions. The thickness of the Cutler is 1,410 feet.

PENNSYLVANIAN

Hermosa formation.—The Hermosa is chiefly dense gray limestone, with a few thin beds of gray calcareous sandstone. The limestone contains chert, oolites, fusulinids and fragments of other fossils, and a few selenite inclusions. Zones of slight porosity are present, one of which showed a stain of dead oil. About 350 feet above the base of the formation is a 40-foot zone of brown granular dolomite. Total thickness of the Hermosa is 1,400 feet. According to Thompson,[2] the upper half is of Missouri and Virgil age, while the lower half is Des Moines and older.

The oil produced on test by the Continental No. 100 Navajo came from limestone in the lower 100 feet of the Hermosa formation.

[2]Thompson, M. L., Personal communication, July 1942.

Molas formation.—A thickness of 250 feet of dark gray and purple shale, with a small amount of white sandstone, is thought to be the Molas formation of southwestern Colorado. Fusulinids found in calcareous shale in the upper 100 feet have been identified as of Bend (early Pennsylvanian) age by M. L. Thompson.[3]

MISSISSIPPIAN

Beneath the gray and purple shales of the Molas formation lie white crystalline limestone, tan dense limestone with crinoid stems, and brown coarsely crystalline very porous dolomite. Total thickness is 215 feet.

DEVONIAN

Green shale, tan dense limestone, and brown dense dolomite, totaling 140 feet in thickness, are believed to represent the Devonian system.

CAMBRIAN

Two feet of white siliceous sandstone penetrated at the bottom of the Continental No. 100 Navajo are stated[4] to be Upper Cambrian. If this is the case, the formation represented is probably the Ignacio quartzite, so named in southern Colorado.

STRUCTURE

The attitude of the surface beds, and contours on the Dakota sandstone, both indicate that the geologic structure is anticlinal. (See map, Fig. 4.) The axis trends slightly west of north. Dips are low on the east or basin side of the structure; those on the west side reach a maximum of about 4½°. The total structural closure amounts to about 350 feet, but the closure above the water level in the Dakota sandstone was originally less than 75 feet. Only minor faulting is present.

DEVELOPMENT

The discovery well on the Rattlesnake dome was completed at 826 feet for 10 barrels per day. Subsequent development has been largely confined to the north part of the structure. Well No. 22 proved the southern part of the anticline to be oil-producing, and several wells were drilled in that part of the field as well as in the intervening area. Well No. 5 was first drilled to a depth of 758 feet in September, 1924, and its initial production was 300 barrels of oil. When the lower sandstone of the Dakota was found to be oil-bearing, the well was deepened to 839 feet in May and June, 1926, and flowed at the rate of 1,500 barrels per day. Many other wells were later deepened to increase production. At the close of 1941 there were 35 wells producing from the Dakota sandstone; 10 shallow wells shut down but not abandoned; two wells converted to water wells, one of which was not in use; and one well (No. 7) being used as an injection well.

[3] Personal communication, May 1942.

[4] Dobbin, C. E., et al., Possible future oil provinces in Rocky Mountain region: Bull, Amer. Assoc. Petrol. Geol., Vol. 25, No. 8, pp. 1504-07, August 1941.

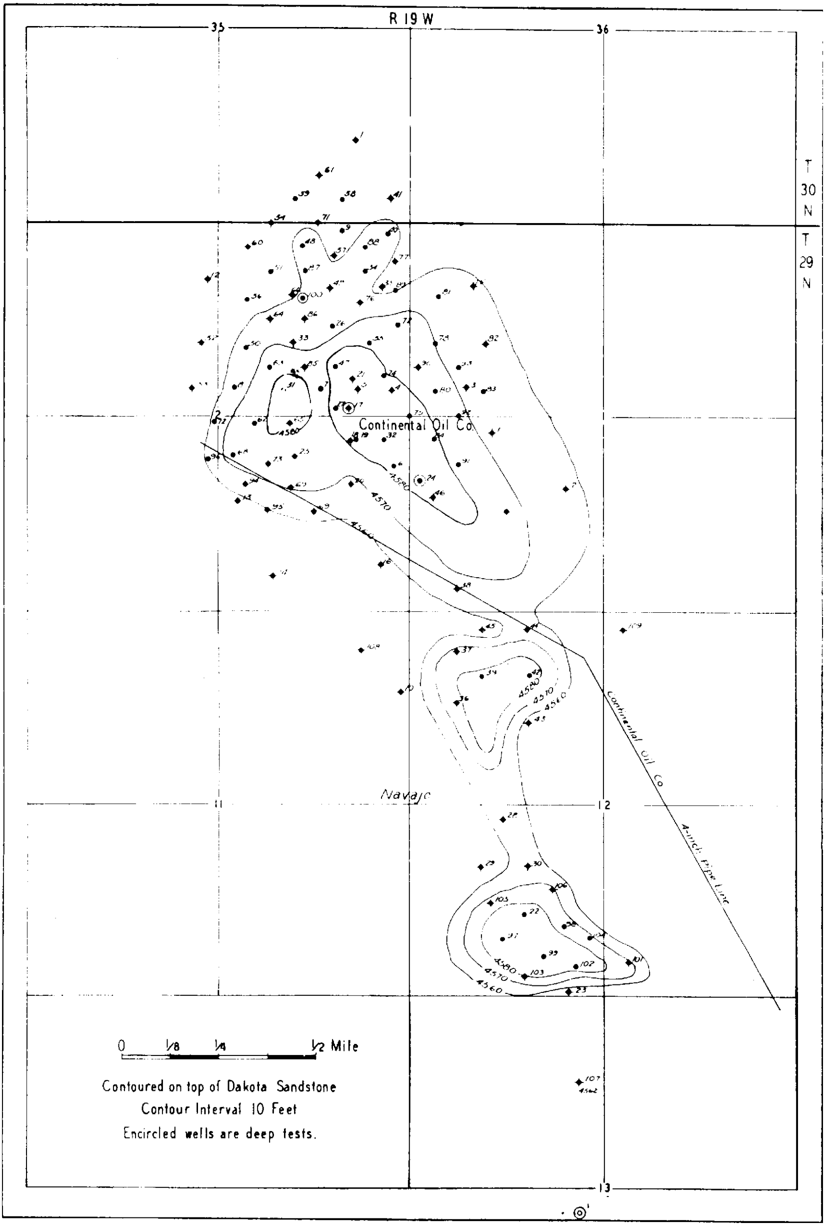
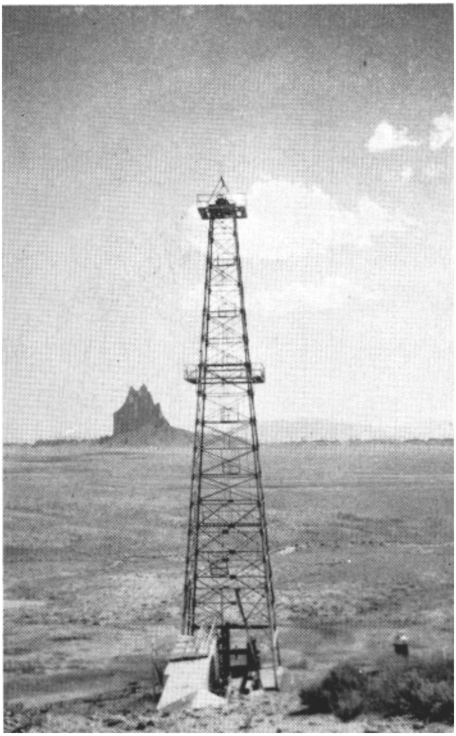


FIGURE 4.—Subsurface contour map of the Rattlesnake pool, San Juan County.



A. Ship Rock, an igneous plug, beyond derrick of Continental Oil Co. No. 24 Navajo, deep test in the Rattlesnake field, San Juan County. Looking southwest.

B. Crude-oil stabilization plant and electric light plant of Continental Oil Co., Rattlesnake field, San Juan County.

Well No. 16 was scheduled to be the first deep test in the Rattlesnake pool, but was abandoned when the Dakota proved dry. Well No. 17, in the SE¼NE¼ sec. 2, T. 29 N., R. 19 W., was spudded in September, 1925, and completed as an oil well in the Pennsylvanian at 6,771 feet in April, 1929. The initial production was 800 barrels of 40° A. P. I. crude oil per day. The well was improperly completed and flowed a large percentage of water throughout its life. According to the driller's log the hole was full of water at 6,746 feet and the oil and gas were encountered at 6,769 to 6,771 feet. A 4¾-inch oil string set at 6,497 feet was evidently too high to give a water shutoff. This well was later deepened to 6,985 feet and was finally abandoned in 1933.

A second deep test, well No. 24, was spudded in August, 1930, in the NW¼SW¼ sec. 1, T. 29 N., R. 19 W., and completed as an oil well in September, 1932. (See Plate 10A.) The initial production was 500 barrels per day with 5 percent water from the Pennsylvanian at 6,585 to 6,620 feet. The well was drilled to a total depth of 7,370 feet. This well has been shut down since 1940.

In July, 1939, well No. 100 was spudded in the SE¼NW¼NE¼ sec. 2, T. 29 N., R. 19 W. The well was completed in the Pennsylvanian for an initial production of 92 barrels of 41° A. P. I. oil and 410 barrels of water per day from 6,724 to 6,732 feet. Testing of the well was extended over a period of about one week after completion in April, 1940. At the end of the testing period the well was shut down and has remained so to date. This test was carried to a total depth of 7,407 feet and is thus the deepest test in the San Juan Basin.

OIL AND GAS

The oil from the Dakota sandstone as it comes from the well is very light amber-colored and looks much like apple-cider vinegar. Fresh samples have a gravity of as high as 76° A.P.I., but the oil quickly weathers to 60° to 63° A.P.I.

Difficulties were experienced when Rattlesnake crude was first sent through the pipe line. As the Shiprock region is quite arid, in the summer months atmospheric and ground-surface temperatures are high. Because of the extremely high gravity and volatile nature of the oil, it vaporized as soon as it entered the warm pipe line to such an extent that it was almost impossible to pump it through the line or to flow it by gravity. Gas from the oil collected in pockets at high points, and the line became "gas locked." An elaborate weathering or stabilizing plant therefore had to be built to condition the oil for pumping through pipe lines or shipping by tank cars. (See Plate 10B.)

Analyses of the crude oils produced from the Dakota sandstone and from the Pennsylvanian section are given below.

Analysis of Crude Oil from Dakota Sandstone, Rattlesnake Fields

Gravity	59.5° A. P. I.
Pour point	Below 5° F.
Color	Green
Base	Paraffin
Sulfur	Less than 0.1 percent

Saybolt Universal viscosity at 100° 30 sec.

Distillation

First drop ---------- 86° F.

	Percent
Gasoline and naphtha	75.2
Kerosene	13.8
Gas oil	4.5
Nonviscous lubricating distillate	3.6
Residuum	0.9
Distillation loss	2.0
Total	100.0

Analysis of Crude Oil from Pennsylvanian Section, Rattlesnake Field

Gravity	41.7° A. P. I.
Pour point	Below 5° F.
Color	Greenish brown
Base	Intermediate
Sulfur	Less than 0.1 percent

Saybolt Universal viscosity at 100° F. 40 sec.

Distillation

First. drop ---------- 93.2°

Component	Percent
Gasoline and naphtha	40.8
Kerosene	11.6
Gas oil	15.8
Nonviscous lubricating distillate	11.5
Medium lubricating distillate	6.0
Residuum .	13.9
Distillation loss	0.4
Total	100.0

As would be expected from the nature of the crude oil from the Dakota sandstone, the accompanying gas carries a high percentage of heavy fractions. Analyses of natural gas from the Rattlesnake shallow and deep producing horizons follow.

Analysis of Gas from Dakota Sandstone, Well No. 21, Rattlesnake Field[5]

Component	Percent
Carbon dioxide	0.00
Oxygen	0.18
Methane	9.83
Ethane	27.58
Propane	41.57
Butane and heavier	19.70
Nitrogen	1.14
Total	100.00

[5] Analysis made in 1932 on stabilized crude oil.

Analysis of Gas from Pennsylvanian Section,
Well No. 17, Rattlesnake Field

Component	Percent
Carbon dioxide	0.39
Oxygen	0.07
Methane	44.83
Ethane	53.56
Nitrogen	0.96
Helium	0.19
Total	100.00

PRODUCTION METHODS

The first few wells in the field were drilled with a standard rig, but all of the remaining shallow wells were drilled by portable drilling machines. The first deep test, Well No. 17, was drilled mainly with standard tools, but rotary equipment was necessary for part of the work. The other deep wells were drilled entirely with rotary equipment.

For the Dakota production it is necessary to set only a few joints of surface pipe through the Tocito sandstone and then an oil string at the top of the Dakota. No water is found above the Dakota. Nearly all of the Dakota wells at first flowed naturally, but it has been found advisable to pump them from central pumping powers. This is done in order to lift the small amount of water produced by some of the wells and thus prevent the water from accumulating and "killing" the well. The Dakota oil is accompanied by considerable amounts of gas. A production test on Well No. 5 approximately one year after completion showed this well capable of producing 420 barrels of oil and 285,000 cubic feet of gas per day. This gave a gas-oil ratio of about 680/1. Reservoir pressure, as determined by Nowels[6] in March, 1928, was 270 pounds per square inch.

In 1941 oil from the Dakota sandstone was being pumped directly into a large separator located at the stabilization plant. The gas from the separator is run through a compression plant, and the oil is run to a preheater to drive off light fractions. The liquid propane and butane that is obtained by stabilizing the crude is stored under pressure and sold for household purposes. All uncondensed gas that is not used on the lease is injected into the Dakota reservoir through Well No. 7, as is all the excess propane and butane which cannot be marketed.

A typical day's production in the spring of 1941 is given below.

Crude oil	318 barrels
Stabilized crude	254 barrels
Loss (butane and gas)	64 barrels
Gas	389,222 cubic feet
Fuel requirements	145,176 cubic feet
Butane[7] produced	116 barrels

[6] Nowels, K. B., Oil production in the Rattlesnake Field: Oil and Gas Jour., June 7, 1928, p. 144.

[7] The product sold as butane also contains some propane.

The stabilized crude oil has an A. P. I. gravity of 60° and a Reid vapor pressure of 5.9 pounds. The Reid vapor pressure of the butane on the first "make" is 126 pounds; the vapor pressure in storage is 117 pounds.

At the end of 1940 the crude oil production from the Dakota sandstone in the Rattlesnake field totaled 4,420,784 barrels, and the 1941 production was 101,791 barrels. A total of 1,404,249 gallons of butane had also been produced to the end of 1940. The total production from the Pennsylvanian rocks amounted to 489,629 barrels. There was no deep production during 1941. Of the total deep production, 357,365 barrels were produced by Well No. 17.

RED MOUNTAIN FIELD

The Red Mountain structure is located in T. 20 N., R. 9 W., McKinley County, about 6 miles east of the Bonita anticline. It is a small fault structure in the Mesaverde, from which formation oil is obtained at 430 to 500 feet.

The discovery well, Stacey, Webber et al. No. 1 Santa Fe, in the SW¼SW¼ sec. 29, T. 20 N., R. 9 W., was completed on June 15, 1934, for a daily production of five barrels from a Mesaverde sand at 475 to 498 feet. Approximately 25 wells were drilled in the next three years, of which seven were productive. All productive wells are in secs. 20 and 29, T. 20 N., R. 9 W. The better wells make from 20 to 25 barrels per day of 40-43° A. P. I. crude.

At the beginning of 1941 there were six producing wells in the field. Production to the end of 1941 amounted to approximately 5,400 barrels and the 1941 production was 750 barrels. An analysis of the crude oil follows:

Analysis of Crude Oil from Stacey, Webber et al. No. 1 Santa Fe, Red Mountain Field

Gravity --- 42.8° A. P. I.
Pour point--Below 5° F.
Sulfur--Under 0.1 percent
Color---Brownish green
Base-- Paraffin
Saybolt Universal viscosity at 100° F. 38 sec.

Distillation

First drop ---95° F.

Fraction	Percent
Gasoline and naphtha	37.3
Kerosene	18.3
Gas oil	10.6
Nonviscous lubricating distillate	11.8
Medium lubricating distillate	5.7
Residuum	15.7
Distillation loss	1.2
Total	100.0

SAN MATEO DOME

The San Mateo dome is located in the center of T. 14 N., R. 8 W., McKinley County, about 6 miles north of the village of San Mateo and 20 miles northeast of Grants. (See map, Plate 9.)

The dome is an irregularly shaped structure with its highest point in the west half of sec. 14, T. 14 N., R. 8 W. Several faults of considerable magnitude are present on the east side of the dome, but independent of these faults the structure has a closure of between 60 and 100 feet. The surface beds near the apex of the structure belong to the Mancos shale, and Mesaverde sandstones are exposed in the high cliffs around the south, east, and north sides.

In 1923-24 the Midwest Refining Co. drilled a test well in the SE¼ sec. 14, T. 14 N., R. 8 W., to a total depth of 1,320 feet, finishing in the Morrison formation. The top of the Dakota was reached at 1,075 feet. No oil or gas was reported.

SEVEN LAKES AREA

The Seven Lakes area in T. 18 N., Rs. 10 and 11 W., McKinley County, was one of the first areas in New Mexico in which oil was found. (See map, Plate 9.) According to Gregory,[1]

> Oil was discovered on the Chaco Plateau in 1911. In sinking a well for water in sec. 18, T. 18 N., R. 10 W., New Mexico principal meridian, Henry F. Brock unexpectedly found a considerable amount of gas and some oil. As a result, three thousand claims were located in twenty townships nearby and drilling on a moderate scale was begun. By the end of 1912, oil and gas had been found in six wells, in quantity not sufficient to justify exploitation on a commercial scale, and in 1913 the field was practically abandoned.

The surface beds are sandstones and shales of the Mesaverde formation, and such production as has been developed has been found at a depth of 300 to 400 feet. No structure is evident, and no wells of commercial importance have been completed. From time to time activities in the Seven Lakes area have been renewed, but the results so far have not justified the cost.

According to records available, some 35 wells have been drilled within an area embracing secs. 17, 18, and 19, T. 18 N., R. 10 W., and secs. 13, 23, 24, and 26, T. 18 N., R. 11 W. Approximately one-third of these wells have found oil, the maximum initial production reported being 20 barrels. About 10 other wells have been drilled within five miles of the above mentioned area, and some of these wells have recorded oil shows.

The San Juan Coal and Oil Co. No. 1 Farris was drilled in the SE ¼ sec. 18, T. 18 N., R. 10 W., to a total depth of 2,002 feet. This well recorded oil sands at 315-27, 350-72, and 388-402 feet,

[1] Gregory, H. E., Geology of the Navajo country: U. S. Geol. Survey, Prof. Paper 93, p. 145, 1917.

and good oil sands at 1,270-1,304 and 1,825 (?) feet. It was abandoned because the operators could not shut off a large volume of water coming into the hole.

In 1921 E. T. Hamilton drilled a well on the Ruby Ranch in sec. 33, T. 19 N., R. 10 W., to a total depth of 3,265 feet. This well showed oil shale at 330-40 feet and oil sand at 350-60 feet. J. M. Craven drilled several wells in 1929 which made from three to five barrels daily, but since then the field has been practically abandoned.

The following analysis of oil from the Seven Lakes area was furnished by the Midwest Refining Co. and was made in the laboratories of the company at Casper, Wyoming, June 16, 1921.

Analysis of Crude Oil from Seven Lakes Area

Gravity	29.7° A. P. I.
Sulfur	0.82 percent

Distillation

Fraction	Percent
Crude naphtha	1.3
Kerosene	14.9
Gas oil	5.5
Wax distillate (rerun)	35.3
Gravity 34° A. P. I.	
Flash 270° F.	
Fuel oil residue	40.5
Loss	2.5
Total	100.0

According to the analyst, this oil is unique so far as the initial boiling point is concerned. This temperature was 478° F., and hence the oil does not contain any gasoline.

STONEY BUTTES ANTICLINE

The Stoney Buttes anticline is located near the south line of San Juan County, on the west side of the San Juan Basin, in Tps. 21 and 22 N., Rs. 13 and 14 W. It is 34 miles north of the Crown Point Indian school and 60 miles north of the town of Thoreau.

The anticline is a long narrow uplift having three high points. The surface beds are soft sandstones and shales belonging to the middle part of the Mesaverde formation. The structure has a closure of at least 200 feet on the west, opposite the basin, although along the axis to the south the closure may not be more than 100 feet. Considerable minor faulting is evident around the sides of the structure, but none of the faults has a throw of more than 50 feet.

Twelve wells have been drilled on or near the anticline. The first, which was drilled by the Midwest Refining Co. in the SE cor. sec. 36, T. 22 N., R. 14 W., was spudded in June, 1928, and carried to 3,063 feet. This well recorded oil shows at 780 to

790 feet and 833 to 860 feet. A 5,000-barrel flow of warm water was encountered at 2,965 feet, and the well was finally sold to the Indian Department for a water well.

Most wells have had shows of oil between 350 and 900 feet. The Reserve Oil Co. No. 4 well, which was drilled in 1934 in sec. 36, T. 22 N., R. 14 W., had an initial production of 42 barrels of 30.7° A. P. I. crude in 11 hours from 815 to 818 feet in the Mesaverde formation.

The presence of at least some oil of good grade in the Mesaverde at shallow depth has been proved at the Stoney Buttes anticline, and the structure probably deserves a test of the Dakota, which should be found at a depth of approximately 3,800 feet There is no production from this structure at the present time,

An analysis of the oil is given below.

Analysis of Oil from the Stoney Buttes Anticline

Gravity	29.5° A. P. I.
Pour point	30° F.
Sulfur	0.2 percent
Color	Brownish black
Saybolt Universal viscosity at 100° F.	75 sec.
Base	Intermediate

Distillation

First drop	163.4° F.
Fraction	Percent
Gasoline and naphtha	13.9
Kerosene	4.6
Gas oil	21.6
Nonviscous lubricating distillate	14.9
Medium lubricating distillate	9.6
Residuum	35.4
Distillation loss	0.0
Total	100.0

TABLE MESA FIELD

The Table Mesa field is about nine miles southwest of the Hogback field. It lies east of the Shiprock-Gallup highway about 13 miles south of the town of Shiprock. (See map, Plate 7.) The structure is just west of the Hogback ridge on lands belonging to the Navajo Indians. The productive part of this structure, consisting of approximately 100 acres, is located in sec. 3, T. 27 N., R. 17 W. (unsurveyed) .

An exploratory lease on the Table Mesa structure was sold to A. E. Carlton for $17,500 at a public auction held at Santa Fe, New Mexico, in October, 1923. In December, 1924, the Producers & Refiners Corp., drilling for Mr. Carlton, completed a well at a total depth of 3,010 feet, in the NW¼SW¼ sec. 3, T. 27 N., R. 17 W., finding water in all sands.

Geologists for the Continental Oil Co. reworked the surface geology of the structure early in 1925, and later in the year this company completed the discovery well in the SE¼SW¼ sec. 3, T. 27 N., R. 17 W. The well had an initial potential of 325 barrels of high-gravity oil per day from the Dakota at 1,317 feet. Following the discovery well, the Continental Oil Co. drilled 11 more wells of which five were commercial producers. These wells were all completed by 1927 with the exception of one drilled in 1939.

At the surface on the Table Mesa dome is drab shale of the Mancos formation, which weathers to rounded forms and includes very few marker beds. Table Mesa, a conspicuous topographic feature southwest of the field, is capped by the Point Lookout sandstone of the basal Mesaverde.

The Tocito sandstone member of the Mancos is found at depths of a little over 500 feet, and the Dakota sand series, which furnishes the oil, is topped at 1,300 to 1,400 feet. It consists of alternating beds of sandstone and shale, with some coal, and is about 200 feet thick.

A number of igneous plugs are situated south and west of the field, approximately in the syncline between the Table Mesa dome and the Tocito dome to the south. These plugs and their connecting dike have a linear arrangement in a general northwest direction.

The Table Mesa dome is an almost symmetrical fold with its major axis trending approximately northeast. (See map, Plate 7.) The closure is reported to be about 150 feet. A single fault with a throw of about 50 feet has been mapped. It is in the eastern half of sec. 3, T. 27 N., R. 17 W., on the northeast edge of the field, and trends in an east-west direction.

In 1939 the Continental Oil Co. completed their No. 12 well for a daily potential of one barrel of oil and 169 barrels of water. Upon completion of this well, the field production jumped 10 barrels per day. Apparently the well is either diverting water from other wells, allowing them to produce a higher proportion of oil than formerly, or it is allowing the water in the reservoir to exert a stronger flushing action than it previously had. Consequently the well has been left on production although by itself it cannot be classed as commercial.

Most of the production from this field has been from six wells. A seventh well was on production for about two months in 1926. Since 1930 the field has been producing at a practically constant rate of 85 barrels per day. Cumulative production for the field was 574,258 barrels at the end of 1941, and the 1941 production was 36,101 barrels. An analysis of the oil is given below.

Analysis of Crude Oil from Dakota Sand, Table Mesa Field

Gravity	56.4° A. P. I.
Pour point	Below 5° F.
Sulfur	Under 0.1 percent
Color	Green
Base	Paraffin
Saybolt Universal viscosity at 100° F.	31 sec.

Distillation

First drop ---------------------------------79° F.

Fraction	Percent
Gasoline and naphtha	63.5
Kerosene	17.0
Gas oil	7.1
Nonviscous lubricating distillate	8.3
Residuum	3.2
Loss	0.9
Total	100.00

The wells are pumped from a central pumping power and are equipped with insert pumps in order to facilitate servicing. No sand trouble is encountered but considerable water is produced with the oil.

The lease is connected with the Continental Oil Co.-Santa Fe Corp. pipe line from the Rattlesnake field to Gallup. In 1941, however, the crude oil was being pumped to the refinery at Farmington via the Rattlesnake and Hogback fields.

TOCITO DOME

The Tocito dome is located just west of the Shiprock-Gallup highway about 21 miles south of Shiprock. It was considered one of the most favorable structures offered for sale at Santa Fe, New Mexico, in October, 1923, the Gypsy Oil Co. paying a bonus of $46,000 for the exploratory lease.

The Tocito structure is a somewhat elongated dome with a northwest-trending axis. (See map, Plate 7.) The total closure is approximately 300 feet, and the area within the lowest closing contour is about 17,000 acres. The structure is crossed by an east-west fault with a downthrow on the north of approximately 50 feet. This fault results in two independent highs on the structure. The north high is located in secs. 7 and 8, T. 26 N., R. 18 W., while the south high is in sec. 17. Both highs have been drilled and found nonproductive in the Dakota. The Tocito sandstone forms the surface of the structure, and the Dakota occurs at a depth of 880 feet in the Continental Oil Co. well on the north closure and 842 feet in the Gypsy Oil Co. well on the south closure.

The Gypsy Oil Co. well, drilled under the terms of the original lease, reached a total depth of 3,022 feet. Nearly every sand contained fresh water, and no shows of oil or gas were obtained.

The Continental Oil Co., after detailed study of the structure early in 1926, drilled a well north of the fault, and again fresh water was found in the sands to a depth of 1,430 feet. The bottom of the hole at this depth was in the top of the Navajo sandstone. The well flowed 2,000 barrels of fresh water per day and was sold to the Navajo Indians for a water well.

None of the wells drilled have reached the equivalent of the deep Pennsylvanian horizon producing at the Rattlesnake field. Such a test should be drilled before the structure can be classed as nonproductive. The Pennsylvanian section should underlie this structure at approximately the same depth as at Rattlesnake.

A request for a lease on Tocito dome in 1938 was not acted on by the Navajo Tribal Council.

WALKER (AMBROSIA LAKE) DOME

The Walker dome, formerly known as the Ambrosia Lake dome, is located in the eastern part of T. 15 N., R. 10 W., McKinley County, approximately five miles north of the Ambrosia anticline. (See map, Plate 9.) The area is very rough, and the structure is surrounded by high sandstone-capped mesas. The structure is a general domal uplift truncated on the south by a series of major east-west faults. A second major fault, located west of the axis, strikes north-south. There is a closure of several hundred feet against the fault, and the closing contour includes approximately 6,500 acres. Additional faulting is evident at several points around the edge of the dome. The surface beds belong to the lower part of the Mesaverde formation.

Six wells have been drilled on the Walker dome. The first test, near the top of the structure, was drilled by the Midwest Refining Co. in 1923. The well was carried to 1,460 feet and abandoned in the Morrison formation. The table on page 131 gives information on the wells drilled on the Walker dome.

ZUNI BASIN

GENERAL GEOGRAPHY AND GEOLOGY

West of the Zuni Mountains the sedimentary formations have been folded into a narrow basin near the center of which the Indian village of Zuni is located. Cretaceous formations—Dakota, Mancos and Mesaverde—are present in the central part of the area, with older formations, down to and including some of the Permian, exposed on the east and west sides. The formations are folded in places into anticlines with but little accompanying faulting. Five anticlinal structures have been recognized, three of which have been partially tested by drilling. Additional drilling is suggested on the Piñon Springs and Ojo Caliente anticlines to determine the possibilities of beds below the Cretaceous.

Wells Drilled on the Walker Dome

Well	Location (T. 15 N., R. 10 W.)	Total Depth, Feet	Year Completed	Results
Midwest Refining Co. No. 1	Cen. W. line sec. 13	1,460	1923	Show of oil and gas 963-70; show of oil and water 1,376-82.
Pierce No. 1	SE ¼ (?) sec. 14	1,100	1926	Dry and abandoned.
Walker Dome Oil Co. No. 2	Cen. E½SE¼NE¼ sec. 14	1,014	1932	Show of oil at 998-1,012.
Johnswood Oil Co. No. 1	SW¼SW¼SE¼ sec. 12	873	1934	Dry. Bottomed in Mancos shale.
McCarter No. 1	SW¼SE¼ sec. 11	1,014	?	Dry.
J. H. Royer No. 1 Santa Fe	NW¼NW¼SW¼ sec. 13	1,027	1935	Oil shows at 60-62, 990-97, and 1,002-08.

CEDAR BUTTE DOME

The Cedar Butte dome is a very small rounded uplift with perhaps 50 feet of closure. The high point is located near the center of the west line of sec. 19, T. 14 N., R. 17 W., about eight miles southeast of Gallup. Sandstones, shales, and thin coal beds of the upper part of the Mesaverde formation are at the surface. No drilling has been done on the Cedar Butte dome.

DEFIANCE (TORRIVIO) ANTICLINE

The Defiance anticline, first called Torrivio anticline by Gregory,[1] is a long, narrow uplift in the western part of Tps. 14 and 15 N., R. 19 W., McKinley County. The axis of the fold crosses the Santa Fe railroad at Defiance siding, hence the name. As mapped by geologists for the Marland Oil Co. of Colorado (now Continental Oil Co.) the anticline has a maximum closure of approximately 300 feet. Along its axis there is a distinct saddle near the railroad with local highs on either side. The total area within the lowest closing contour is approximately 4,800 acres and the maximum width of the structure a little over' one mile. The axis of the fold trends about N. 30° W. The structure is cut by numerous minor faults, most of which are at right angles to the axis. Soft shales of the Mancos formation occupy the surface over the heart of the structure.

In 1918 the Carter Oil Co. drilled a hole in the saddle near the axis of the anticline in the SW¼, sec. 29, T. 15 N., R. 19 W., to a total depth of 1,155 feet. The top of the Dakota sandstone was encountered at 765 feet and the well was completed in the Navajo sandstone. Neither oil nor gas was found, but a good flow of artesian water was obtained at a depth of 1,030 feet.

After a re-study of the anticline, the Marland Oil Co. of Colorado in 1926 drilled on the crest south of the railroad in sec. 5, T. 14 N., R. 19 W. The well found the top of the Dakota at 822 feet and was abandoned at 1,405 feet without finding either oil or gas.

GALLUP DOME

The Gallup dome, located in McKinley County about two miles southeast of Gallup, is a small nearly round uplift having a maximum closure of approximately 40 feet, and a closed area of perhaps 100 acres. Surface rocks belong to the basal part of the Mesaverde formation and consist of resistant sandstones, organic shales, and coal.

The structure was tested by the Producers and Refiners Corp., which in 1923 drilled a well on the crest of the dome in the SW¼ sec. 25, T. 15 N., R. 18 W. The Dakota was encountered at 1,185 feet. The hole was carried to a total depth of

[1] Gregory, H. E., Geology of the Navajo country: U. S. Geol. Survey Prof. Paper 93, p. 110, 1917.

2,265 feet, and was converted into a commercial water well. No oil or gas was found.

OJO CALIENTE ANTICLINE

Southeast of Ojo Caliente pueblo on the Zuni Indian Reservation, limestones of the San Andres formation (Permian) are exposed in an anticlinal fold which according to Darton[2] has its highest point two miles southwest of Ojo Caliente pueblo, flattens toward the southeast, and within the next few miles either dies out or becomes very low. South of Ojo Caliente pueblo the anticline shows dips as high as 54° on the west side of the axis, with much lower dips (4° to 18°) on the east. The syncline west of the fold is very sharp and at the south boundary of the Zuni Indian Reservation is less than a mile distant from the axis of the anticline. So far as known the Ojo Caliente anticline has never been mapped in detail and has never been tested. Its value depends on whether or not beds older than the Permian are present. If they are present the structure is worth testing.

PISTON SPRINGS (MANUELITO) ANTICLINE

The long Piñon Springs anticline is situated on the west side of the Zuni Basin. It is crossed by the railroad between Manuelito and the state line and extends southeastward to near Blackrock on the Zuni Indian Reservation. Sears[3] gives the following information.

> On the crest of the arch are exposed beds at the top of the Chinle formation. Maximum dips of 15° SW. and 12° NE. were seen near Piñon Springs. The anticline plunges toward the northwest and flattens out a few miles north of the railroad. It also flattens to the south and disappears within the Zuni Reservation.

In 1919 the Carter Oil Co. drilled a test in the SW¼ sec. 17, T. 11 N., R. 19 W., to a total depth of 1,980 feet. An interpretation of the log of this well is given below.

Log of Well in the SW¼ *Sec. 17,T., 11 N., R. 19 W., on the Piñon Springs Anticline*

	Feet
Chinle formation:	
Shale, red	0-1,006
Sandstone, gray to white	1,006-1,010
Shale, red	1,010-1,070
San Andres formation:	
Limestone	1,070-1,100
Glorieta sandstone:	
Sandstone, gray	1,100-1,355
Yeso formation:	
Shale, red	1,355-1,630
Limestone, very hard; some grit	1,630-1,650
Shale, red	1,650-1,980 T. D.

[2]Darton, N. H., "Red Beds" etc.: U. S. Geol. Survey Bull. 794, p. 154, 1928.

[3] Sears, Julian D., Geology and coal resources of the Gallup-Zuni Basin, New Mexico: U. S. Geol. Survey Bull. 767, p. 22, 1925.

ACOMA BASIN

GENERAL GEOGRAPHY AND GEOLOGY

South of the Santa Fe railroad and east of the Zuni Mountains, Cretaceous and older formations are intensely folded and faulted in an area here called the Acoma Basin. Volcanic rocks in the form of flows, dikes, sills and plugs are present everywhere. Sedimentary formations range from Carboniferous in the Ladron Mountains to the relatively recent Datil formation composed largely of volcanic debris exposed in the Datil Mountains. Granite forms the core of the Zuni Mountains to the west as well as the Ladron Mountains to the east. The topography of most of the basin is exceedingly rough, erosion having produced narrow canyons bordered by cliffs and high mesas.

Intricate folding in the Cretaceous and underlying Jurassic and Triassic formations gives rise to many anticlinal structures, most of which are much faulted. A few of the structures have been drilled, but most of those mapped have not yet been tested, many being considered unfavorable because of faulting or probable absence of beds competent to produce oil.

ALAMOSA CREEK AND RIO SALADO VALLEYS

GENERAL FEATURES

This district is in the southeastern part of the Acoma Basin and includes some 600 square miles in Socorro, Valencia, and Catron Counties northwest of Magdalena. The area is north of the Bear, Gallina, and Datil Mountains, and between the Ladron Mountains on the east and the Continental Divide on the west. A thorough study of the district was made by Winchester,[4] and a detailed examination of a small part of the area by E. H. Wells.[5] The following descriptions are taken largely from their reports.

As indicated by its name, the area lies entirely within the valleys of Alamosa Creek and Rio Salado. Both of these streams contain running water during most of the year. On either side of the streams the surface rises in rough and broken topographic forms to maximum altitudes of over 9,000 feet in the mountains to the south and only slightly lesser altitudes in the high mesas and peaks to the north. The district has a maximum relief of over 4,000 feet. There are numerous hogback ridges and cuestas formed by beds of resistant sandstone, and deep canyons and valleys cut in the softer beds below. High lava-capped mesas form conspicuous landmarks at several places.

The nearest railroad point is Magdalena, 35 miles to the southeast at the end of a branch line of the Atchison, Topeka

[4] Winchester, D. E., Geology of the Alamosa Creek valley, Socorro and Valencia Counties, New Mexico: U. S. Geol. Survey Bull. 716, pp. 1-15, 1921.

Wells, E. H., Oil and gas possibilities of the Puertecito District, Socorro and Valencia Counties, New Mexico: N. Mex. Sch. of Mines, Min. Res. Survey Bull. 3, 1919.

& Santa Fe railway from Socorro. Ungraded roads connect the area with Magdalena as well as with Suwanee, 50 miles to the north on the main line of the Santa Fe.

The sedimentary rocks exposed within the district have a maximum thickness of about 8,000 feet and range from Carboniferous to Recent in age. The oldest beds, consisting of hard limestones of Pennsylvanian age, are exposed on the west flank of the Ladron Mountains. Successively younger formations found to the west include Permian and Triassic redbeds, Dakota sandstone, Mancos shale (Miguel formation), Mesaverde sandstone (Chamiso formation), and the relatively recent Datil formation. Lava caps several high mesas in the area, and plugs of intrusive rock are present at several places. The Mancos and Mesaverde formations each include thick beds of sandstone, organic shale, and coal.

The sedimentary formations are intricately folded and faulted within the district, as will be seen by reference to the map, Fig. 5. Descriptions of the major structural features are given on the following pages.

COW SPRINGS ANTICLINE

West of D-Cross Mountain, the Mesaverde formation and underlying Mancos beds are folded and cut by several strike faults. Near the western border of the area a single anticlinal fold is present. This fold, known as the Cow Springs anticline, has its crest in secs. 30 and 31, T. 4 N., R. 9 W., where, due to the folding, a small area of Mancos shale is exposed along Miguel Creek Canyon near Cow Springs. The area is exceedingly rough and almost impassable. The axis of the fold trends roughly north-south.

In 1925-26, the Red Feather Oil Co. drilled a test well in the NE¼ sec. 30, T. 4 N., R. 9 W., which test was abandoned at 1,330 feet. A show of oil at 1,000 feet in what was supposed to be the Dakota sandstone was reported.

LA CRUZ ANTICLINE

The La Cruz anticline is a long irregular fold that trends northwest from east of the Tres Hermanos Buttes to La Cruz, and into the northwest corner of T. 1 N., R. 5 W. This fold is cut by a large number of small faults, notably north of La Cruz and near the Chavez ranch, most of which strike parallel to the axis of the fold and none of which have a throw of much over 100 feet. Careful study of the structure will probably make it evident that this fold consists of several domes or small anticlines separated by low saddles. The high part of this fold at the south end, where the Dakota sandstones and underlying red-beds are exposed, is distinctly separated from the main portion of the anticline north of Alamosa Creek by the saddle near La Cruz, in sec. 13, T. 2 N., R. 6 W., where the Gallego sandstone near the middle of the Mancos shale is exposed on both sides of

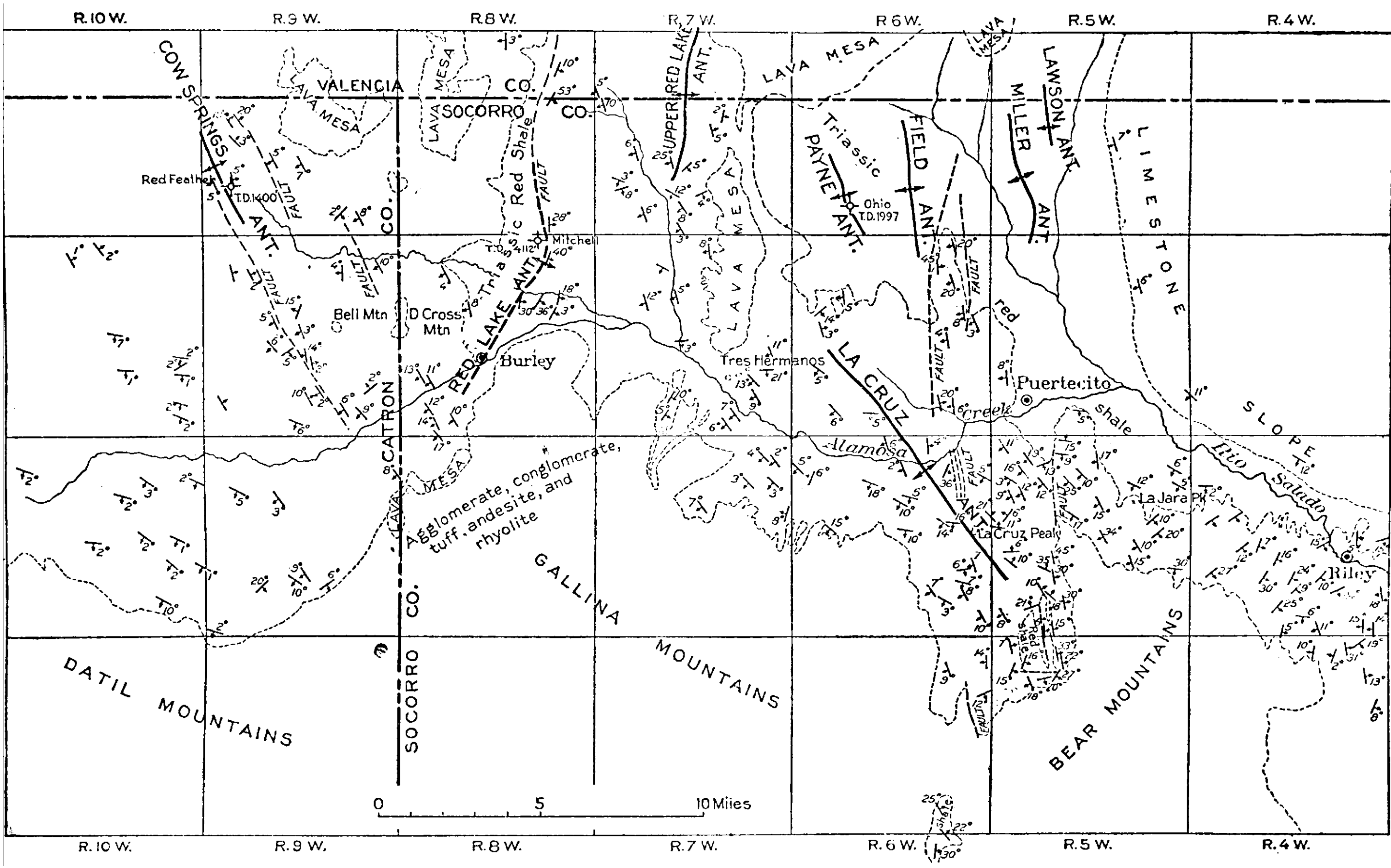


FIGURE 5.—Map showing geologic structure in valleys of Rio Salado and Alamosa Creek, Socorro and Catron Counties.

a narrow canyon. Dips of 2° to 18° prevail on the southwest side of this uplift, and similar or steeper dips occur on the opposite side.

RED LAKE ANTICLINE

East of D-Cross Mountain in Tps. 3 and 4 N., R. 8 W., is the large faulted Red Lake anticline. This structure has a closure of several hundred feet against a profound fault on the east. Triassic redbeds occur over the top of the structure with younger formations consisting of the Dakota, Mancos, and Mesaverde exposed on the west in the east face of D-Cross Mountain. The fault brings Mesaverde beds on the east side against redbeds on the west.

L. H. Mitchel and Sons in 1924-25 drilled a test well to a total depth of 4,012 feet in sec. 2, T. 3 N., R. 8 W., on the crest of this structure. At this depth, the well was reported to have been finished in granite.

According to Darton,[6] the Red Lake No. 1 well probably encountered the base of the Triassic at about 1,028 feet, the base of the Chupadera [Yeso] at 2,205 feet, the base of the Abo at 3,410 feet, and the base of the Magdalena at 3,952 feet.

PUERTECITO DISTRICT

Topography.—The Puertecito district, described by Wells,[7] is in the northeastern part of the Alamosa Creek-Rio Salado Valley area. The anticlinal structures are in a basin which is bounded on the north by a high basalt-capped mesa and on the west by a narrow ridge capped by basalt, which separates the Puertecito Basin from the Red Lake Valley. Beds of resistant sandstone form prominent ridges to the south. Surface elevations range from 6,000 to 7,275 feet, the higher elevations occurring on the lava-capped mesas surrounding the basin.

Geology.—The oldest beds exposed within the area include. maroon, purplish red, and gray shales, purplish red sandstones, and thin conglomerate beds of Triassic and Jurassic ages. The series is from 1,150 to 1,250 feet thick, and was called by Wells the Puertecito formation.

Unconformably overlying the Puertecito formation is the Dakota sandstone, five to 60 feet thick, consisting chiefly of hard partly cross-bedded yellow sandstone. Above the Dakota is a series of Cretaceous beds composed of drab shales, carbonaceous shales, sandstones, and thin coal beds. These rocks, which contain many fossils, belong to the Mancos shale. Unlike the Mancos at its type locality in southwestern Colorado, the formation contains thick persistent sandstones amounting to more than 50 percent of its total thickness. Capping the high mesas to the north and east is a considerable thickness of hard

[6] Dar ton, N. H., "Red Beds" etc.: U. S. Geol. Survey Bull. 794, p. 132, 1928.
[7] Wells, E. H., Op. cit.

basaltic rock. Dikes, sills, and plugs of similar rock are found at several places in the area.

Structure.—The sedimentary formations in the Puertecito district are considerably folded and faulted (see map, Fig. 5). Wells has mapped several minor folds with anticlinal axes trending in a general north-south direction. Faulting, mainly parallel to the axes of folding, is evident east and south of the Field anticline, where resistant Cretaceous sandstones are involved in a downthrown block. However, in the surface Puertecito beds no faults are evident in the central part of the basin.

The following notes on the local structures are based chiefly on Wells' report and are quoted at some length by Winchester.[8]

Payne Anticlinal Dome.—This is a well-defined upfold lying in the southwestern part of T. 4 N., R. 6 W., and in the northwestern part of T. 3 N., R. 6 W. It is a fairly symmetrical structure and trends north-northwest. The apex is in the NE 1/4 sec. 32, T. 4 N., R. 6 W. The surface formation is the Puertecito. In 1926 the Ohio Oil Co. drilled a well to a total depth of 1,997 feet on the Payne anticline without finding oil or gas. Drilling was discontinued after 587 feet of igneous rock (probably a sill) had been penetrated, as it was assumed that the intrusion of the sill had probably produced the surface structure and if so this structure would not be reflected in underlying beds.[9] An excellent flow of artesian water was developed, and the well is being used for watering stock and for irrigation.

Field Anticlinal Dome.—The largest part of this structure lies in the east half of T. 4 N., R. 6 W. It is a regular, symmetrical, northward-trending fold with its apex in the south part of sec. 27. The Puertecito is the surface formation. Faulting is lacking and igneous rocks are thought to be absent.

Miller Anticline.—This upfold is located in the southwest part of T. 4 N., R. 5 W. and has a length at the surface of some four miles. Its axis curves slightly but lies in a general north-south direction. The Miller anticline is the only one in the district whose structure is reflected in the topography, the position of the fold being marked by a hill which rises 75 to 125 feet above the surrounding country. The highest part of the axis is in secs. 19 and 30, T. 4 N., R. 5 W. The sandstones and shales of the Puertecito formation, at the surface on the Miller anticline, contain a number of large igneous sills and a few dikes and irregular intrusions. Faulting of small displacement is apparent in places.

Lawson Anticline.—A minor flexure designated as the Lawson anticline lies northeast of the Miller anticline in secs.

[8] Winchester, D. E. The oil and gas resources of New Mexico: N. Mex. Bur. Mines Bull. pp. 111-114, 1933.

[9] Emery, W. B., Personal communication to Dean E. Winchester.

8, 17, and 20, T. 4 N., R. 5 W. Its length is about one and one-half miles and its trend nearly due north. Closure to the north appears to be lacking. Igneous intrusions are present in small amounts. The south end of the structure is in an area of considerable volcanic activity and its details are obscured.

Upper Red Lake Anticline.—This anticline is situated in the central part of T. 4 N., R. 7 W., trends in a northerly direction, and has a length of at least seven miles. About half of the structure lies north of the Puertecito district proper. Surface rocks are shales and sandstones of the lower Mancos. No intrusive rocks are known to occur. The structure is one of some complexity, and detailed field work has not been done on it.

MISCELLANEOUS ANTICLINAL STRUCTURES

Although comparatively little detailed mapping has been done in the Acoma Basin outside the areas above described, several anticlinal folds are known, and wells have been drilled to test some of these structures. Details are lacking and it is possible only to give the most meager information.

ACOMA ANTICLINE

This anticline, in Tps. 8 and 9 N., R. 7 W., is as yet untested. Triassic rocks are at the surface.

J. Q. MEYERS ANTICLINE

A structure called the J. Q. Meyers anticline is located in T. 11 N., R. 11 W., on the east flank of the Zuni Mountains. Rocks of the San Andres and Yeso formations (Permian) are at the surface. The structure is untested.

MESA LUCERO ANTICLINE

On this anticline in T. 7 N., R. 3 W., Permian rocks are exposed at the surface. One 700-foot test well has been drilled.

SOUTH SUWANEE DOME

Triassic redbeds are exposed at the surface of the South Suwanee dome in T. 7 N., R. 4 W., and two wells have been drilled. The first reached a total depth of 4,028 feet and the second is reported to have been abandoned in granite at 5,065 feet.

DOMES SOUTH OF MOUNT TAYLOR

Three domes on the south flank of Mount Taylor (see map, Plate 9), are described by Hunt[10] as follows.

> Along the south side of Mount Taylor there are three domes which, though they cover but small areas, have considerable structural relief. Their closure cannot be determined, however, because their north sides are partly concealed beneath the extensive lava flows that are spread out south of

[10] Hunt, C. B., Geology and fuel resources of the southern part of the San Juan Basin, New Mexico: U. S. Geol. Survey Bull. 860-B, pp. 59-60, 1936.

the peak of Mount Taylor. The dome in the NW¼ sec. 13, T. 11 N., R. 8 W., seems to have not less than 300 feet of closure and perhaps considerably more. If there are any associated faults, they must be confined to the flanks, for the crest evidently is not broken by any major fault. The second dome is in the SE¼ sec. 25, T. 11 N., R. 8 W. Here a possible closure of 900 feet is suggested by the south and west flanks, but the north and east flanks are covered. The westward-dipping flank can be seen from U. S. Highway 66. The most striking feature of this dome is the abruptness with which the west and south flanks flatten out into nearly horizontal rocks. Numerous minor faults are associated with this fold. Little is known of the third dome, in sec. 33, T. 11 N., R. 7 W., and its location, shape, and closure, as indicated on the structure map (Plate 9), must be considered only approximate.

NORTHEAST AREA[1]

ROBERT L. BATES

GENERAL GEOGRAPHY AND GEOLOGY

The Northeast Area includes that part of the State east of the Sangre de Cristo Mountains and the Pedernal Hills of the Rocky Mountain uplift, and north of the Belen "cut-off" of the Atchison, Topeka & Santa Fe railway. (See map, Plate 5.) South of the railroad thick saline deposits are present in the Permian, while to the north saline beds are either absent or in relatively thin beds scattered through great thicknesses of clastic rocks.

The area is characterized by broad, gently rolling plains bordered by high mesas capped by resistant sandstones or lava. In places resistant beds underlying the shales which give rise to the plains areas are in turn cut by erosion to form deep canyons. The area is drained by the Canadian River except in the extreme southwest part where the Pecos River has its source.

Sedimentary formations ranging in age from late Cretaceous down to and including Pennsylvanian are steeply tilted along the east face of the mountains. They flatten, however, within a few miles and continue over the rest of the area in an essentially horizontal position, except where gently folded locally into low anticlines and domes. Character and thickness of formations in northeastern New Mexico are indicated on the correlation chart, Plate 2. The general geology and ore deposits have been discussed by Harley.[2]

OIL AND GAS

Many of the local structures of the Northeast Area have been partially tested by drilling, but up to December, 1941, nothing of commercial importance except carbon dioxide gas had been found, although shows of both oil and hydrocarbon gas were reported at a number of places. Granite or schist is reported to have been reached in wells on the Jaritas dome in Colfax County, the Cimarron and Sierra Grande structures in Union County, the Cherry Vale and Esterito domes in San Miguel County, and the Mesa Leon anticline in Guadalupe County. In some of the wells, as in the one on the Cherry Vale anticline, there is little doubt that pre-Cambrian rocks were reached ; in others, it is possible that "granite wash" or arkose was mistaken for true granite. Some deep wells in the northeast area have found

[1] Based in considerable part on Winchester, D. E., The oil and gas resources of New Mexico : N. Mex. Bur. Mines Bull. 9, pp. 116-138, 1933. The writer also acknowledges with thanks the assistance of A. Andreas, former State Geologist.

[2] Harley, G. T., The geology and ore deposits of northeastern New Mexico: N. Mex. Bur. Mines Bull. 15, 1940.

considerable arkose in the Permian, underlain by thick beds of limestone and shale.

In spite of the lack of favorable results so far obtained from drilling in northeastern New Mexico, it is believed that deeper drilling is warranted on a number of the more pronounced structures. On many of these, the lower Permian and underlying Pennsylvanian rocks have not been tested. It would seem good policy to use heavy rotary drilling equipment which is capable of deep drilling and of penetrating thick beds of arkose. Much more accurate information than is now available would be secured if good cuttings, and preferably cores, were obtained where the question of arkose versus granite arose.

COLFAX COUNTY

CAPULIN ANTICLINE

The Capulin anticline is a small dome-like structure on the west 'flank of the Sierra Grande regional uplift. This dome has a closure of approximately 200 feet, and its high point is located in sec. 10, T. 28 N., R. 26 E. Shales of the Carlile formation (Cretaceous) are at the surface along the crest of the dome, and a well drilled in 1926 by the Red Feather Oil Co. in the NW¼SW¼ sec. 10 is reported to have reached the top of the Dakota sandstone at 435 feet. The well was carried to a total depth of 970 feet without favorable results.

CHICO DOME

A small north-trending structure in T. 24 N., R. 25 E., known as the Chico dome, has a structural closure of about 80 feet. Its high point is in the NW¼ sec. 6. Cretaceous beds in the zone of the Greenhorn limestone are at the surface. The top of the Dakota was found at 190 feet in a well drilled in 1927 by the Frontier Oil Co. The well was abandoned at a total depth of 1,326 feet.

JARITAS DOME

The Jaritas dome is one of three small local domes along a single axis of folding, the others being the Abbott and Lunsford domes. The Jaritas structure is located in the center of T. 23 N., R. 24 E., and has a closure of about 40 feet.

In 1925 the California Co. drilled a test well in the SW¼ sec. 15. At a depth of 1,509 feet this well struck about 500,000 cubic feet of non-combustible gas which contained 67 percent carbon dioxide, 4.1 percent oxygen, 28.7 percent nitrogen, and a small amount of helium. The well was abandoned at 2,556 feet after having penetrated several hundred feet of what was reported to be granite. Concerning this well Darton [3] makes the following statements:

[3] Darton, N. H., "Red Beds," etc.: U. S. Geol. Survey Bull. 794, p. 310, 1928.

It began on the Dakota sandstone, penetrated the underlying Purgatoire and Morrison beds, and the soft white and pink sandstone from 600 to 705 feet is believed to be the Wingate sandstone. Red shales and sandstone, probably the Dockum group, extend from 705 to 1,394 feet, interrupted by hard gray sandstone at 840 to 890 feet, hard blue sandstone at 1,078 to 1,118 feet, and a few thin beds of brown and blue shale and some hard "shells." The rock from 1,394 to 1,779 feet is sandstone, alternating hard and soft and all white or gray, probably of Permian age, in which the only interruption recorded is sandy limestone from 1,718 to 1,755 feet, and similar limestone occurs from 1,779 to 1,800 feet, a succession which suggests Chupadera. Next below is 179 feet of hard sandstone, red above and brown and pink below, interrupted by five feet of gray limestone at 1,915 to 1,920 feet. The strata from 1,800 to 1,979 feet strongly suggest the Abo sandstone. From 1,979 to 2,556 feet (bottom) pink sands were found derived from a hard rock believed to be granite.

LUNSFORD DOME

The Lunsford dome is a small structure at the southwest end of the Sierra Grande uplift. It is situated in secs. 13, 14, 23, and 24, T. 24 N., R. 24 E., and has an independent closure of only about 10 feet. It has not been tested with the drill.

RITO DEL PLANO ANTICLINE

This anticline is an elongated uplift extending southwesterly through secs. 7, 8, and 18, T. 25 N., R. 24 E., and secs. 13, 24, 26, and 34, T. 25 N., R. 23 E. The crest is in sec. 7, T. 25 N., R. 24 E. The surface rocks belong to the Benton and associated Cretaceous formations above the Dakota sandstone. The structural closure amounts to about 100 feet.

In 1927 W. D. Weathers et al. put down a core-drill test well to 1,097 feet in sec. 7, reaching the top of the Dakota at 431 feet. The well was abandoned in the Morrison without finding either oil or gas. In 1940 a 1,650-foot test was drilled in the NW1/4 sec. 5. This well, the Sierracita (Marks) No. 1 State, was plugged and abandoned without reporting any shows of gas or oil. A 1,600-foot test was drilled in 1940 by York Denton et al. in sec. 2, T. 26 N., R. 24 E., on the structural trend of the Rito del Plano anticline some six miles north of the Sierracita well. A flow of 150,000 cubic feet of carbon dioxide per day was encountered at 1,515 feet.

SIERRA GRANDE UPLIFT

The principal anticlinal fold of northeastern New Mexico is a broad enlongated arch known as the Sierra Grande uplift. It extends in a southwest direction from southeastern Colorado well into New Mexico. (See maps, Plate 4 and Fig. 6.) The structure is most prominent in Colfax and Union Counties, but it may continue southwest in the subsurface across parts of Harding, Mora, and San Miguel Counties. The axis of folding passes between Folsom and Des Moines near the north line of the State and continues southwest to beyond Abbott and Roy.

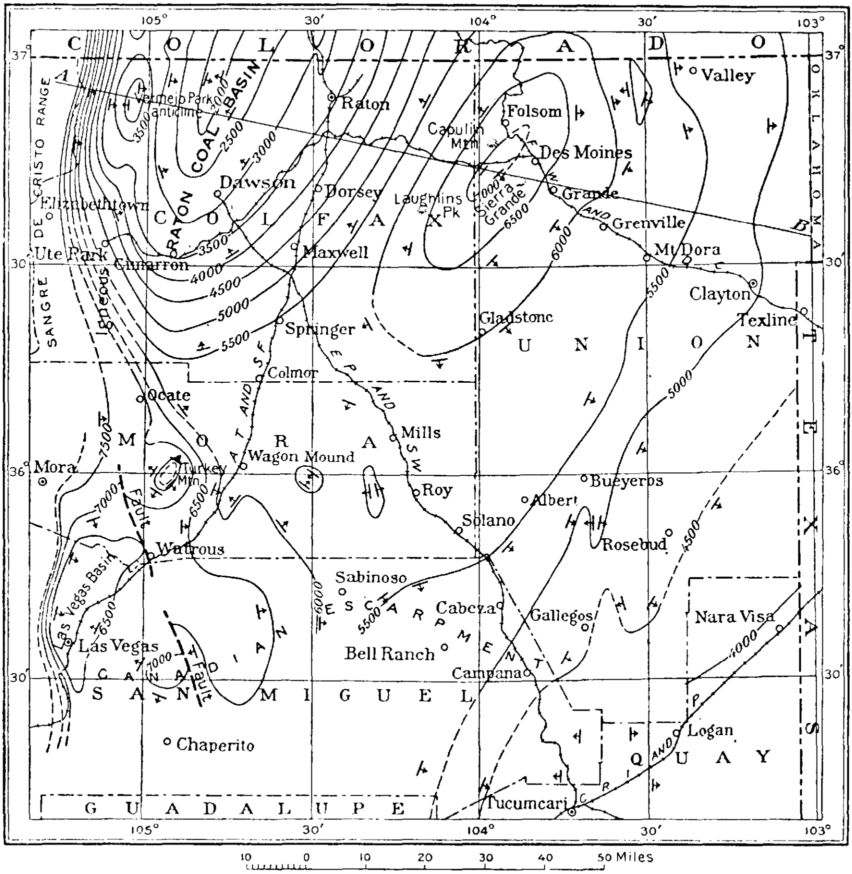


FIGURE 6.—Map showing the larger structural features of northeastern New Mexico, by contours on the surface of the Dakota sandstone. Contour interval 500 feet. Elevations approximate. (Courtesy of U. S. Geological Survey.)

The highest part of the fold appears to be near Capulin Mountain and Des Moines. Numerous minor domes and anticlines have been found along the general line of folding. The surface formations over nearly the entire area belong to the Cretaceous system ; Jurassic beds are exposed in some of the deeper canyons.

In 1935 the Sierra Grande Oil Co. No. 1 Rogers was drilled in sec. 4, T. 29 N., R. 29 E., Union County, to a total depth of 2,800 feet. It was located near the crest of the structure. The drill passed from a redbed section, probably of Permian age, into granite which was encountered at about 2,700 feet. There is a question as to whether the material logged as granite may have been arkose. No shows of oil or gas were recorded.

VERMEJO PARK DOME

The Vermejo Park dome is located on the Bartlett ranch in northwestern Colfax County about 35 miles west of Raton, the nearest point on the Atchison, Topeka & Santa Fe railway. (See Fig. 6.) The Park, in which the apex of the structure is located, is reached by good automobile road from Raton via Dawson. The Vermejo River crosses the Park near its southern border. Surface elevations range from 7,435 feet on the Vermejo River below the Bartlett ranch headquarters in sec. 25, T. 31 N., R. 18 E., to more than 8,100 feet on the rim surrounding the Park.

The dome is slightly elongated, with a structural closure of at least 1,400 feet. The upper part of the Pierre shale is exposed over a large area in the heart of the structure. The massive Trinidad sandstone forms the rimrock surrounding the Park, while the overlying coal-bearing rocks of the Vermejo formation occur back of the rim. The high point of the dome is located in sec. 23, T. 31 N., R. 18 E., near the middle of the Park, and the area within the lowest closing contour is in the neighborhood of 18,000 acres.

Three deep wells have been put down on the structure. The first, drilled prior to 1908, was at the Bartlett ranch headquarters in the SE¼ sec. 25, T. 31 N., R. 18 E., and was located some 400 feet structurally below the crest of the dome. This well, according to reports, was entirely in shale to a depth of approximately 2,300 feet. In 1926 the Union Oil Co. of California completed a test to 4,411 feet near the middle of the north line of sec. 23, T. 31 N., R. 18 E. This well penetrated a great thickness of igneous rock and was abandoned on February 10, 1926. The same company then drilled a second well near the southwest corner of sec. 23, which was abandoned at 3,265 feet. Neither well seems to have reached the Dakota sandstone.

It appears from the records of these wells that the heart of the dome is occupied by an igneous intrusion, and it is suggested that drilling on the flank, preferably the east flank towards the major basin, might find the Dakota present and possibly oil-bearing. Evidence obtained by geophysical instruments might aid in locating a proper place to drill.

GUADALUPE COUNTY

ESTERITO DOME

The Esterito dome is an elongated domal structure in the eastern part of the Anton Chico grant. The surface rocks are resistant sandstones and soft shales of the Glorieta and Yeso formations, which outcrop in prominent cliffs and steep slopes. The structure, as mapped by Newby, Garrett, Crabtree and Wright, has a closure of at least 250 feet and a closed area of approximately 11 square miles. The high point is in sec. 25, T. 11 N., R. 18 E. (See map, Fig. 7.)

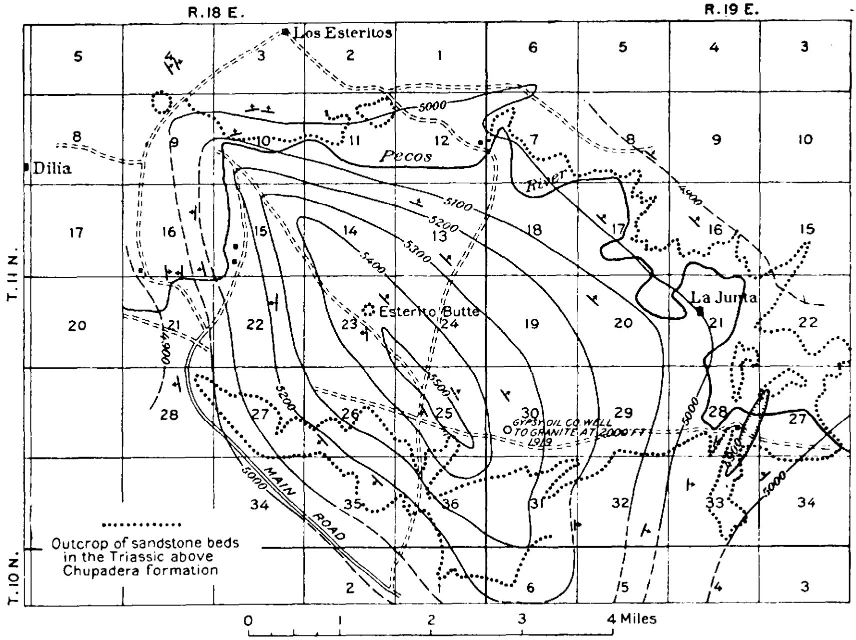


FIGURE 7.—Structure map of the Esterito dome, Guadalupe County. By Messrs. Newby, Garrett, Crabtree, and Wright for the Gypsy Oil Co. (Courtesy of U. S. Geological Survey.)

In 1918-19, the Gypsy Oil Co. drilled a well to a depth of 2,013 feet in the southeast corner of sec. 30, T. 11 N., R. 19 E. The well is reported to have been completed in granite. An examination of the log of the well, and of cuttings from the so-called granite, suggested to D. E. Winchester that the well finished in arkose of the Abo formation. In this part of the State beds of arkose are common in the Abo, and if this assumption is correct the well does not constitute a thorough test of the structure.

In June, 1942, a well located by the Franklin Petroleum Corp. in the SW¼ sec. 24, T. 11 N., R. 18 E., was reported to be drilling in redbeds at 1,690 feet.

MORA COUNTY

CANADIAN ANTICLINE

The Canadian anticline is located in Tps. 20 and 21 N., R. 23 E., at the east end of the high lava-capped mesa which continues westward to the town of Wagon Mound. Rocks from the top of the Dakota to the Greenhorn limestone are exposed at the surface. The main axis of the fold runs in a northwest direction from the high point near the southwest corner of sec. 15, T. 20 N.,

R. 23 E., with a nose or terrace to the northeast through secs. 25 and 19, T. 21 N., R. 24 E. No drilling has been done on the dome, but it appears worthy of a test, at least to the Santa Rosa sand, in which carbon dioxide gas may be expected. Structural closure amounts to more than 200 feet, and more than 15,000 acres are enclosed by the lowest closing contour.

TURKEY MOUNTAIN DOME

Turkey Mountain, about 10 miles west of Wagon Mound in Mora County, is a conspicuous landmark. Sedimentary formations are upturned on all sides forming a prominent dome. Dar-ton [4] describes the geology of the structure as follows:

> It presents an extensive section of the upper members of the "Red Beds" succession and overlying Cretaceous rocks. The high central peak consists of hard gray sandstone, undoubtedly representing the member of the Chupadera formation that is conspicuous west of Las Vegas and in Glorieta Mesa [Glorieta sandstone]. Apparently the underlying rocks are not revealed.
>
> In the section (see Fig. 8) the shales *a* and *c* and the included sandstone *b* appear to belong to the Dockum group. The sandstone *d* is nearly

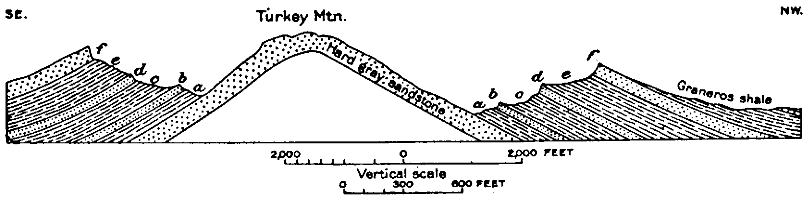


FIGURE 8.—Section through Turkey Mountain, 10 miles west of Wagon Mound, Mora County. *a,* red shale grading down into gray sandy shale; *b,* hard gray sandstone; *c,* dark red shale and red sandstone, mostly soft; *d,* hard light-colored massive sandstone; *e,* greenish-gray shale; *f,* hard gray massive sandstone (Cretaceous). (Courtesy of U. S. Geological Survey.)

> white and very conspicuous, much more resembling the sandstone member in the Morrison formation so noticeable in Union County than the Wingate sandstone. If it is Morrison the Wingate is absent. The shale is typical Morrison shale, and the sandstone *f,* although in one thick body, probably represents both Purgatoire and Dakota....

WAGON MOUND ANTICLINE

The Wagon Mound anticline, in Mora,County, is about eight miles south of the town of Wagon Mound, which is located on the main line Of the Atchison, Topeka & Santa Fe railway. The structure is roughly coincident both in shape and size with Cerra Monga, a conspicuous hill of the area. The principal axis trends nearly north, and the crest of the structure is in secs. 11 and 14, T. 19 N., R. 21 E. The fold has a closure of about 350 feet, the

[4] Darton, N. H., "Red Beds" etc.: U. S. Geol. Survey Bull, 794, p. 310, 1928.

Dakota sandstone forming the surface rocks over most of the structure. Some 35,000 acres of land are within the lowest closing contour.

The Arkansas Fuel Oil Co. drilled a test well in 1925-26 to a total depth of 2,613 feet in the SE¼NE¼ sec. 11, T. 19 N., R. 21 E. This well obtained a heavy flow of non-inflammable gas (estimated to be 12,000,000 cubic feet) containing 90 percent carbon dioxide, at 1,420 to 1,425 feet, and an additional flow estimated at 2,000,000 cubic feet at 1,795 feet. At 2,225 feet there was another gas flow estimated at 10,000,000 cubic feet. The record of the well indicates that it was drilled in "metamorphosed formation and fresh undisturbed granite" from 2,220 to 2,613 feet, but it also shows that water was encountered at 2,513 feet, which rose 1,000 feet in the hole. Probably the last 400 feet of formation drilled in this well was not "fresh granite" but arkose or "granite wash." If this is the case, the well does not constitute a complete test.

A second well was drilled in 1931, by the Santa Fe Dioxice Co. This well encountered the top of the Santa Rosa sandstone at 1,312 feet and was bottomed at 1,390 feet. A flow of carbon dioxide gas was secured, but has not been developed commercially. See also section on Carbon Dioxide, pages 300 to 304.

QUAY COUNTY

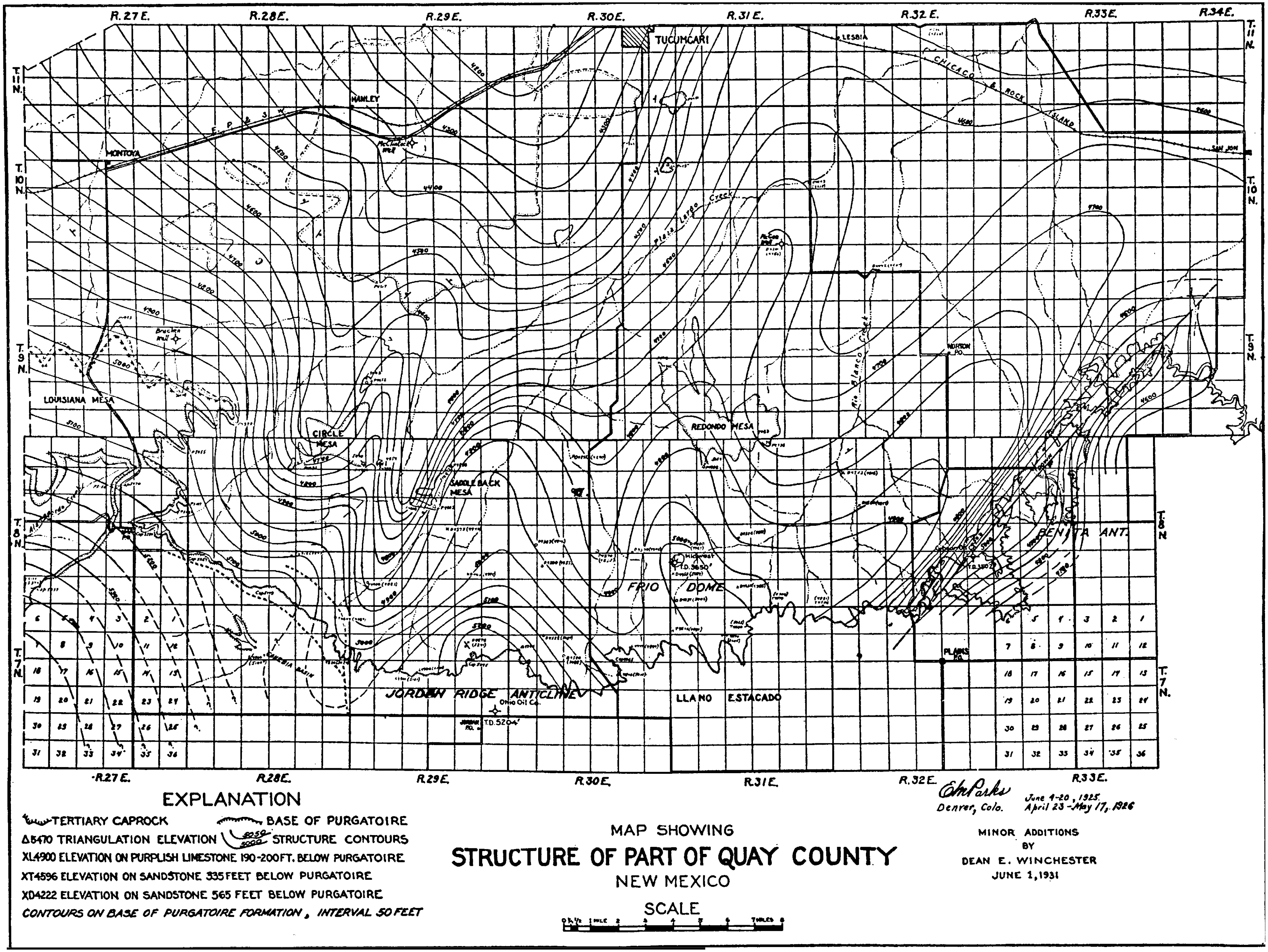
BENITA ANTICLINE

One of the conspicuous structural features of the area shown on the map, Plate 11, is the great Benita fault, in the eastern part of the area. The fault has a downthrow on the north of some 500 feet and trends in a general northeast direction. Near the north line of T. 7 N., R. 32 E., it passes beneath Recent caliche deposits of the high plains. The strata are domed against the fault on its south side.

In 1927 the Gibson Oil Co. drilled a well to a total depth of 3,502 feet in sec. 25, T. 8 N., R. 32 E. No oil was found and the well was abandoned about 700 feet below the top of the Yeso formation, without reaching the base of the sedimentary series. In 1936 the Quay County Development Co. No. 1 Wallace was completed as a dry hole in sec. 19, T. 9 N., R. 33 E., on the northwest flank of the Benita anticline. Total depth of the well was 1,322 feet. Shows of oil were reported at 802 and 1,240 feet. The well did not reach a good limestone section, but ended in sandy shale which contained salt water.

DRIPPING SPRINGS ANTICLINE

The surface rocks of this anticline consist of strata just above the Santa Rosa sandstone. The main axis of the fold trends northwest, with the high point in the N½ sec. 25, T. 13 N., R. 31 E. The anticline has a closure of nearly 100 feet and an area of approximately six square miles within the lowest closing


R.27 E.
R.28 E.
R.29 E.
R.30 E.
R.31 E.
R.32 E.
R.33 E.
R.34 E.
T. 11 N.
T. 10 N.
T. 9 N.
T. 8 N.
T. 7 N.
TUCUMCARI
LESBIA
CHICAGO & ROCK ISLAND
SAN JON
HANLEY
MONTOYA
E. P. & S. W.
Plaza Largo Creek
Rio Blanco Creek
NORTON P.O.
LOUISIANA MESA
CIRCLE MESA
SADDLE BACK MESA
REDONDO MESA
BENITA ANT.
FRIO DOME
T.D. 3650'
T.D. 3802'
JORDAN RIDGE ANTICLINE
Ohio Oil Co.
T.D. 5204'
LLANO ESTACADO
PLAINS P.O.
EXPLANATION
TERTIARY CAPROCK
BASE OF PURGATOIRE
Δ5470 TRIANGULATION ELEVATION
STRUCTURE CONTOURS
XL4900 ELEVATION ON PURPLISH LIMESTONE 190-200 FT. BELOW PURGATOIRE
XT4596 ELEVATION ON SANDSTONE 335 FEET BELOW PURGATOIRE
XD4222 ELEVATION ON SANDSTONE 565 FEET BELOW PURGATOIRE
CONTOURS ON BASE OF PURGATOIRE FORMATION, INTERVAL 50 FEET
MAP SHOWING
STRUCTURE OF PART OF QUAY COUNTY
NEW MEXICO
SCALE
Denver, Colo.
June 4-20, 1925.
April 23 - May 17, 1926
MINOR ADDITIONS
BY
DEAN E. WINCHESTER
JUNE 1, 1931

contour. The Standard Petroleum Co. in 1925 completed a test well in sec. 25, T. 13 N., R. 31 E., to a total depth of 3,016 feet. This well had shows of oil and gas in the Santa Rosa sandstone, the San Andres limestone, and the Pennsylvanian rocks. Arkose and black shale from 2,980 to 2,987 feet showed rich color when cut with ether. Granitic material was encountered from 2,996 feet to the bottom of the hole.

FRIO DOME

The Frio dome (see map, Plate 11) has a closure of approximately 125 feet and a closed area of perhaps 11,500 acres. The area is traversed by good roads and is easily reached from Tucumcari, 20 miles to the north, on the Chicago, Rock Island & Pacific railway.

The well of the Midwest Refining Co. on the top of the Frio dome, sec. 30, T. 8 N., R. 31 E., was drilled only to a depth of 3,650 feet and should not be considered a complete test of the dome in the light of the findings of the test of the Ohio Oil Co. at the Jordan Ridge anticline. It appears probable that the Frio Dome deserves a complete test and that a well should be carried some distance into the lime series before being abandoned. This might require drilling to a depth of 6,000 feet or more. Should such a test reveal commercial amounts of oil or gas, many other structures in Quay County would be considered with additional favor.

In 1939 N. H. Martin and Son drilled their No. 1 Doak in sec. 3, T. 9 N., R. 31 E., on the north end of the Frio dome. As the hole was abandoned at only 2,527 feet without entering a good lime section, it cannot be considered a true test of the structure.

HUDSON ANTICLINE

This is a relatively low irregular domelike structure, the high point being located in the SE¼ sec. 20, T. 12 N., R. 33 E., and the closure amounting to 50 feet. The total area within the lowest closing contour is approximately 2,000 acres. The Santa Rosa sandstone is within a few feet of the surface on the crest of the structure.

JORDAN RIDGE ANTICLINE

The Jordan Ridge anticline (see map, Plate 11) is in Tps. 7 and 8 N., Rs. 29 and 30 E., Quay County. The north end of this structure is well exposed in the area immediately north of the Llano Estacado rim, but the shape and closure to the south are obscured by the Llano deposits of caliche and sand.

In 1926-28 the Ohio Oil Co. drilled its No. 1 Wells on the Jordan Ridge anticline, in sec. 24, T. 7 N., R. 29 E. The well was carried to a total depth of 5,204 feet where it was abandoned. An interpretation of the log follows.

Log of Ohio Oil Co. No. 1 Wells, Sec. 24, T. 7 N., R. 29 E., on the Jordan Ridge Antieline

	Feet
Wingate sandstone:	
Brown sand	0- 200
Chinle formation:	
Red shale	200-1340
Santa Rosa sandstone:	
Gray sand and shale	1340-1665
Whitehorse group:	
Redbeds, salt, and anhydrite	1665-2820
San Andres formation:	
Brown and gray lime, with some anhydrite	2820-3260
Glorieta sandstone:	
Lime and sand	3260-3310
Yeso formation:	
Anhydrite, salt, and varicolored shale	3310-3990
Abo formation:	
Hard red sand and brown shale	3990-4660
Pennsylvanian system:	
Gray lime and shale	4660-5204 T. D.

EASTERN SAN MIGUEL COUNTY

GENERAL FEATURES

Eastern San Miguel County is an area in which the sedimentary rocks have been greatly folded, and in which consequently several deep tests have been drilled. The locations of these wells are shown on the large State map, Plate 4. The area is drained by the Canadian River, which flows across the county in a general southeasterly direction. High mesas capped by Dakota and underlying Comanchean rocks are cut by the deep canyons of the Canadian River and its tributaries. In the southern part of the district are large rolling areas which are 600 to 800 feet below the mesa tops.

The Chicago, Rock Island & Pacific railway traverses the southern part of the area, while a branch line of the Southern Pacific railway extends northward from Tucumcari to Mosquero, and to the coal mining town of Dawson in the Raton Basin.

GEOLOGY

This general area is located east of the Rocky Mountain uplift and south of the Sierra Grande uplift, in the synclinal area between these major structures and the Amarillo uplift in Texas to the east. A careful study of the structures has suggested to some that most of the folds are the result of differential settling controlled by old buried hills and associated basins.

The rocks exposed at the surface range in age from Triassic to Cretaceous, with Tertiary caliche covering a number of the high mesas. The Santa Rosa sandstone, which here is the basal member of the Triassic, consists of 400 to 500 feet of massive medium-grained gray sandstone and some red shale and conglomeratic partings. In its type locality near Santa Rosa, this sandstone is saturated with asphaltic oil. (See page 305.) Above the Santa Rosa in this area is another sand zone averaging about 340 feet in thickness, which is locally known as the Trujillo sandstone and belongs to the lower Dockum. Between the Trujillo sandstone and the Wingate sandstone is the Chinle formation, consisting of red shales, thin red sandstones, and dolomite beds having a total thickness of 520 feet. Above the Wingate is the Morrison, which in turn is overlain by a series referred to the Comanchean. Next above is the Dakota, which caps some of the high mesas, and ranges in thickness from 185 to 200 feet.

BALD HILL DOME

This is a small dome located in secs. 29, 30, 31, and 32, T. 13 N., R. 30 E., and capped by Dakota sandstone. The closure is about 50 feet.

BELL RANCH ANTICLINE

A horseshoe-shaped structure known as the Bell Ranch anticline is located in the northern part of T. 12 N., R. 29 E. It has two highs. The closure is approximately 100 feet, and the closed area about 5,100 acres.

CANADIAN AND CARROS ANTICLINES

A small irregular dome called the Canadian anticline is in secs. 8, 9, 16, and 17, T. 13 N., R. 30 E. The closure is nearly 100 feet and the closed area possibly 1,300 acres. Immediately to the north is a small structure known as the Carros anticline. It is separated from the Canadian anticline by a low structural saddle.

CARPENTER'S GAP ANTICLINE

This is a relatively pronounced dome with its crest in sec. 25, T. 13 N., R. 28 E. It has a maximum structural relief of 400 feet to the north and east, 300 feet to the southwest, and 100 feet to the southeast. The closed area is approximately two and one-half square miles.

DIVIDE ANTICLINE

A very prominent structure trending north and known as the Divide anticline is located along the east boundary of the Bell Ranch in Tps. 15 and 16 N. R. 28 E. It has a closure of 100 to 150 feet. The Dakota and Comanchean sandstones constitute the surface rocks. About 2,000 acres are within the lowest closing contour.

JOHNSON DOME

This is a large oval-shaped dome located in T. 12 N., R. 28 E., and occupying most of the township. The surface beds belong to the Dockum group of the Triassic system, and the Wingate, Morrison, and Dakota formations are exposed in the immediate vicinity. The crest of the dome is in secs. 15 and 28. The fold has a closure of 250 feet.

MEDIA ANTICLINE

The Media anticline is a long fold which plunges to the south and has two structural highs along its axis. The fold lies just east of the Dawson line of the Southern Pacific railway, with the more pronounced dome approximately three miles northeast of Media Station in the southeastern part of T. 17 N., R. 28 E. This dome has a closure of 50 feet, and there are 1,200 acres within the closing contour. Surface rocks range from middle Jurassic to Dakota. The second and smaller dome is located near Mosquero in Harding County and close to the county line.

MESA RICA ANTICLINE

This is a long eastward-plunging anticline with its axis extending through parts of T. 11 N., Rs. 24 and 25 E. and T. 12 N., Rs. 25, 26, and 27 E. North and east dips are gentle, but the dips to the south of the axis reach as much as 8°.

MONILLA CREEK ANTICLINE

This is a small irregularly shaped structure with over 50 feet of closure, located in secs. 27, 34, and 35, T. 14 N., R. 29 E.

PINO MESA ANTICLINE

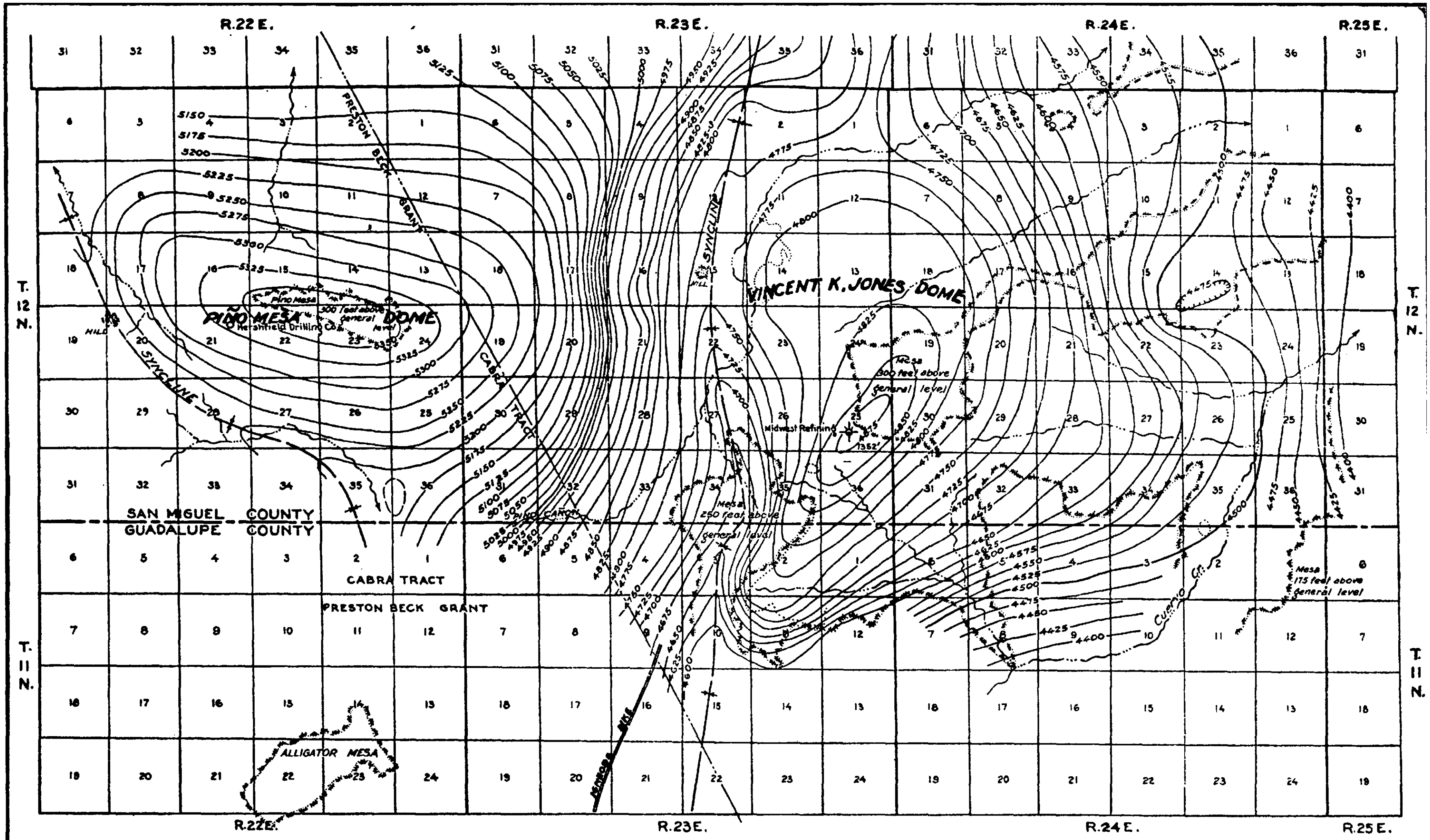
The elongated east-trending fold known as the Piño Mesa anticline is located in T. 12 N., R. 22 E. (See map, Plate 12.) The fold is quite symmetrical, the closure being a little over 100 feet and the enclosed area amounting to between 9,000 and 9,500 acres. Piño Mesa, rising 300 feet or more above the general level of the surrounding country, occupies the heart of the structure.

In 1932 the Hershfield Oil Development Co. No. 1 Thompson was completed as a dry hole in the NE¼ sec. 21, T. 12 N., R. 22 E. Its total depth was reported as 2,700 feet; no shows of oil or gas were logged. The Cabra Springs Oil and Gas Co. later drilled a 4,160-foot test in sec. 22, but no records are available as to section penetrated or fluids, if any, encountered.

RATTLESNAKE ANTICLINE

This structure is a northward-trending plunging anticline and has its high point near the southwest corner of sec. 3, T. 13 N., R. 29 E. The local closure amounts to about 75 feet. The Wingate sandstone and shales of the Upper Dockum group are the surface rocks.

The Marland Oil Co. of Colorado completed a test on this structure in 1926 to a total depth of 4,990 feet without securing production. The well was located near the west quarter corner of sec. 3. An interpretation of the log of this well follows.



EXPLANATION

- DRILLING WELL
- DRY AND ABANDONED HOLE
- ABANDONED WITH SHOW OF OIL
- ABANDONED WITH SHOW OF GAS

FIGURE GIVEN AT WELL IS TOTAL DEPTH

OUT LINE OF MESA

STRUCTURE CONTOURS, INTERVAL 25 FEET

CONTOURS ON CONGLOMERATE 500 FT. ABOVE SANTA ROSA SANDSTONE

MAP OF
VINCENT K. JONES & PIÑO MESA DOMES
SAN MIGUEL AND GUADALUPE COUNTIES, NEW MEXICO.

COMPILED BY
DEAN E. WINCHESTER

SCALE
0 1/2 1 MILE 2 MILES 3 MILES 4

Drafting by R.W. Phillips

Log of Marland Oil Co. of Colo. No. 1 Bell Raneh, Sec. 3, T. 13 N., R. 29 E., on the Rattlesnake Antieline

	Feet
Wingate sandstone:	
Red sand	0- 320
Chinle formation:	
Red shale and sand	320-1390
Santa Rosa sandstone:	
Gray and white sand	1390-1640
Whitehorse group:	
Redbeds and gypsum	1640-1970
San Andres formation:	
Gray lime and sand; some salt	1970-2602
Glorieta sandstone:	
White and pink sandstone	2602-2630
Yeso formation:	
Pink and white sand, and red lime and shale	2630-3554
Abo formation:	
Red and brown sandy shale and arkose	3554-4990 T. D.

TRIANGLE DOME

This is a triangular-shaped dome in the southwest part of T. 12 N., R. 29 E. The crest of the structure is located in the NE¼ sec. 19. The closure amounts to between 75 and 100 feet and the closed area is about 2,000 acres.

V. K. JONES DOME

This structure is pear-shaped in outline. Its axis trends northeast, and the crest is in sec. 25, T. 12 N., R. 23 E. (See map, Plate 12.) The structural closure amounts to approximately 100 feet and the enclosed area about 14 square miles. The dome is separated from the Piño Mesa anticline to the west by a syncline located in the central part of T. 12 N., R. 23 E. On the synclinal axis in sec. 15 is an igneous plug. No other igneous rocks are reported in the immediate vicinity. In 1924 the Midwest Refining Co. drilled a well to a total depth of 1,352 feet at the foot of the high mesa in the SW¼, sec. 25, T. 12 N., R. 23 E. The Glorieta sandstone was penetrated from 1,035 to 1,140 feet. A small show of gas was obtained at 980 feet, and bubbles of black oil appeared in the water at 1,106 feet. This well by no means constitutes a complete test of the structure.

WESTERN SAN MIGUEL COUNTY

CHERRY VALE DOME

The Cherry Vale dome is located in Tps. 16 and 17 N., Rs. 19, 20, and 21 E. The structure is broad and characterized by low dips, and the apex is near the southwest corner of T. 17 N., R. 20 E. The dome is bounded on the west by a north-south fault located about two miles west of the crest of the dome, which has a downthrow on the east side of 100 to 150 feet. The structural closure is between 150 and 200 feet. The Dakota sandstone is the surface rock over most of the area, except where deep canyons have cut through into lower strata, consisting of the Morrison and Wingate formations and the Dockum group. The structure is unusually large, with some 35 to 40 sections of land within the closing contour.

In 1931-32 the Con-O-Kul Oil Co. drilled a 1,027-foot test in the NE¼ sec. 34, T. 17 N., R. 21 E. The hole was abandoned in a redbed section. Shows of hydrocarbon gas were reported at 518 and 886 feet, and a show of carbon dioxide gas at 937 feet. In 1941 a well drilled by the Southwestern Drilling Co., also located in the NE¼ sec. 34, reached 3,512 feet. Examination of cuttings from this well below a depth of 1,805 feet gave the following record.

Partial Log of Southwestern Drilling Co. No. 1 Stevenson, See. 34, T. 17 N., R. 21 E., on the Cherry Vale Dome

Interval	Description
1805-2155	Predominantly light-colored fine quartz sandstone.
2155-2175	Gray dolomite.
2175-2565	Red shale and fine red sandstone.
2565-3512 T. D.	Purple, pink, and gray rock consisting chiefly of muscovite and fresh clear angular quartz. Traces of chlorite in lower samples. Believed to be pre-Cambrian mica schist.

GRAHAM ANTICLINE

The Graham anticline is a small domal uplift in T. 17 N., R. 16 E., a few miles north of Las Vegas. The Benton shale is at the surface. A number of wells have been drilled on this structure without encountering commercial amounts of oil or gas.

The Starr Oil Co. No. 3 Adams, in sec. 25, T. 17 N., R. 16 E., reached a depth of 5,092 feet. The record of this well is of special interest because it shows the presence of a thick section (4,400 to 5,092 feet) of dark limestone and shale, carrying gas shows, below an 800-foot section which contains thick beds of arkose. It thus indicates that sedimentary sections of possible value for oil or gas may be found beneath an arkose or "granite wash" cover.

On the Cherry Vale structure, less than 30 miles to the east, only 2,565 feet of sedimentary rock was found above pre-Cambrian basement rocks. The presence of nearly 5,100 feet of sediments in the Starr Adams well indicates a deep sedimentary basin between the Sierra Grande-Cherry Vale trend and the main Rocky Mountain mass to the west.

UNION COUNTY

CIMARRON DOME

The Cimarron dome is located near the north line of the State several miles east of the main axis of the Sierra Grande uplift. In 1924 the United Oil Co. completed a well on the axis of the Cimarron dome in the NW¼NW¼ sec. 6, T. 31 N., R. 33 E. The log of this well shows red sandstone from 2,670 to 2,725 feet, although the well was reported to have been bottomed at 2,725 feet in granite. Drilling commenced in the Dockum group. The Wingate, Morrison and Dakota formations crop out in the cliffs surrounding the "park" which occupies the highest part of the dome. Dips of 3° to 6° are reported for some distance on both east and west sides of the structure. The long axis of the dome has a northeast trend.

CLAPHAM, LEON, AND TATE ANTICLINES

A series of three anticlines trending slightly west of north is situated in Tps. 22, 23, and 24 N., Rs. 33 and 34 E. The area has a gently rolling surface with broad valleys and low ridges. Maximum relief is about 600 feet. The Dakota sandstone is at the surface over much of the area, but is covered in places by Tertiary lava, sand, clay, and caliche. The Tate anticline, northernmost structure, is about 15 miles southwest of Clayton.

The three structures have an aggregate length of 18 miles and a width of from three to five miles. The accompanying map, Fig. 9, is reproduced through the courtesy of Messrs. James R. Thomas and D. W. Ohern, who have surveyed the anticlines.

Some years ago, seepage of gas was noticed on the banks of Penevetras Creek near the town of Clapham. The gas burned freely. Samples were sent to the U. S. Bureau of Mines in Amarillo for analysis. Mr. James R. Thomas furnishes the following analysis of the seep gas, together with an analysis of gas from the Borger, Texas, field.

Comparative Gas Analyses

Component	Clapham Seep Gas, Union County, N. M. (Percent)	Borger Gas. Texas Panhandle (Percent)
Methane	75.7	65.7
Ethane	4.1	20.5
Carbon dioxide	6.5	0.5
Nitrogen	11.1 [5]	12.4
Oxygen	2.6	0.0
Helium	0.0	0.3
Totals	100.0	99.4

In 1936 the Olson Drilling Co. completed a test on the Zurick ranch in sec. 2, T. 21 N., R. 34 E. The hole was abandoned at

[5] Computed by difference.

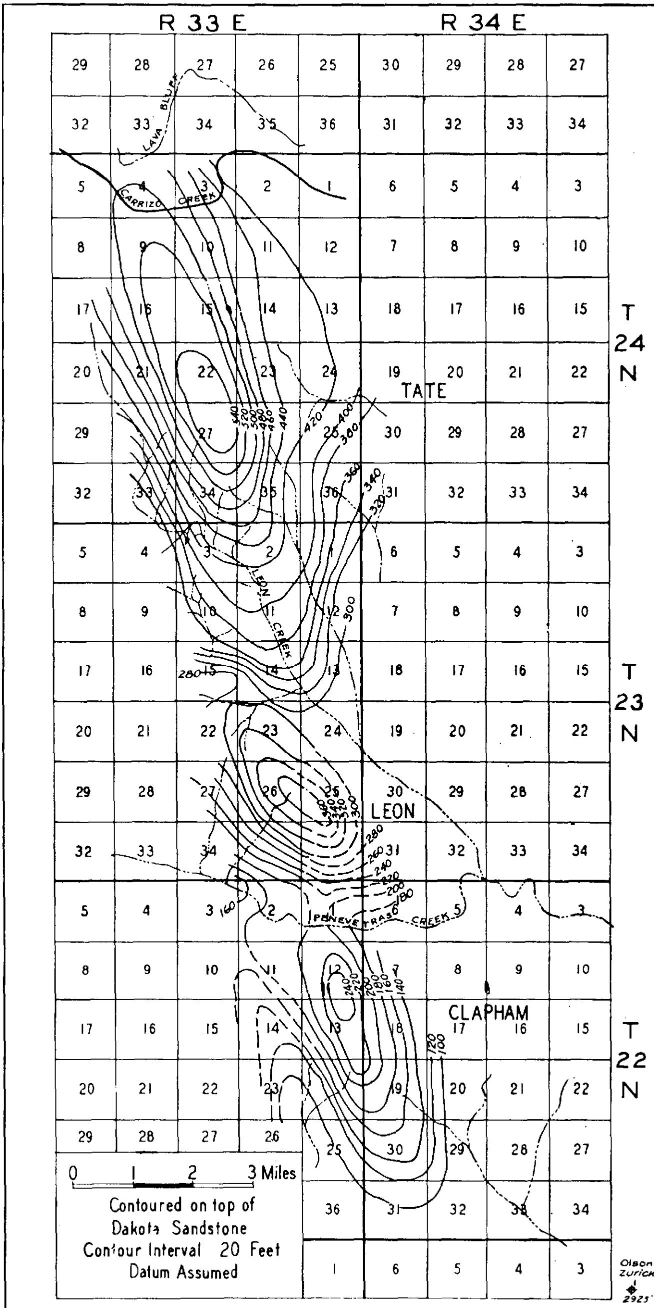


FIGURE 9.—Structure map of the Tate, Leon, and Clapham anticlines, Union County.

Miscellaneous Structures in the Northeast Area				
Name	Location		Surface Formation	Remarks
	T.-N.	R.-E.		
DE BACA COUNTY				
Buchanan anticline	1, 2	20, 21	Triassic	National Exploration Co. No. 1 Buchanan; T. D. 3,200 feet; dry.
Salado anticline	4, 5	19, 20	Ogallala	Matador Oil Co. No. 1 State-Wood; T. D. 4,662 feet; dry.
Spaulding dome	6, 7	25	Triassic	Spaulding Dome Syndicate well; T. D. 3,820 feet; dry.
GUADALUPE COUNTY				
Guadalupe anticline	9, 10	19	Ogallala	100 feet of closure. Untested.
Mesa Leon anticline	5, 6	16, 17	Permian	Large structure with 300 feet of closure; Bellevue Syndicate No. 1 McMullen; T. D. 4,717 feet; dry; entered schist and quartzite at about 4,250 feet.
Santa Rosa anticline	8	22	Triassic	Untested.
HARDING COUNTY				
Abbott dome	23	24	Dakota	30 feet of closure. Untested.
Baca anticline	20, 21	30	Dockum	Broad low anticline. Several wells produce carbon dioxide gas.
Fowl Canyon anticline	15	30	Dakota	Untested.
Lost anticline	16	29	Dakota	Untested.
Sierra Negra anticline	19, 20	31	Dockum	Untested.
QUAY COUNTY				
Circle S anticline	8, 9	28, 29	Triassic	Untested.
Hargis anticline	11	29	Dakota	Untested.
Logan anticline	13	34	Triassic	Olean Petroleum Co. No. 1 Woods; T. D. 3,960 feet; dry; reported to have entered granite.
SAN MIGUEL COUNTY				
Bell arch	14, 15	25-28	Triassic	Untested.
Gaucho anticline	14	29	Triassic	Untested.
Las Vegas anticline	17	18	Dakota	Untested.
Lourdes anticline	14-16	18	Triassic	Untested.
Nuevo anticline	12	14, 15	Permian	Plunging anticline, no closure. Untested.
Plunging anticlines	13, 14	26, 27	Triassic	Plunging anticlines, no closure. Untested.
Portales anticline	15	29	Dakota	Comanche Oil Co. No. 1 Trigg; T. D. 2,100 feet; dry.
Ribera anticline	13	13, 14	Permian	Small elongated structure; less than 100 feet of closure; untested.
Romero anticline	15	16	Dakota	Midwest Refining Co. No. 1 Farmer; T. D. 2,215 feet; dry. Believed to have ended in Yeso formation.
Ross anticline	15	29	Dakota	
UNION COUNTY				
Cimarron Valley anticline	31	36	Jurassic	Untested.
Pasamonte anticline	23, 24	30	Dakota	Pasamonte No. 1 Heringa; T. D. 2,787 feet; dry. Believed to have ended in granite.
Perico anticline	26	33	Dakota	Small domal uplift; 50 feet of closure; untested.

2,925 feet in "granite wash." There seems little doubt that the material at total depth was correctly identified, as Thomas[6] reports that cuttings from the bottom of the hole effervesced freely in hydrochloric acid and therefore cannot be considered true granite. The Zurick well thus is not a thorough test of the structure. It is thought that the Clapham-Leon-Tate trend deserves a complete test.

OTHER ANTICLINAL STRUCTURES IN THE NORTHEAST AREA

Anticlinal folds evident in surface beds are present in many parts of the Northeast Area and the axes of several such structures are shown on the Oil and Gas Map, Plate 4. Detailed data for most of these structures are not available, and they are therefore listed in the table, page 157, together with such information as is at hand regarding their size, shape, surface formations, and results of drilling.

[6]Thomas, James R., Personal communication, December 1941.

SOUTHEAST AREA

GENERAL GEOGRAPHY

ROBERT L. BATES

Southeastern New Mexico is divided into three physiographic areas: the Sacramento and Guadalupe Mountains on the west, the Pecos Valley in the central part, and the Llano Estacado on the east.

SACRAMENTO AND GUADALUPE MOUNTAINS

These mountain ranges are cuestas, with steep western fronts facing the Tularosa and Salt Basins, and gently sloping eastern flanks. (See map, Plate 13.) The eastern slopes have been dissected by many tributaries of the Pecos River, most of which flow only intermittently. A considerable forest cover is present in the higher parts of the Sacramentos, which reach an altitude of more than 9,000 feet. On the lower slopes of this range, and over most of the Guadalupes, the country is open and offers good ranching land. Farming and fruit-growing are done on a small scale in the narrow but fertile valleys of the Rio Hondo and Rio Penasco, which are permanent streams.

The Guadalupes are served only by ungraded roads. The Sacramentos are crossed in the central part by State Highway 83, and on the north by U. S. Highway 70. Large parts of both ranges are included in the Lincoln National Forest, and the northern Sacramentos lie within the Mescalero Apache Indian Reservation.

PECOS VALLEY

The Pecos River has excavated a wide shallow valley between the mountainous area on the west and the plains to the east. The west side of the valley is formed by the long slopes of the Sacramento and Guadalupe Mountains. The east boundary is Mescalero Ridge, the west edge of the high plains. There is well-developed drainage from the west into the Pecos, but essentially none from the east. The strip of territory 20 to 30 miles wide between the river and Mescalero Ridge contains so many sink-holes, other closed depressions, and sand-dune areas that all drainage is local.

A prominent feature of the Pecos Valley is a long row of westward-facing bluffs composed of redbeds and gypsum, which extend from the foothills of the Guadalupe Mountains west of Carlsbad northeast to the south end of Lake McMillan, and thence north along the east side of the river to beyond Roswell. Where this row of hills crosses the Pecos a few miles above Carlsbad, the stream crosses bedrock ledges and the channel narrows slightly. South of the town the channel again widens.

The Pecos Valley carries U. S. Highway 285 and the line of the Atchison, Topeka, and Santa Fe railway which connects Clovis with Pecos, Texas.

LLANO ESTACADO

The Llano Estacado (Spanish, staked plain), is a flat treeless plateau. The soil is good for farming but moisture is scant. Drainage is into sink-holes, which in places thickly pock-mark the Llano surface.

The Llano Estacado ends on the west along an escarpment, Mescalero Ridge. This ridge persists toward the north for more than 100 miles, but it diminishes in prominence toward the south, practically disappearing in southern Lea County. The towns of Tatum, Lovington, and Hobbs are situated on the Llano Estacado.

MAJOR STRUCTURAL FEATURES

RONALD K. DEFORD[1]

Midland, Texas

For the purpose of this discussion southeastern New Mexico is subdivided as shown on the map, Plate 13, into seven large structural units:

1. Delaware Basin (northern part)
2. Central Basin Platform (northwestern part)
3. Carlsbad Shelf
4. Artesia-Vacuum Trend
5. Guadalupe Mountains and Foothills
6. Sacramento Cuesta
7. Roswell-Tatum Area.

DELAWARE BASIN

Only a part of the Delaware Basin lies in New Mexico (see map, Fig. 10). All of southeastern New Mexico and west Texas subsided practically throughout Permian time. The Delaware Basin, which sank more rapidly than the other units, was and remains the dominant structural feature. Relative to it the Central Basin Platform, the Artesia-Vacuum Trend, and even the Carlsbad Shelf were uplifted.

CENTRAL BASIN PLATFORM

A wide flat-topped ridge, known as the Central Basin Platform, separates the Delaware Basin from the Midland Basin in Texas (see map, Fig. 10) . Like the Delaware Basin, it is a cardinal feature of subsurface structure in southeastern New Mexico. Most of the major oil fields of Lea County are located on the northwestern part of the Central Basin Platform.

[1] Geologist, Argo Oil Corporation.

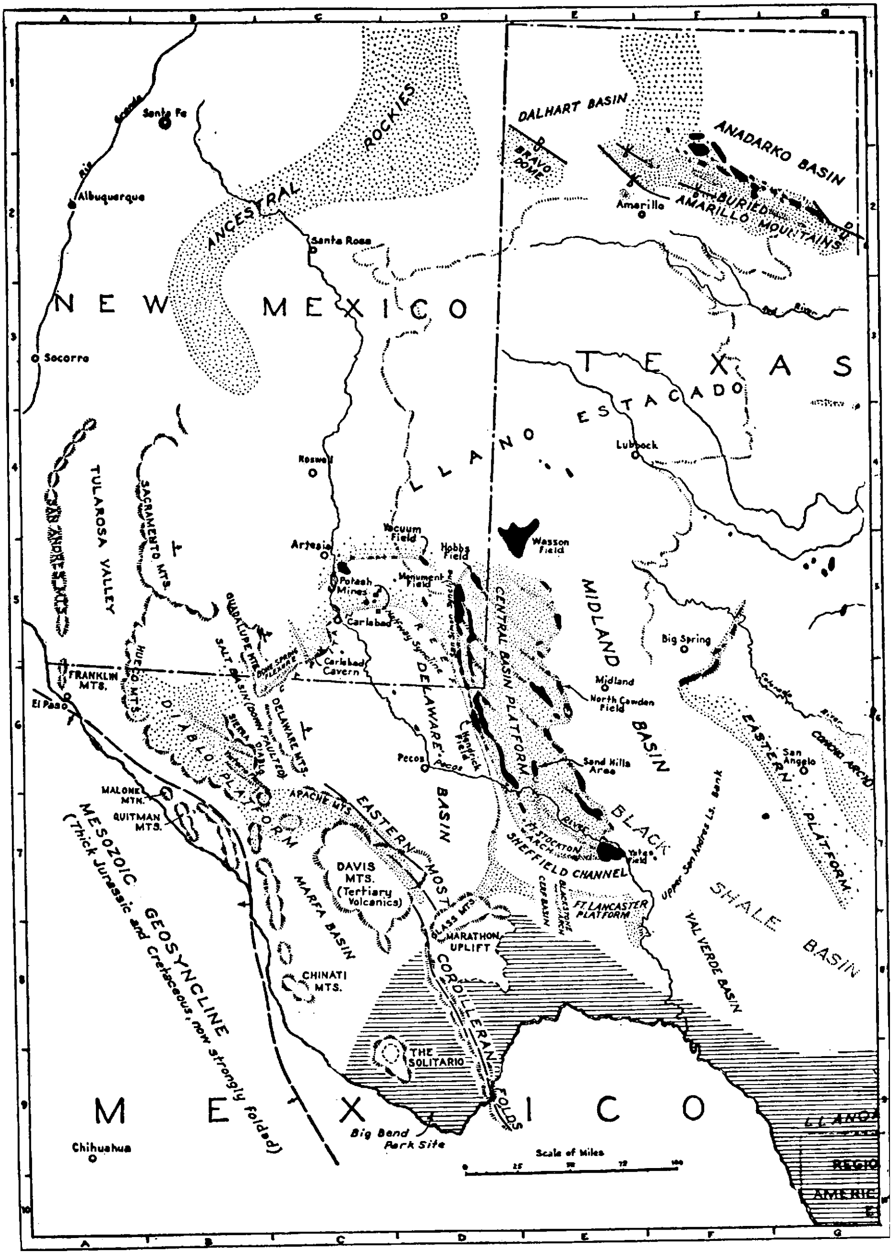


FIGURE 10.—Map showing regional structure of West Texas and eastern New Mexico. (From Lewis, F. E., Position of San Andres group, West Texas and New Mexico: Bull. Amer. Assoc. Petrol. Geol., Vol. 25, No. 1, p. 76, 1941.)

CARLSBAD SHELF

The Carlsbad Shelf is bounded on the south by the Delaware Basin, on the east by the Central Basin Platform from which it is separated by the San Simon Syncline, on the north by the Artesia-Vacuum Trend, and on the west by the Pecos River. (See map, Plate 13.) The Carlsbad Shelf is really a part of the Delaware Basin; since Capitan time, however, its southern edge has been marked by the steep basinward face of a thick barrier reef. In Castile time, next after the Capitan, the Permian sea was confined within the reef, but subsequently it spread again beyond this rim northward and eastward before its final retreat southward into Texas and old Mexico.

The name Carlsbad Shelf connotes the presence in the subsurface of the Carlsbad limestone,[2] the thin-bedded lagoonal correlative of the massive Capitan reef rock that forms the basin rim. The Carlsbad limestone includes the thin-bedded limestone facies of the Tansill, Yates, and Seven Rivers formations that adjoin the Capitan reef and grade into it.

ARTESIA-VACUUM TREND

The Artesia-Vacuum Trend has long been known as the Artesia-Maljamar Trend, but exploration has shown that it extends eastward to the Vacuum pool. As the Maljamar pool now lies midway on its extent, the name Artesia-Vacuum has become more definitive than the older term.

The distinctive element of the Artesia-Vacuum Trend is its steep south flank. Like the Capitan reef this steepened southern limb faces the Delaware Basin, but its steepness is only relative : the face of the Capitan reef dips 25° to 30° basinward, at the rate of 2,500 to 3,000 feet per mile, whereas basinward dip on the south flank of the Artesia-Vacuum Trend is but 2° to 3°, or 200 to 300 feet per mile.

GUADALUPE MOUNTAINS AND FOOTHILLS

The Guadalupe Foothills adjoin the Carlsbad Shelf on the west. (See map, Plate 13.) They are formed by the outcrops of thin-bedded Carlsbad limestone and Capitan reef limestone, which emerge from the subsurface west of the Pecos River and rise westward to the northwest-trending crest of the Guadalupe Mountains.

Rocky Mountain folding raised these mountains in Tertiary time; they are much younger than the Delaware Basin and other Permian structures. Consequently it might seem that the area herein called "Guadalupe Mountains and Foothills" is not a separate structural unit but merely a part and continuation of the Carlsbad Shelf brought to the surface by the mountain-making

[2] DeFord, R. K., and Lloyd, E. R., West Texas-New Mexico symposium, Part I; Editorial introduction: Bull. Amer. Assoc. Petrol. Geol., Vol. 24, No. 1, pp. 10-11, January 1940.

uplift. Such a picture, however, is not entirely accurate. West of the Pecos River the Rustler formation rests directly on Carlsbad limestone; east of the river these formations are separated by the thick Salado halite. This condition shows that eastward tilting of the region began in Permian time. The geologic section in the Guadalupe Mountains and Foothills is thus not simply a continuation of the section of the Carlsbad Shelf.

SACRAMENTO CUESTA

The area north of the Guadalupe Mountains and west of the Pecos River is called the Sacramento Cuesta.[3] The precipitous west face of the Sacramento Mountains rises more than a mile above Tularosa Valley. From the crest of the mountains the outface of the cuesta descends in a long slope to the Pecos River, which is 80 miles to the east and nearly 6,000 feet lower. The long slope of the Sacramento Cuesta is capped by San Andres limestone.

ROSWELL-TATUM AREA

East of the Pecos River the eastward dip of the Sacramento Cuesta continues in the subsurface to the Texas line and beyond. The floor of the Pecos Valley slopes westward toward the river at 20 to 25 feet per mile. A westward-facing escarpment about 100 feet high marks the boundary between the valley and the high plains. The flat surface of the Llano Estacado is the outface of this high plains cuesta. It descends about 15 feet per mile in a southeasterly direction.

The Llano Estacado is formed by a capping of from 50 to 200 feet of Pliocene gravel, sand, and caliche. The original plain extended westward to the mountains from which it is now separated by the Pecos Valley. It also extended somewhat farther south: two remnants or outliers in southern Lea County are shown by hachures on the map, Plate 13, one overlying the Carlsbad Shelf and the other over the Delaware Basin.

King[4] calls the area north of the Delaware Basin and the Central Basin Platform the "Northwestern Shelf Area." The Sacramento Cuesta and the Roswell-Tatum Area constitute the major part of the Northwestern Shelf Area.

STRATIGRAPHY

ROBERT L. BATES

The stratigraphy of southeastern New Mexico has been the subject of a number of papers published over a period of several years. A recent comprehensive work by King[1] summarizes much of the information in earlier papers and contains a large amount

[3] Darton, N. H., Geologic structure of parts of New Mexico: U. S. Geol. Survey Bull. 726-E, pp. 207-210, 1922.

[4] King, P. B., Permian of West Texas and southeastern New Mexico: Bull. Amer. Assoc. Petrol. Geol., Vol. 26, No. 4, Table VII, p. 667 ; Fig. 18, p. 665 ; Pl. I; April 1942.

[1] King, P. B., Op. cit., pp. 535-763.

of new data. Stratigraphic details of individual oil fields in Eddy and Lea Counties are given in the present bulletin on the following pages, and a stratigraphic section for southeastern New Mexico is shown on the correlation chart, Plate 2. A discussion of the most important formations of the Southeast Area is found under Permian System, pages

The stratigraphy of southeastern New Mexico is essentially Permian stratigraphy. Rocks older than the Permian have been found in Texas, by deep drilling on the Central Basin Platform; but they have not been explored by the drill in southeastern New Mexico. Rocks younger than the Permian include the Triassic, Tertiary, and Quaternary, none of which record stratigraphic history of any importance in comparison with that of the Permian.

The Permian strata are divided in ascending order into the Wolfcamp, Leonard, Guadalupe, and Ochoa series. Throughout the time of deposition of the first three of these series, and during the early part of the Ochoa epoch, the Delaware Basin was the controlling factor of sedimentation in southeastern New Mexico. During Wolfcamp and Leonard time, one set of strata was built up in the basin and a second set on the shelf area back of the basin rim. (See cross section, Fig. 11.) The first included the Hueco and Bone Spring limestones; the second included the Abo, Yeso, Glorieta, and San Andres formations and the Victorio Peak limestone which is equivalent to the San Andres. After the contemporaneous deposition of these two sets of strata, a period of extensive reef-building began along the margin of the Delaware Basin sea. Limestone reefs were in existence throughout Guadalupe time. They consisted of massive nearly structureless limestone, and they served to separate completely the sediments being deposited in the Delaware Basin from those being laid down in the shelf area. Consequently the picture was complicated to the extent that the Guadalupe series, instead of having two facies like the Wolfcamp and Leonard series, had three facies: basinal, reef-zone, and shelf or lagoonal. In the basinal facies is the Delaware Mountain group, consisting of three formations which are dominantly sandstone; in the reef facies, contemporaneous in age but completely different in Ethology, are hundreds of feet of massive limestone known as the Capitan limestone; and in the shelf or lagoonal facies are five well-stratified formations of the Whitehorse group. In the Guadalupe Mountains a fourth facies has been recognized, intermediate in position between the Capitan limestone and the Whitehorse beds and consisting of the Goat Seep and Carlsbad thin-bedded limestones.

The Capitan Reef flourished for a long time but finally ceased developing. A thick deposit of evaporites, chiefly anhydrite, then accumulated in the Delaware Basin; it had no counterpart in the shelf area. When the basin had been filled with this

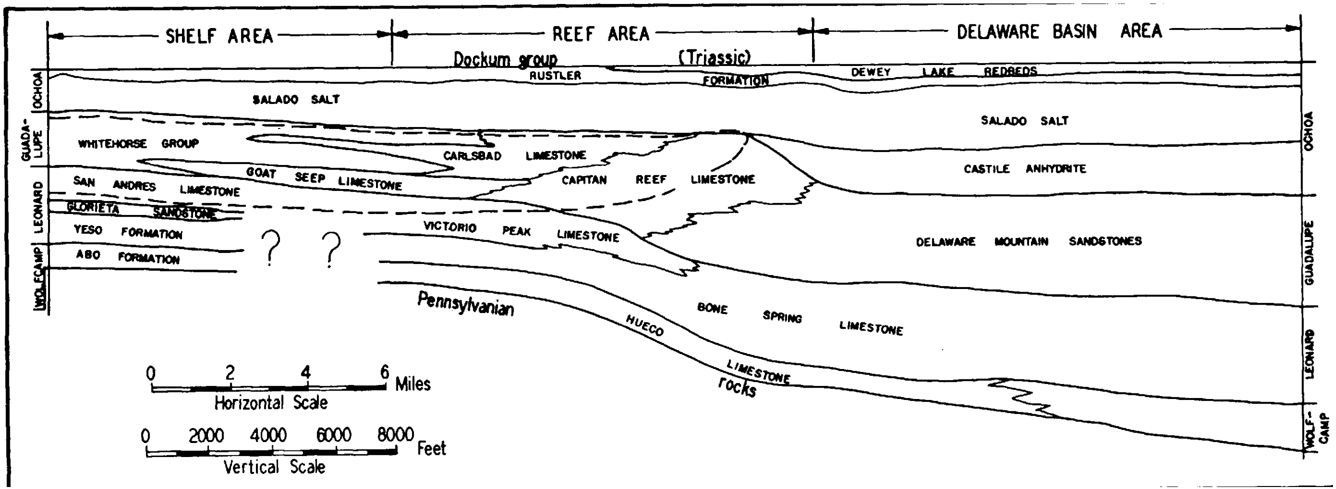


FIGURE 11.—Northwest-southeast cross section of the Capitan Reef and associated strata in central Eddy County, drawn parallel with the greatest change in facies. Dashed line encloses part of section in which commercial amounts of oil and gas have been found. (Modified from King, P. B., Permian of West Texas and southeastern New Mexico: Bull. Amer. Assoc. Petrol. Geol., Vol. 26, No. 4, Fig. 2-A, p. 542, April 1942.)

material, known as the Castile formation, the entire region was flooded and then subjected to intense evaporation, so that a great thickness of rock salt, the Salado formation, accumulated. This covered shelf, reef, and basinal areas and is the oldest Permian formation to maintain uniformity over the whole region. The Salado was succeeded by younger Permian formations and these in turn by Triassic redbeds.

OIL AND GAS

ROBERT L. BATES

All the oil and gas produced in southeastern New Mexico comes from rocks of the Leonard and Guadalupe series of Permian age that lie above the Capitan Reef or on its shelf side (see map, Plate 13, and cross section, Fig. 11.) These rocks extend from the base of the Salado formation down to a horizon somewhere near the middle of the San Andres limestone.

Oil and gas are found in porous limestone, for example the San Andres in the Hobbs pool and the Seven Rivers in the Cooper pool; and in sandstone, for example the Queen formation in the Mattix pool and the Loco Hills sand (middle Grayburg) in the Loco Hills pool. Oil and gas are found in anticlines with closure, as at Hobbs and Vacuum, and in noses or terraces with little or no closure, as at Grayburg-Jackson and Maljamar. The tendency has been for oil and gas to accumulate on the reefward side of noses and anticlines—i.e., the south side of the long Artesia-Vacuum trend and the west side of the Cooper-Jal and Langlie-Mattix trends.

In the Hobbs and Eunice-Monument pools accumulation seems to have taken place according to the well-known anticlinal theory, with a gas cap overlying an oil reservoir which in turn overlies a water zone. Fluid levels are under gravity control and cut across stratigraphic lines. In many of the other pools, however, accumulation in sandstone has been controlled by loss of permeability or by complete wedging-out up the dip, forming a so-called stratigraphic trap; and accumulation in limestone has taken place where pores on the upper side of a porous zone have been sealed, forming a porosity trap. Although isolated anticlinal structures are not difficult to locate by means of geophysics, sandstone lenses or porosity traps are generally difficult to find.

The important general questions of origin of the oil and origin of limestone porosity remain unanswered. Distribution of oil accumulations indicates that the oil may have been derived in some way from the Capitan Reef, where great amounts of organic material must have been formed. Porosity may have been produced in part at least by the dolomitization of great thicknesses of limestone after solidification.

An oil and gas map of southeastern New Mexico is included as Plate 14.

EDDY COUNTY

ARTESIA POOL

ROBERT L. BATES

LOCATION

The Artesia pool lies in Eddy County, and as now defined includes T. 18 S., Rs. 27 and 28 E.; T. 19 S., R. 28 E; and the southern row of sections in T. 17 S., Rs. 27 and 28 E. (See map, Plate 14.) The total area is 120 square miles. The field's western boundary is three miles east of Dayton. The Pecos River flows through the westernmost tier of sections. The altitude of the field approximates 3,600 feet.

HISTORY

The following discussion is quoted from Winchester.[1]

The location that brought in the Artesia field is credited to V. H. McNutt, geologist for Flynn, Welch & Yates. Several wells had previously been drilled west of the Pecos with encouraging showings of oil, and many of the artesian wells drilled in the Pecos Valley had found both oil and gas showings. Mr. McNutt recommended that a well be drilled on the east side of the Pecos River, and a well was spotted in sec. 31, T. 18 S., R. 28 E., on a block held by Flynn, Welch & Yates. The well was completed at a depth of 1,930 feet in August, 1923, making 1,500,000 cubic feet of gas and some oil. Well No. 2, in sec. 25, T. 18 S., R. 27 E., came in in February, 1924, with 2,500,000 cubic feet of gas at a depth of 2,085 feet. Well No. 3, located down the dip and east of the earlier wells, in sec. 32, T. 18 S., R. 28 E., was completed on April 9, 1924, as a 15-barrel well at a depth of 1,947 feet. This well attracted much attention, and many operators began to acquire acreage in the vicinity. The next important development occurred when a group of mining men from Joplin, Mo., and Picher, Okla., operating under the name of the Picher Oil Co., moved a rig into sec. 12, T. 18 S., R. 27 E. In August, 1924, their well made a natural flow of oil from 1,957 feet, was shot, and settled to 10 barrels of oil per day. The next important well was the Twin Lakes No. 2, in sec. 28, T. 18 S., R. 28 E., which was completed late in 1924 at a depth of 2,070 feet. This well made several natural flows, and after being shot had an initial production of more than 250 barrels a day. Drilling progressed rapidly thereafter, and the Artesia field soon became a reality.

In the decade 1931-41 few additional wells were drilled in the producing districts. A small area was developed in 1932-36, when Flynn, Welch & Yates completed six producers and two dry holes in sec. 10, T. 19 S., R. 28 E. A second area of recent development lies in secs. 35 and 36, T. 17 S., R. 27 E., where a number of wells were drilled in 1941 to depths of 450 to 600 feet.

STRATIGRAPHY

The geologic section encountered in wells in the northern part of the pool is similar to that of the Red Lake area. (See page 187.) Information on the geologic section in the central part of the Artesia pool is provided by the following logs.

[1] Winchester, D. E., The oil and gas resources of New Mexico: N. Mex. Bur. Mines Bull. 9, p. 147, 1933.

Log of Ohio Oil Co. No. 1 Toomey-Allen
NW¼SE¼ Sec. 28, T. 18 S., R. 28 E.
Completed in 1925

Formation and Description	*Bottom (Feet)*
Dewey Lake, 195 feet.	
Red sandy shale	100
Red conglomeratic sandstone	172
Red shale	195
Rustler, 170 feet.	
Light gray limestone, and quartz sandstone	210
Red shale	215
Light gray limestone with a few fine quartz grains	245
Red shale	265
Red shale and gypsum	287
White gypsum	300
Pale red shale and gypsum	349
Slightly iron-stained gypsum	365
Salado, 105 feet.	
Salt and gypsum	415
White salt	470
Tansill, 245 feet.	
Anhydrite and gypsum	644
Gray dolomite, gypsum, and anhydrite	700
Gypsum and anhydrite	715
Yates, 250 feet.	
Fine-grained quartz sand; gypsum, and anhydrite	720
White and gray gypsum and anhydrite	770
Gypsum, anhydrite, and red shaly sandstone	775
White and red gypsum and anhydrite	815
White gypsum and anhydrite, and red shaly sandstone	845
Dull red anhydrite and shaly sandstone	965
Seven Rivers, 635 feet.	
Gray and white gypsum and anhydrite	1005
White anhydrite with small amount of red shale	1020
Gray and white anhydrite	1050
Anhydrite with small amount of yellowish dolomite	1055
Buff to gray dolomite and anhydrite	1065
Gray anhydrite	1110
Dolomite and gray anhydrite	1125
Anhydrite	1135
Anhydrite 30%, dolomite 70%	1145
Anhydrite	1210
Anhydrite 50%, dolomite 50%	1305
Anhydrite	1330
Anhydrite and red shale	1340
Anhydrite with small amount of dolomite	1350
Anhydrite	1365
Anhydrite with small amount of red shale	1380
Red shale	1390
Anhydrite and red shale	1425
Anhydrite	1465
Gray and red shaly anhydrite	1600
Queen, 300 feet.	
Red anhydrite and quartz sandstone	1630
Anhydrite and gray dolomitic limestone	1640

Anhydrite	1650
Anhydrite and red sandy shale	1670
Anhydrite	1675
Anhydrite and red shale	1740
Anhydrite, red shale, and dolomitic limestone	1750
Anhydrite and red shale	1820
Anhydrite and dolomitic limestone	1835
Anhydrite, red shale, and dolomitic limestone	1840
Gray dolomitic limestone, quartz sandstone, and some anhydrite	1850
Dark red sandstone and sandy shale with small amount of anhydrite	1900
Grayburg, 178+ feet.	
Buff dolomitic limestone	1930
Gray limestone and anhydrite	1945
Red shale 50%, anhydrite 30%, limestone 20%	1950
Gray to cream dolomitic limestone	2003
Limestone 80%, gray shale 15%, anhydrite 5%	2010
Light gray dolomitic limestone	2030
Light gray dolomitic limestone 65%, gray shale 35%	2036
Gray shale 85%, remainder limestone and anhydrite	2042
Fine-grained quartz sandstone 80%, gray shale 20%	2046
Fine-grained quartz sandstone 80%, dark red shale 20%	2053
White finely crystalline dolomitic limestone; oil pay; total depth	2078

The entire Grayburg formation and 565 feet of the underlying San Andres dolomite were penetrated in a dry hole four miles southeast of the Toomey-Allen well. A description of these beds follows.

Partial Log of Ohio Oil Co. No. 1 Merchant
SW ¼SE¼ Sec. 1, T. 19 S., R. 28 E.
Completed in 1925

Formation and Description	*Bottom (Feet)*
Basal sandstone of Queen formation. Same bed as in last entry under Queen in previous log. 73 feet.	
Fine-grained red and gray sandstone	1845
Grayburg, 645 feet.	
Gray dolomitic limestone	1900
Gray dolomitic limestone with small amounts of sandstone and anhydrite	1945
Gray dolomitic limestone	2070
Gray dolomitic limestone with small amount of anhydrite	2090
Dull gray mottled dolomitic limestone	2170
Dark gray mottled dolomitic limestone, and quartz sandstone	2175
Gray fine quartz sandstone with dolomitic limestone and small amount of anhydrite	2185
Dark gray dolomitic limestone	2240
Gray dolomitic limestone with quartz sandstone	2245
Fine gray quartz sandstone, and dolomitic limestone	2255
Gray dolomitic limestone and fine quartz sandstone	2265
Gray dolomitic limestone	2290
Gray fine quartz sandstone with dolomite and anhydrite	2305
Gray dolomitic limestone 85%, sandstone 15%	2310
Gray dolomitic limestone	2320
Light gray dolomitic limestone	2355
Fine quartz sandstone	2360

Sandstone and dolomitic limestone	2385
Light gray dolomitic limestone	2395
Light gray quartz sandstone	2400
Dolomitic sandstone	2410
Gray dolomitic limestone	2430
Light gray dolomitic limestone 85%, sandstone 15%	2485
Fine quartz sandstone	2490

San *Andres, 565+ feet.*

Cream-colored dolomitic limestone	2530
Light colored dolomitic limestone and quartz sandstone	2540
Yellow-white dolomitic limestone, small amount of anhydrite	2707
Yellow-white and dark gray dolomitic limestone	2734
Dark gray shale 65%, white dolomitic limestone 35%	2787
White dolomitic limestone	2800
White dolomitic limestone 50%, dark gray shale 50%	2812
Light gray to white dolomitic limestone; total depth	3055

STRUCTURE

The producing districts in the central part of the Artesia field are located on structural noses on the south flank of a wide northeast-trending high beneath the northern part of the field. The producing area in secs. 35 and 36, T. 17 S., R. 27 E., occupies a position at the crest of the main trend.

RESERVOIR ROCKS

The Ohio No. 1 Toomey-Allen, the log of which is given above, is typical of the wells in sec. 28, T. 18 S., R. 28 E. In it oil is secured from a porous dolomite zone 150 to 175 feet below the top of the Grayburg formation, at a total depth of 2,078 feet. Average total depth of 38 wells in the same section is 2,073 feet, and they all produce from the same zone.

However, such uniformity of reservoir rocks is the exception rather than the rule for the Artesia area. Winchester[2] states:

> The producing portion of the rocks in the Artesia field must be considered as a zone rather than as a definite stratigraphic horizon. The producing zone is that portion of the dolomite beds which is porous. With rare exceptions sand does not constitute more than 15 percent of the reservoir rocks, and in many of the wells the percentage of sand is much less than this figure. The porosity of the zone is thought to be due largely to the solution of inclusions of anhydrite and of some of the dolomite by underground water. There is conclusive evidence of circulation of water in close proximity to the producing zone. The drill has passed through strata, both above and below the pays, in which the dolomite has been honeycombed by solution and in which a considerable amount of travertine has been deposited. Large samples of this material have been obtained when wells have been shot. In a well on the lease of the Williams Petroleum Co. in sec. 17, T. 18 S., R. 28 E., several hundred feet of oil disappeared from the hole when the drill passed into one of the honeycombed formations below.
>
> In local areas the producing horizon seems to occupy a definite place in the log, as in sec. 28, T. 18 S., R. 28 E. A few miles away, as in sec. 4, only a small showing is encountered at this horizon, and the principal pay is approximately 350 feet lower in the dolomite. In sec. 17 an intermediate condition is found, the upper horizon producing in one well, the lower in another, and a third stray sand in another.

[2] Op. cit., p. 151.

From a study of the well logs and the production of the Artesia field, it is quite apparent that porosity is the controlling factor influencing productivity, and that geologic structure is only of secondary importance. The Empire pool [in sec. 35, T. 17 S., R. 27 E.], located at the top of a subsurface anticlinal uplift, has only a few wells and these are relatively small. . . . The principal producing areas are located well down the dip from the structural high. Oil accumulation appears to be restricted to the up-dip ends of porous lenses. Salt water occurs in the producing zone in wells east of the field.

Oil and gas do not maintain the ideal relationship. Wells that yield gas and very little oil are irregularly distributed among the oil-producing wells, and Davis[3] has suggested that this is explainable by varying degrees of porosity in the dolomite.

THE OIL

Oil from the Artesia pool has a gravity of 32° to 37° A. P. I., and a sulfur content of 0.85 to 1.02 percent, as indicated by the following analyses made by the United States Bureau of Mines.

Analyses of Oil from the Artesia Field

Sample No.	25226		27596		25421	
THE CRUDE OIL Specific gravity (°A. P. I.).	32.1		37.8		35.4	
Pour point.	15° F.		Below 5° F.		10° F.	
Sulfur (percent).	1.02		0.84		0.87	
Universal Saybolt viscosity at 100° F., seconds	47		39		42	
DISTILLATION, BUREAU OF MINES HEMPEL METHOD						
DRY DISTILLATION. First drop.	63° C.		28° C.		29° C.	
	Per-cent	Gravity (°A. P. I.)	Per-cent	Gravity (°A. P. I.)	Per-cent.	Gravity (°A. P. I.)
Up to 50° C. (122° F.)			3.0		1.7	77.2
50° to 75° C.	0.7		3.4	80.3	2.3	74.2
75° to 100° C.	2.7	63.1	4.8	62.9	6.6	64.2
100° to 125° C.	5.4	55.7	8.0	55.7	7.4	56.9
125° to 150" C.	6.2	50.9	6.5	50.9	6.3	51.8
150° to 175° C.	6.0	47.6	5.0	47.6	5.2	47.8
175° to 200° C.	4.9	45.4	4.5	45.2	4.7	44.9
200° to 225° C.	5.8	42.8	4.7	43.0	5.0	42.3
225° to 250° C.	6.1	39.8	5.6	39.8	5.4	39.4
250° to 275° C.	7.1	36.8	5.9	36.4	6.5	36.2
VACUUM DISTILLATION (40 mm.)						
Up to 200° C.	4.9	32.5	2.8	32.5	3.7	33.0
200° to 225° C.	7.9	31.1	5.4	31.7	6.0	32.8
225° to 250° C.	5.3	28.2	51.1	29.1	5.3	30.0
250° to 275° C.	4.7	25.9	4.9	26.8	4.9	28.9
275° to 300° C.	5.1	24.4	5.5	24.3	6.3	26.4
Carbon residue of residuum	9.6		8.3		8.4	
Carbon residue of crude	2.6		1.8		2.1	
SUMMARY						
Light gasoline	3.4	63.1	11.2	72.4	10.6	68.4
Total gasoline and naphtha	25.9	51.6	35.2	57.2	34.2	56.2
Kerosene distillate	5.8	42.8	4.7	43.0	5.0	42.3
Gas oil	23.5	35.2	19.5	35.4	21.5	35.2
Nonviscous lub. distillate	11.0	30.6-25.6	9.3	30.4-26.1	11.2	31.5-27.5
Medium lub. distillate	6.6	25.6-23.1	6.4	26.1-23.1	5.4	27.5-25.0
Residuum	26.8	15.1	21.9	15.1	22.0	15.3
Distillation loss	0.4		3.0		0.7	

Sample No. 25226; Picher Oil and Gas Co. No. 1 Well, sec. 12, T. 18 S., R. 27 E. ; depth 1,963-2,003 feet.

Sample No. 27596; Empire Gas and Fuel Co. No. 1 Russell Well, sec. 35, T. 17 S., R. 27 E.; depth, 1,592-1,608 feet.

Sample No. 25421; V. K. F. Producing Co. Well, sec. 17, T. 18 S., R. 28 E.; depth 1,995 feet.

[3] Davis, M. J., Artesia field, Eddy County, New Mexico : in Structure of Typical American Oil Fields, Vol. 1, p. 120, Amer. Assoc. Petrol. Geol., 1929.

THE GAS

Many of the wells in the Artesia area yield considerable amounts of gas which is fairly rich in gasoline content. Some 200 wells in the area are connected with the absorption plant of the Phillips Petroleum Co. in the field.

The gas from the Leonard and Levers area is a sweet gas with a heating value of 1,050 B.t.u.

PRODUCTION

Most of the recent drilling, in secs. 35 and 36, T. 17 S., R. 27 E., has been with cable tools. Unlike the early wells of the Empire Gas and Fuel Co., which produced from the Grayburg limestone section at 1620-30 feet, the newer wells have found oil in the upper Whitehorse beds at depths of only 450 to 600 feet. Most of these wells are pumping, and the average daily potential is well under 100 barrels. Casing programs vary.

Production of the Artesia field for 1941 was 159,079 barrels; cumulative production to the end of 1941 totaled 4,637,034 barrels.

FUTURE POSSIBILITIES

Parts of the south half of T. 18 S., R. 27 E., and much of the south half of T. 19 S., R. 28 E., are still unexplored. Small producing structures or depositional traps may be found in these areas at depths now productive elsewhere. Possibility of production over the entire field from greater depths, in the San Andres, Yeso, or older beds, is problematical.

DAYTON POOL

JOHN EMERY ADAMS[1]

Carlsbad, New Mexico

The Dayton pool is located in the southeastern part of T. 18 S., R. 26 E., Eddy County. (See map, Plate 14.) It lies west of the Pecos River and south and east of the town of Dayton. The producing area includes secs. 15, 24, 25, 26, and 35, which lie in the flood plain of the river. The limits of production are not entirely defined, but as dry holes have been drilled among producers, production will probably be spotty.

The first productive wells in New Mexico were in the Dayton pool. Two oil wells and a gas well were drilled here in 1909. Oil came from below the artesian water of the area. Although these wells flowed appreciable amounts of oil, they were not commercial producers; the water could not be shut off due to poor cementing technique. Fifteen more wells were drilled in the township between 1912 and 1940. Most of these encountered shows of oil below the water, but none was completed as an oil well. The deepest was the National Exploration No. 2 Dayton, drilled to 4,046 feet in 1919.

The discovery well of the present producing pool was the Bassett and Birney No. 1 Platt, in the SW¼SW¼ sec. 26. It was spudded May 5, 1940, drilled to 2,545 feet, plugged back to 1,182

[1] Geologist, Standard Oil Company of Texas.

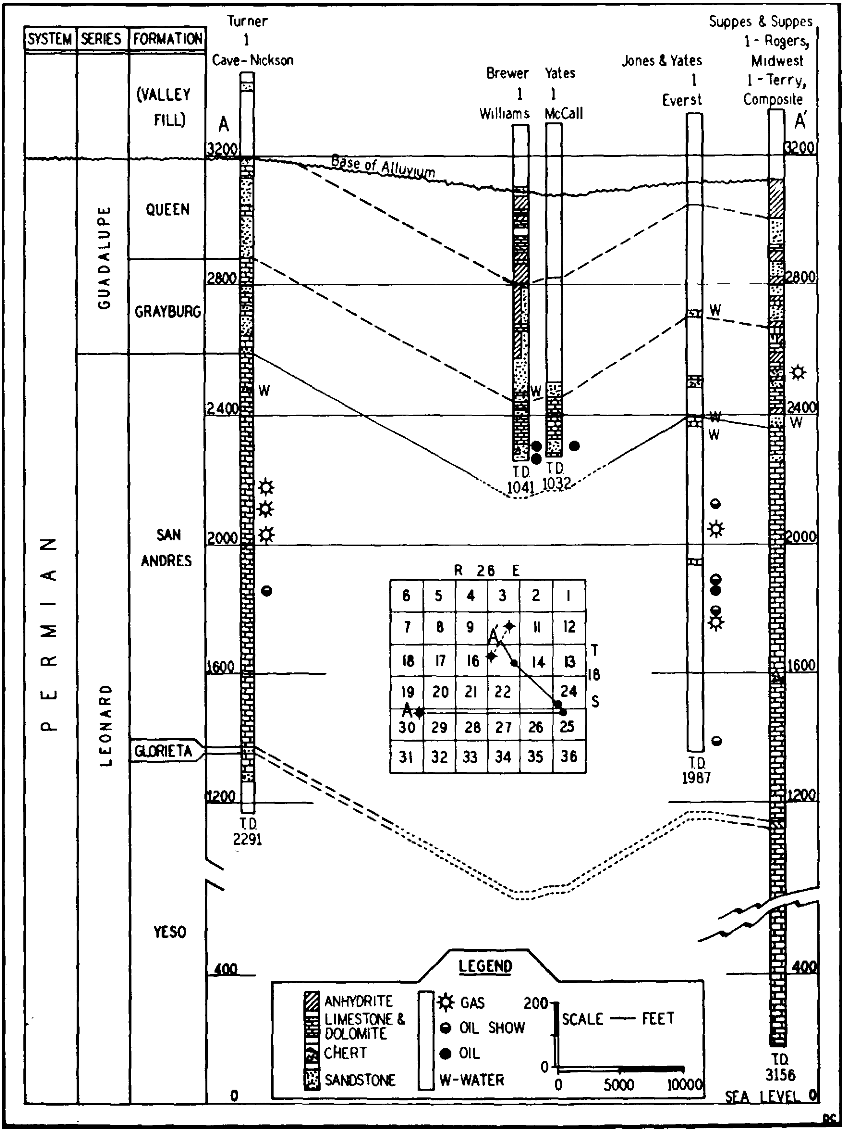


FIGURE 12.—Cross section of the Dayton pool, Eddy County. Line of section is shown on inset map.

feet, and completed on September 3, 1940, for an estimated two barrels of oil daily from pay topped at 930 feet. Since the completion of this well, eight more oil wells, a gas well, and several dry holes have been completed. Initial production ranges from two to 100 barrels of oil per day.

The first formation encountered beneath the cover of alluvium is the Seven Rivers, which has been truncated leaving only the basal 200 to 300 feet. The Queen sandstone, next below, is about 360 feet thick, and the Grayburg about 300 feet. These formations are underlain by 1,350 feet of San Andres dolomite, beneath which lies a thin section of Glorieta sandstone and an unknown thickness of Yeso and older formations. All the wells encountered flowing artesian water in the lower Queen or upper Grayburg formations.

Local structure seems to consist of a series of small domes located on the eastward regional dip. As indicated by the cross section, Fig. 12, both structural and stratigraphic interpretations are hampered by the lack of information from cuttings and other essential data.

Wells produce from two zones, one a sand near the middle of the Grayburg formation and the other a porous dolomite in the upper part of the San Andres. Oil from the Grayburg is sweet, that from the San Andres contains sulfur. Gravity of the oil runs about 36° A. P. I. No chemical analyses have been made, but the oil appears similar to that in pools east of the Pecos River. Gas, which occurs with the oil and in the one gas well, is sweet. The wells are drilled with spudders. Two strings of casing are used, the oil string being cemented below the artesian water. All the oil wells flow pipe line oil.

The land in the Dayton area is divided into farms and the oil is being produced by independent operators. Production for 1941 was 30,219 barrels, while total production to the end of that year was 38,889 barrels.

Although the limits of production from present producing depths have not been fully defined, and deeper possibilities have only been partly tested, it seems probable that the Dayton pool will never be a major producing area. The acidizing of shows such as are encountered in most of the deeper tests in the San Andres and older limestones, and the introduction of other improved completion methods, may make possible an extension of the present producing area.

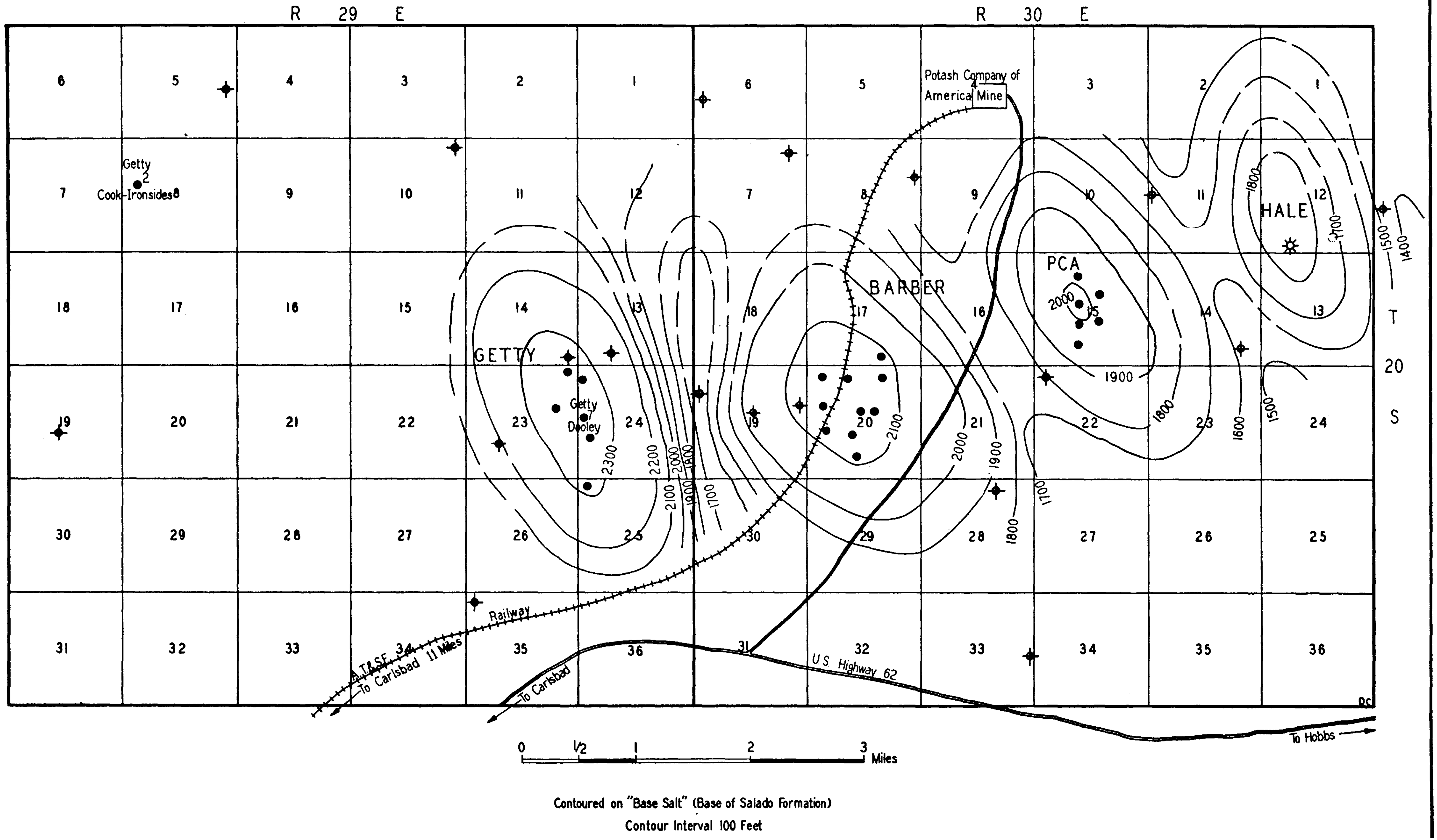
GETTY-BARBER AREA

NEIL H. WILLS[1]
Carlsbad, New Mexico

LOCATION

The Getty-Barber area includes T. 20 S., Rs. 29 and 30 E., Eddy County, New Mexico. (See map, Plate 15.) It lies about

[1]Consulting geologist.



Subsurface contour map of the Getty-Barber area, Eddy County

15 miles northeast of Carlsbad. U. S. Highway 62, connecting Carlsbad and Hobbs, approximately follows its south boundary, and the spur of the Atchison, Topeka and Santa Fe railway from Carlsbad to the mine of The Potash Company of America divides the area diagonally from southwest to northeast.

HISTORY

First oil in the area was found in July, 1927, by the drilling of the George F. Getty Oil Company's No. 2 Rawson, located in the SE¼SE¼ sec. 14, T. 20 S., R. 29 E. On account of mechanical difficulties this well was not completed as a producer. In November, 1927, the same company's No. 2 Dooley, a south offset to the No. 2 Rawson, was completed for an initial production of 100 barrels per day at a depth of 1,368 feet. From 1928 through 1935 the Getty Company drilled six additional wells, including the No. 7 Dooley, which was drilled to a depth of 6,683 feet and is the deepest hole in Eddy County.

It was not until February, 1937, that the Barber pool was discovered by drilling of a well in the NW¼NE¼ sec. 20, T. 20 S., R. 30 E. This was followed in December, 1939, by the discovery of the PCA pool by a well in the SE¼NW¼ sec. 15, T. 20 S., R. 30 E. During September, 1940, a gas well drilled in the SE¼SW¼ sec. 12, T. 20 S., R. 30 E., proved the Hale pool for gas production. To date the entire area has 22 producing oil wells, each on a 40-acre unit. None of the four small pools is completely defined.

STRATIGRAPHY

Surface materials.—The area is covered with a thin mantle of gravel, windblown sand, and gypsite, concealing all Permian sediments except along the extreme eastern edge. Along the western margin of the area deep channels have been cut in the Permian rocks, and Recent sediments have filled these trenches. In places the fill attains a thickness of 500 feet.

PERMIAN

Dewey Lake.—Along the eastern edge of the area, red sandy shales and shaly sands of the Dewey Lake formation reach a thickness of 250 feet.

Rustler.—Lying beneath the Dewey Lake, apparently conformably, are evaporites of the Rustler formation. Where completely penetrated by the drill, this formation shows an upper 200-foot gypsum-anhydrite member and a lower 150-foot clastic member. In the upper member are two thin magnesian limestones, one about 40 feet below the top and the other at the base. The lower of these limestones is commonly water-bearing.

Salado.—Below the Rustler are salt beds of the Salado formation. The thickness ranges from about 150 feet at the west up to 1,000 feet at the east. From west to east, progressively younger beds of the Salado lie unconformably beneath the Rustler.

In the vicinity of sec. 4, T. 20 S., R. 30 E., The Potash Company of America is mining potash salts, principally sylvite intimately mixed with halite, from about 525 feet below the top of the salt at a depth of some 950 feet below the surface.

Castile.—Beneath the Salado formation, a wedge-shaped tongue of Castile anhydrite extends northward across the area from the Delaware basin. This anhydrite is approximately 80 feet thick on the south. It thins to about 10 feet along the northern edge of the area.

Tansill.—Limestone and anhydrite beds of the Tansill formation lie beneath the Castile. From the south, where the formation is almost entirely magnesian limestone, there is gradation into anhydrite to the north, and in places along the northern edge of the area the formation consists of 75 percent or more of anhydrite. Approximately 40 feet below the top of the Tansill is a 10- to 15-foot clastic zone, the Ocotillo member, that carries commercial gas in the Wills and Abell No. 1 Hale, sec. 12, T. 20 S., R. 30 E.

Yates.—Below the Tansill is a formation composed of beds of light-colored magnesian limestone alternating with five distinct sandstone beds which are 10 to 30 feet thick. On the south, the Yates is predominantly dense limestone ("reef lime") with thin sandstone beds, but lateral gradation occurs and along the northern edge of the area the formation is almost entirely sandstone. It is 200 to 430 feet thick.

Seven Rivers.—A thick unit of light-colored limestones and magnesian limestones lies below the Yates. This unit has been entered by the drill in only a few wells, and completely penetrated in only the Getty No. 7 Dooley in sec. 23, T. 20 S., R. 29 E. The formation is equivalent in large part to the material in the Capitan Reef exposed at Guadalupe Point, Culberson County, Texas.

Delaware Mountain.—Beneath the limestone section is a thick sandstone, the Delaware Mountain. It was completely penetrated in the Getty No. 7 Dooley, in which the thickness is about 2,450 feet.

Bone Spring.—Below the Delaware Mountain sandstone, the black shale and limestone section of the Bone Spring formation was encountered in the Getty No. 7 Dooley from 6,264 feet to the total depth, 6,683 feet.

STRUCTURE

The accompanying subsurface map, Plate 15, shows the attitude of the "Base Salt" (approximate base of the Salado formation) by 100-foot contours. Regional tilting eastward at about 90 feet to the mile is demonstrated. This tilting corresponds closely to the rate and direction of dip in the Delaware basin to the south.

The structural highs shown on the map are depositional features directly associated with reef building, and are occasionally referred to as "reef bumps." Continued deposition of younger beds over the original reef topography progressively levelled off the irregularities, so that the surface of the Rustler formation indicates only a faint, and in places a false, picture of the older structure.

RESERVOIR ROCKS

Along the west-east trend of pools in the Getty-Barber area, oil is produced entirely from porous limestones in the Yates formation. Porosity and fluids are generally found at the contact of a limestone with an overlying sandstone. The main producing zone is below the fifth sand, at or very near the base of the Yates. The stratigraphically highest occurrence of oil is at the base of the second sand, roughly 80 to 100 feet below the top of the formation. A few wells produce from below the third and fourth sands. No commercial production has been secured from the sandstone members themselves along the main trend of the area.

North of the area that produces oil from limestone, the Getty Company's No. 2 Cook-Ironsides well has established an area of possible production from sandstone members of the Yates. This well, in the SW¼NW¼ sec. 8, T. 20 S., R. 29 E., was drilled in June, 1934, to a depth of 1,597 feet. It was later plugged back to 1,160 feet and completed as a 10- to 15-barrel pumper, after shot, from sand pay at 1,100 to 1,124 feet. The well may not be considered commercial, as it has not produced regularly.

A third producing zone in the area is the Ocotillo silt member of the Tansill formation, which produces gas in the Wills and Abell No. 1 Hale, sec. 12, T. 20 S., R. 30 E.

OIL AND GAS

Oil from the limestone trend of the Getty-Barber area has a gravity ranging from 19° to 24° A. P. I. It is black and has an average sulfur content of about 2 percent and a low cold test. The "topped" gasoline content is low, probably not exceeding 15 percent, but the asphalt content runs as high as 40 percent. Below are tabulated characteristics of a representative Barber crude:

Analysis of Oil from Barber Pool

Gravity	20.0° A. P. I.
Specific gravity at 60° F.	0.9340
B. S. & W.	0.1 percent
Sulfur	2.12 percent
Furol viscosity at 122° F.	25.0 seconds
Flash (COC)	130° F.
Paraffin	1.57 percent
Initial boiling point	112° F.
Percent over at 221° F.	1.3
284° F.	3.2
392° F.	7.7
410° F.	8.7
437° F.	11.3
Water	Trace
Residue and loss	88.7 percent

Gas from the Wills and Abell No. 1 Hale in sec. 12, T. 20 S., R. 30 E., is sweet. It has a 550 B.t.u. content.

Considerable water is produced with the oil. It is a typical "reef lime" water, containing much hydrogen sulfide.

DRILLING METHODS

Except for the deep test drilled by Getty, all wells in the area have been drilled with cable tools, usually with spudders or National machines. Twelve-inch or 10-inch casing is generally set at shallow depths to shut off caving beds found near the surface. Eight-inch casing is usually set at the "top salt," at depths of 400 to 600 feet, and cemented with 50 sacks of cement. If oil is encountered, 7-inch casing is run above the pay at depths of 1,300 to 1,800 feet and cemented with 50 sacks.

The average drilling time for a producer in this area is between four and five weeks, including six days shut down while cement sets on two strings of casing. Most of the wells are completed without acid or shot.

PRODUCING METHODS

All wells in the area are pumpers. Tubing sizes range from 2-inch to 4-inch, and tubing is generally set near the bottom of the hole. On large-volume wells making high percentages of water, the tubing is raised some distance off bottom. This results in an increase in oil and a corresponding decrease in water. Common working barrels are used almost entirely, and of course only low-pressure fittings are necessary. Casing pumps will probably be used in the future as water percentages increase.

Central power units are used in each of the three pools. In the Getty pool a geared unit is used, in the Barber pool a band-wheel power unit, and in the PCA pool a unit generating electricity for pumping the wells with individual units and motors.

An elaborate treating set-up is necessary to remove the water produced with the oil. Chemicals and heat are used to break down the emulsion, and a mechanical separation of oil and water is obtained by running through a "hay" tank.

As the area is not served by a pipe line, all oil is moved by truck or tank car.

PRODUCTION

The production in barrels of oil is shown in the following table.

	Getty	Barber-PCA-Hale	Total
1941	50,930	85,996	136,926
Discovery to end of 1941	424,122	163,794	587,916

FUTURE POSSIBILITIES

Additional pools should be found in depositional structures along the limestone trend. Oil from the Yates sand should be found from stratigraphic traps north of that trend. From a study of the Getty No. 7 Dooley it appears that the area is underlain by possibly 10,000 feet of Permian sedimentary rocks, and it seems reasonable to assume that oil occurs somewhere in structural or stratigraphic traps in this thick section.

GRAYBURG-JACKSON POOL

ROBERT L. BATES

LOCATION

The Grayburg-Jackson pool is located in T. 17 S., Rs. 30 and 31 E., Eddy County. (See map, Fig. 13.) It lies about midway between Artesia and Lovington. The east boundary of the area is the Eddy-Lea county line. State Highway 83 traverses the full length of the area.

Nearly all the wells are in a strip two sections wide across the middle of the two townships. Four wells in sec. 24, T. 17 S., R. 29 E., are geologically part of the Grayburg-Jackson pool. Subsurface connection between the Grayburg-Jackson and Maljamar pools has been shown by recent drilling in T. 17 S., R. 31 E.

HISTORY

Oil was discovered in the Flynn, Welch & Yates No. 1 Jackson Permit, in the NE$^1/_4$ sec. 13, T. 17 S., R. 30 E. The test was completed in March, 1929, for an initial production of 260 barrels per day, natural flow, from a total depth of 3,560 feet. Although this discovery caused some additional drilling, major development did not take place for several years because of adverse business conditions and low price of oil. Active drilling began in 1935, and has continued to date. In December, 1941, a total of 173 wells were producing a daily allowable of approximately 15,000 barrels of oil.

STRATIGRAPHY

Surface materials and redbeds.—The materials at the surface consist of caliche and windblown sand. These are underlain by red sand and shale 400 to 600 feet thick, the upper part of which is Triassic in age and the lower part Permian.

PERMIAN

Rustler.—Beneath the redbeds is the Rustler anhydrite, 100 to 200 feet thick. In some places dolomitic limestone is present.

Salado.—The Salado consists of salt with thin beds of anhydrite. Its thickness increases from 350 feet on the west side of the area to 1,000 feet on the east side.

Tansill.—The Tansill is anhydrite 175 feet thick. Its character and thickness are constant throughout the area.

Yates.—The Yates consists of red sand and shale 50 to 60 feet thick.

Seven Rivers.—The Seven Rivers formation, which is 850 feet thick, is chiefly anhydrite. Beds of sandstone, shale, and dolomitic limestone are present. A 200-foot section of dolomitic

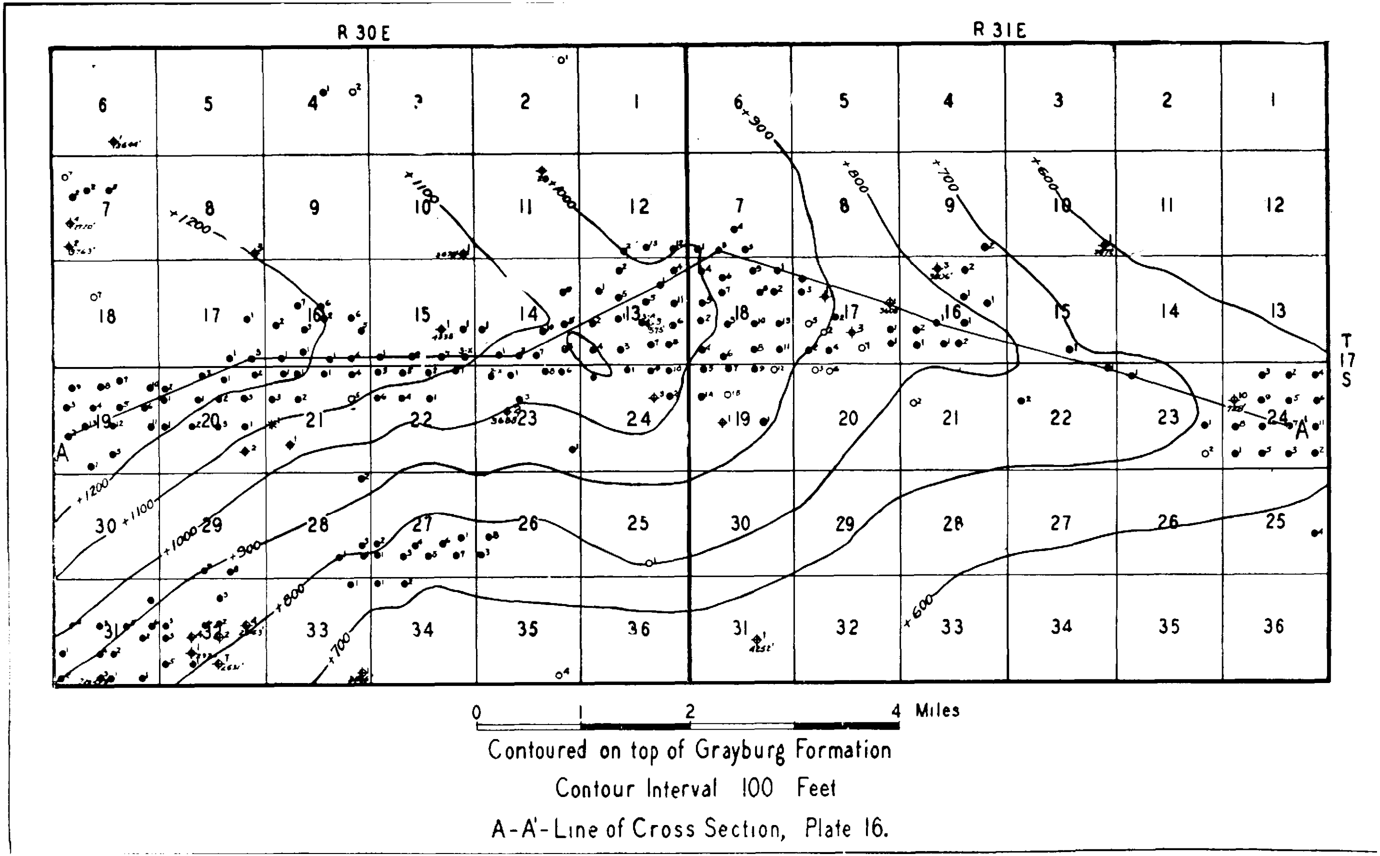


FIGURE 13.—Subsurface contour map of the Grayburg-Jackson pool, Eddy County.

limestone in the middle part of the formation carries oil and gas shows.

Queen.—The topmost member of the Queen, the "Artesia red sand," is 40 to 50 feet thick and serves as a local subsurface marker. The remainder of the formation is anhydrite with thin zones of sandstone and dolomitic limestone. The lowermost 100 feet carries much sandstone. Total thickness is 400 feet.

Grayburg.—This formation consists of dolomitic limestone, with subordinate amounts of anhydrite and sandstone. Its top is the most commonly used subsurface marker in the pool. The Grayburg-Jackson pool contains the type section of the Grayburg formation, as designated by Dickey.[1] This section was penetrated in the Cecil H. Lockhart No. 2 Root Permit, in the SW¼ sec. 7, T. 17 S., R. 30 E. Thickness at the type section is 300 feet.

San Andres.—Uniform dolomitic limestone below the Gray-burg falls within the San Andres formation. Generally the limestone is white to buff and finely crystalline. Its total thickness has not been penetrated by any well in the area.

STRUCTURE

Subsurface contours show the structure to be an eastward plunging nose. (See map, Fig. 13, and cross section, Plate 16.) Numerous terraces lie on the crest of the main structure, and use of a small contour interval allows closures to be shown on them.

RESERVOIR ROCKS

All production is from porous zones in the San Andres dolomitic limestone. Porosity varies from fine to cavernous, and changes abruptly from place to place. The best development of porosity, and hence the best production, is found on the small terraces along the crest of the main trend. Porous zones on the south flank also yield oil. Beds of sandstone and dolomitic limestone in formations above the San Andres contain non-commercial amounts of oil and gas.

FLUIDS

The oil has a paraffin base and an average gravity of 36° A. P. I. It is sour, but not of high enough sulfur content to corrode well equipment or pipe lines.

The small amount of gas that is produced with the oil is used only for lease purposes. Low content of hydrogen sulfide makes treatment before use unnecessary. The field does not have a gasoline plant.

Water is present in only a few wells, and in small quantities. There is no effective water drive.

[1] Dickey, R. I., Geologic section from Fisher County through Andrews County, Texas, to Eddy County, New Mexico: Bull. Amer. Assoc. Petrol. Geol., Vol. 24, No. 1, pp. 44-47, January, 1940.

DRILLING AND PRODUCTION METHODS

All wells are drilled with cable tools. Surface casing is set in the Rustler anhydrite, generally a few feet above the top of the salt; this casing is almost invariably cemented back to the surface. A production string is set near the top of the San Andres formation, with enough cement to reach the base of the salt. This casing procedure protects the salt section from contamination by water from above and by oil or gas from below.

Very few wells are completed without acidizing or shooting. The dolomite pay reacts readily to acid treatment. Wells in which permeability of reservoir beds is low generally respond best to shooting with nitroglycerin.

All wells are produced through tubing. The majority of the wells flow on completion, but absence of a water drive and loss of gas pressure has made it necessary to put a number of wells on the pump. Wells in areas of poor porosity and permeability. are almost invariably pumped.

Production of oil in the Grayburg-Jackson pool during 1941 was 1,631,012 barrels; cumulative production through that year was 10,109,357 barrels.

LAND OWNERSHIP

Only one section is owned by the State of New Mexico, and there is no patented land in the pool. Twenty-four companies operate 59 leases on Government land.

FUTURE POSSIBILITIES

Considerable additional drilling will be necessary to define completely the limits of commercial production. The northwest quarter of T. 17 S., R. 30 E., and the south half of T. 17 S., R. 31 E., are as yet largely unexplored. Only one deep test has been drilled in the pool. This is the Flint Production Co. No. 1-L Dexter, in the SE¼ sec. 15, T. 17 S., R. 30 E. The test was abandoned at 4,335 feet without encountering any oil below that in the regular pay zone. The rocks at the bottom of this well are probably basal San Andres. Deeper zones are unexplored.

ACKNOWLEDGMENTS

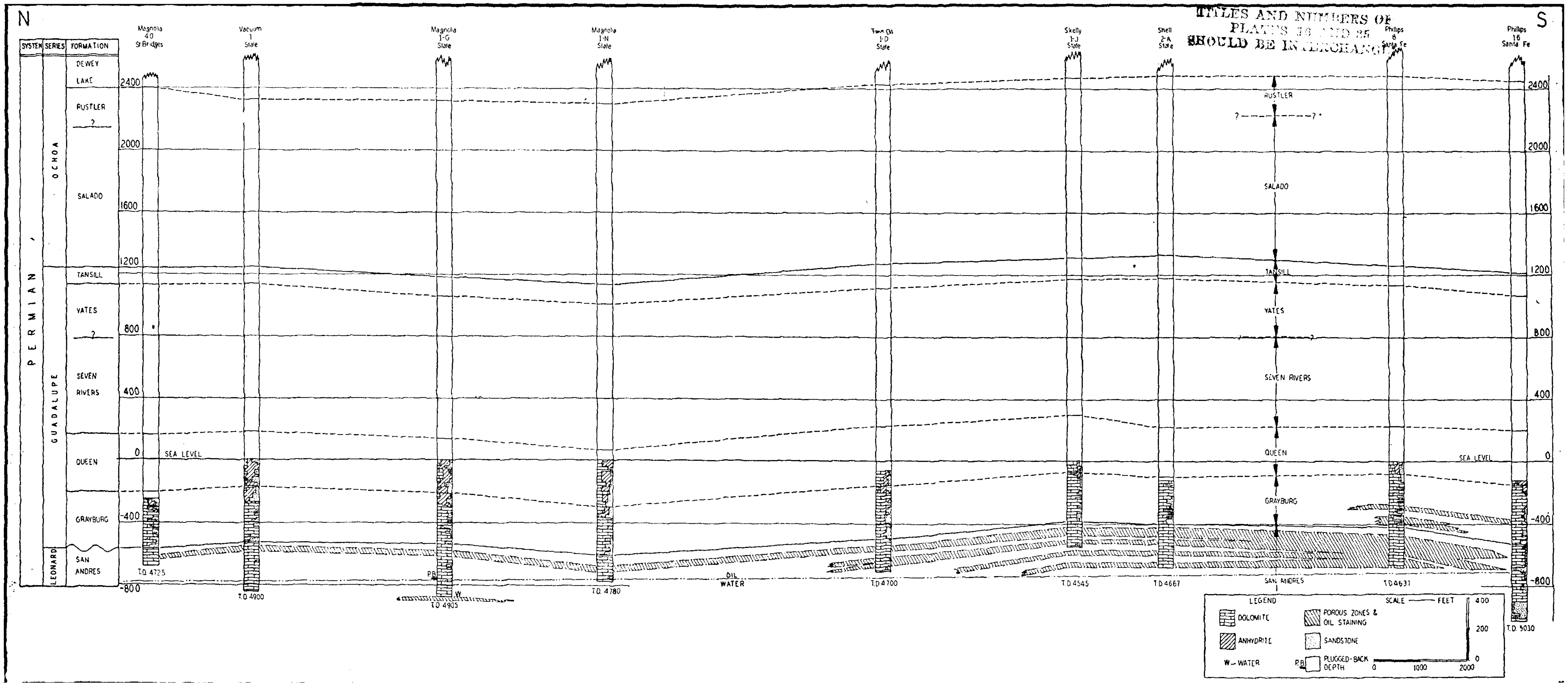
The writer wishes to express his appreciation to the Sinclair Prairie Oil Co., and to N. B. Larsh, their district geologist at Midland, Texas, for providing much of the information on which this report is based.

LEONARD POOL

ROBERT L. BATES

LOCATION AND HISTORY

The Leonard pool includes all of T. 17 S., R. 29 E., except the southern parts of secs. 32, 35, and 36, which fall within the limits of the Loco Hills pool. (See map, Plate 14.) A few wells in the west half of sec. 24 belong geologically with the Grayburg-Jackson area, under which they are discussed. The west edge of the



West-east cross section of the Grayburg-Jackson pool, Eddy County. Along line A-A', Fig. 13.

township is 16 miles east of Artesia. State Highway 83, connecting Artesia and Lovington, crosses the southern half of the area.

There are three producing districts in the Leonard pool. The oldest of these is the Leonard and Levers gas area in secs. 20, 21, 28, and 29, in which gas was discovered in 1929. Seven wells are producing in this area. Indication of oil was furnished in 1933, when Barnsdall Oil Co. completed their No. 1 Dodd, in the SE¼SW¼ sec. 22, for an initial daily production of 24 barrels of oil and 1,740,000 cubic feet of gas. The Barnsdall No. 2 Dodd, in the NE¼SE¼ sec. 22, was completed in July, 1935, for 100 barrels of oil daily after shot. During the next two years, 10 more wells secured oil in the Dodd area.

The Root area, in the northeast quarter of the township, contains nearly 30 oil wells, virtually all of which were drilled in 1940 and 1941. Drilling was still going on at the end of 1941.

STRATIGRAPHY

The following brief discussion is based on the section penetrated in the Herbert Aid No. 1 Leonard-State, dry hole in the SE¼SW¼ sec. 16.

The Rustler formation, which is at or just below the surface, is predominantly limestone. Some red shale and sandstone are present, and anhydrite is prominent in the lower part. The formation is about 200 feet thick. The underlying Salado formation, which is about 500 feet thick, consists of salt. The Tansill is chiefly anhydrite, with a salt zone near the middle. Its thickness is 150 feet. The Yates contains sandstone carrying the diagnostic frosted quartz grains, and subordinate amounts of porous dolomitic limestone, red shale, and salt. It is about 200 feet thick.

The Seven Rivers consists mainly of anhydrite to a thickness of approximately 600 feet. The "Artesia red sand" is present at the top of the Queen formation. Below this member the Queen is anhydrite and limestone in the upper half and predominantly sandstone in the lower half. Total thickness is some 400 feet. The Grayburg formation is limestone, sandstone, and anhydrite in the upper part, dolomitic limestone containing the "Loco Hills sand" in the middle part, and red sandstone and dolomitic limestone in the lower part. The thickness is about 400 feet.

The Aid well penetrated 570 feet of solid dolomitic limestone below the Grayburg. This, is the upper part of the San Andres formation. It is similar in character to the San Andres in other fields of Eddy County.

STRUCTURE

The Leonard-Levers and Dodd producing districts are situated on the crest of the Grayburg-Jackson high, and show slight structural closure. Accumulation in the Root area occurs in depositional traps formed by sandstone beds that wedge out up-dip. Arching, with resultant structural closure, does not seem to be present.

RESERVOIR ROCKS

Gas in the Leonard-Levers area comes from a porous zone about 150 feet below the top of the San Andres limestone. The oil reservoir in the Dodd district is another porous zone in the San Andres, occurring about 550 feet below the top of the formation. Wells in the Root area to the northeast produce from a sandstone in the Grayburg formation, about 100 feet below the "Loco Hills sand."

FLUIDS

Oil from the Leonard pool is generally sour and has an intermediate base. Its average gravity is 27° to 30° A. P. I. The oil is moved by pipe line and truck to refineries at Artesia.

The dry gas is sufficiently sweet so that it is put directly into pipe lines which supply the nearby towns of the Pecos Valley. Output of the Leonard-Levers gas wells has remained fairly steady for a number of years.

Water is known as "sulfur water" and occurs sporadically in the geologic section at a number of places.

DRILLING AND PRODUCTION METHODS

Most of the drilling has been done with cable tools. Common casing procedure is to cement a surface string at 550 to 650 feet and a 7-inch production string above the top of the pay. Water which is generally found in the "Artesia red sand" is thus cased off. Pay section in most of the wells of the Root district is shot with nitroglycerin, resultant initial productions averaging 75 to 100 barrels per day flowing.

During 1941, the Leonard pool produced 305,342 barrels of oil. Cumulative production to the end of 1941 was 1,165,362 barrels.

FUTURE POSSIBILITIES

The northwest quarter of the township is largely unexplored by the drill, and further development may be expected. That this development will probably be on a small scale is indicated by the completion in 1941 of the Herbert Aid No. 2 Leonard-State, a test well in the NW¼ sec. 16, for an initial production of only six barrels. To the northeast, it appears likely that the Root area may be shown to connect in the subsurface with the Square Lake area north of the Grayburg-Jackson field.

Important reservoirs may exist in the thick pre-Grayburg section of Permian and Pennsylvanian rocks.

ACKNOWLEDGMENTS

The writer hereby expresses his appreciation to the Continental Oil Co., and to N. R. Lamb, geologist in their Hobbs office, for providing much of the material on which the preceding discussion is based.

LOCO HILLS POOL

CHAS. A. ASTON
Loco Hills, New Mexico

LOCATION

The Loco Hills pool is situated in northeastern Eddy County, about 20 miles east-southeast of Artesia. The largest part of the pool is in the north half of T. 18 S., R. 29 E. ; other parts include secs. 32, 35, and 36, T. 17 S., R. 29 E.; secs. 31 and 32, T. 17 S., R. 30 E. and secs. 5, 6, and 7, T. 18 S., R. 30 E. The area is about 7,000 acres. (See map, Plate 14.)

HISTORY

The pool was indicated in 1937 by the Franklin Petroleum Corp. No. 1 Nelson, in the NW¼NW¼NW¼ sec. 4, T. 18 S., R. 30 E., which had an excellent show of oil before water was encountered at 2,906 feet. This was proved to be an edge well by the completion of the discovery well, Yates et al. No. 1 Yates, in the center of the NW¼SW¼ sec. 6, T. 18 S., R. 30 E. This well, which was drilled on a sub-lease from the Franklin Petroleum Corp., was completed in February, 1939, for an initial production of 630 barrels daily at a total depth of 2,874 feet. It led to the development of the Loco Hills field.

STRATIGRAPHY

The following composite sample and driller's log gives the stratigraphic section as encountered by the drill.

Age	Formation	Lithology	Interval and Thickness
RECENT		Caliche, windblown sand.	
TRIASSIC		Red sandstone and shale.	0- 400 (400)
	Dewey Lake	Red sandstone and shale.	
	Rustler	Anhydrite.	
	Salado	Salt.	400-1050 (650)
	Tansill		
	Yates	Anhydrite, sandstone, redbeds.	1050-2250 (1200)
	Seven Rivers		
PERMIAN	Queen	Anhydrite, red sand and shale, limestone, and bentonitic shale. "Artesia red sand," 30 feet thick, at top.	2250-2600 (350)
	Grayburg	Chiefly gray and brown sandy limestone; some anhydrite, red sandstone, and bentonite in upper part. "Loco Hills sand," 20 feet thick, lies about 185 feet below top of formation.	2600-? (200+)

[1] Consulting geologist.

STRUCTURE

The Loco Hills pool lies on the south flank of a structurally high limestone trend plunging eastward into Lea County. Accumulation has occurred in a stratigraphic trap, with local structural conditions determining productivity. (See map, Plate 17, and cross section, Plate 18.) The regional dip of the beds is to the south and east at about 60 feet per mile. On the north edge of the pool the porosity of the main pay decreases due to cementation. Although edge water has been encountered on the southern and eastern edges, no active water drive has become apparent and it is thought that oil recovery is controlled solely by gas drive. No gas cap has developed, although average gas-oil ratios have practically doubled since the field's discovery.

RESERVOIR ROCKS

The Loco Hills sand averages approximately 20 feet thick, and is composed of sub-angular quartz grains with varying proportions of dolomitic cementing material and small amounts of gypsum. Analyses of cores have shown the pay to have a porosity of about 20 percent, a saturation of about 80 percent, and a connate water content ranging from 15 to 25 percent. Under original recovery methods it is estimated that the ultimate oil yield would have been 4,500 barrels per acre; but under the pressure maintenance program currently in operation, it is expected that the ultimate recovery will he 9,000 to 10,000 barrels per acre.

OIL AND GAS

The oil is of the sweet type and averages about 36° gravity A. P. I. Approximately 6,500 barrels is produced and marketed daily. Production totaled 2,304,373 barrels in 1941, while total production from discovery to the end of 1941 was 4,936,351 barrels.

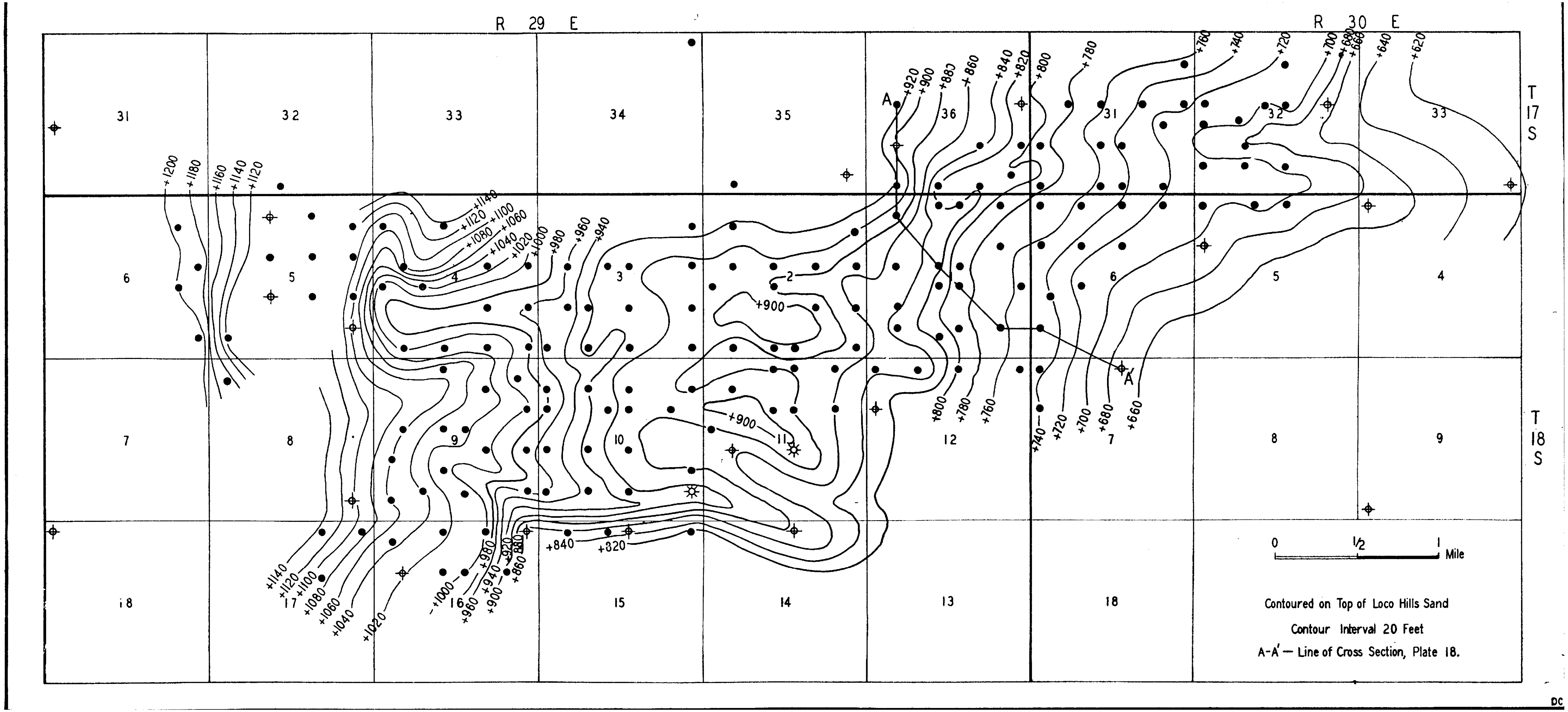
Approximately 6,500,000 cubic feet of gas is produced daily with the oil. The gas contains an average of about 600 grains of hydrogen sulfide per 100 cubic feet. An analysis is as follows:

Average Analysis of Gas, Loco Hills Field

Component	Percent
Acid gases	1.00
Methane	60.34
Ethane	17.83
Propane	11.84
Butanes	5.54
Pentanes plus	3.43
Total	99.98

WATER

The water which has been encountered on the south and east edges of the field has been found to contain a high percentage of sodium chloride. It also contains a large amount of sulfur, which is presumed to have been dropped by the gas in prior passage.



Subsurface contour map of the Loco Hills pool, Eddy County

DRILLING AND PRODUCTION METHODS

Over 90 percent of the drilling is done with cable tools. About 85 percent of the wells are flowing. Two types of control of flowing wells are: (1) bean or choke flow; and (2) intermittent flow, either manual or mechanical.

LAND OWNERSHIP

Approximately two-thirds of the productive area is owned by the United States Government and the remaining one-third is owned by various agencies of the State of New Mexico. Only about 160 acres are owned in fee.

FUTURE POSSIBILITIES

It is only logical to assume that there will be a number of future extensions to the field because of the definitely irregular character of its borders. Present structural indications also favor this conclusion.

RED LAKE AREA

ROBERT L. BATES

LOCATION

The Red Lake area, in Eddy County, includes all of T. 17 S., Rs. 27 and 28 E., except the southern tier of sections in each township. (See map, Plate 14.) The western boundary of the field is four miles east of Artesia. State Highway 83, connecting Artesia and Lovington, diagonally crosses the western part of the area.

HISTORY

In 1925 gas was discovered in the Vandergriff area in sec. 5, T. 17 S., R. 28 E. During the next ten years a number of gas wells were drilled in the north one-third of this township, chiefly by the Pecos Valley Gas Co. At about the same time as the gas discovery, commercial oil was first produced in the Sanders-Bobb area, in secs. 13 and 24 of the western township and secs. 18 and 19 of the eastern. In the period 1934-37, Red Lake Oil Co. drilled a number of small producers on State land in sec. 22, T. 17 S., R. 28 E. Scattered among these three chief producing districts are a number of dry holes which have been drilled over a period of more than 15 years.

A flurry of activity in the Red Lake area resulted in the completion of more than 40 wells during 1941. Most of these produce small amounts of oil from shallow depths. As 10-acre spacing has been allowed in the central part of the area, a large number of wells have been drilled in sec. 24, T. 17 S., R. 27 E., and in adjacent sections.

STRATIGRAPHY

Although the Tansill formation of Permian age crops out over a considerable part of the area, much of the surface is covered with Recent windblown sand, and with caliche and gypsite derived from the bedrock.

PERMIAN

Tansill.—The surface formation is mainly anhydrite, with a few beds of limestone and red sandstone. It is 300 to 450 feet thick.

Yates.—The Yates consists of beds of red sandstone with frosted quartz grains, separated by anhydrite and porous dolomitic limestone. The sandstone zones number five at the west, but tend to combine eastward. The thickness of the Yates is 150 to 250 feet.

Seven Rivers.—This formation is dominantly anhydrite. Small amounts of salt have been found in cuttings. A prominent dolomite zone occurs about 120 feet below the top of the formation, and a sandstone, the "Bowers sand", is found 200 feet above the base. The formation is 550 to 650 feet thick.

Queen.—The "Artesia red sand," widespread top member of the Queen, is about 40 feet thick and carries frosted quartz grains. The remainder of the upper Queen is chiefly anhydrite, with sandstone and limestone stringers. The lower half of the formation contains much sandstone, which in places is the chief constituent. The Queen is 350 to 450 feet thick.

Grayburg.—The upper 100 feet of the Grayburg consists of limestone, sandstone, and anhydrite ; the abundance of the limestone differentiates the formation from the overlying Queen. The middle part is dolomitic limestone, except for the 10-foot "Loco Hills sand" about 220 feet below the top. The lower part of the Grayburg is interbedded red sand and dolomitic limestone. Total thickness is about 400 feet.

San Andres.—Fifty-five feet of uniform dolomitic limestone below the Grayburg was penetrated in the Hughes No. 3 Brooks, in sec. 19, T. 17 S., R. 28 E. This limestone is undoubtedly San Andres. Further information on its distribution and character in this area is lacking.

STRUCTURE

A long east-west structural high underlies the Red Lake area. Oil and gas have accumulated in two types of reservoir,— stratigraphic traps on the south flank of the main trend, and small closed domal structures on the south flank or on the top. No oil has been found on the north flank. Depositional features and distribution of porosity seem to have played the major part in controlling accumulation.

RESERVOIR ROCKS

In the Red Lake area, fluids are encountered in these zones:

1. Several sandstones of the Yates formation.
2. A dolomite 120 feet below the top of the Seven Rivers.
3. The "Artesia red sand" at the top of the Queen.
4. Several sandstones of the lower Queen.
5. The "Loco Hills sand" in the middle part of the Grayburg.

6. Several sandstones of the lower Grayburg.
7. Porous zones in the San Andres dolomitic limestone.

A number of these porous zones, which apparently are not interconnected, may be encountered in a single well. Not all wells in the same small district produce from the same zone, and in some cases offset wells produce from different zones at different depths. If an operator finds the specific zone for which he was drilling to be dry, he has a number of other chances for production, either by plugging back or by drilling deeper. Some oil is produced from limestone, some from sandstone.

Thus there is no widespread or even approximately uniform "top of the oil," and no general rule can be set forth to apply to reservoir-rock conditions, bottom-hole pressures, and gas-oil ratios. Each well is largely an individual problem.

FLUIDS

Information on oil, gas, and water is meager. No analyses are available. The average gravity of the oil is 29° A. P. I. Water, which is high in sulfur content, occurs erratically throughout the producing section.

DRILLING AND PRODUCTION METHODS

Most of the drilling has been done with cable tools. A number of recently drilled wells in the central part of the area, which average only 500 to 600 feet deep, have been drilled with light spudders. Casing programs, plug-back procedure, and completion practices vary with the operator and with the individual well.

Practically all the oil wells are on the pump. Initial production is low, an appreciable percentage of water is common, and the life of the wells is relatively short. The Red Lake area produced 140,927 barrels of oil in 1941, and 502,688 barrels from discovery to the end of 1941.

LAND OWNERSHIP

Ownership of the land in the Red Lake area is divided about equally between the State and Federal governments. Only a small total acreage is owned in fee. Development is entirely by independent operators, a number of whom have offices in Artesia or Roswell.

FUTURE POSSIBILITIES

Except for the northwest part of the area, considerable exploratory drilling to relatively shallow depths has been done. It suggests that few if any new productive districts will be developed from zones now being exploited. No systematic deep drilling has been done. It is possible that zones in the San Andres or deeper formations will be found to contain oil or gas in commercial quantities.

ACKNOWLEDGMENTS

Appreciation is extended to the Continental Oil Co., and to N. R. Lamb, their geologist at Hobbs, New Mexico, for providing the writer with much of the information contained in this report.

SHUGART AREA

ROBERT E. MORGAN [1]

Carlsbad, New Mexico

LOCATION

The Shugart area is situated in northeastern Eddy County and includes all of Tps. 18 and 19 S., R. 31 E. (See map, Plate 14.) An improved road traverses the area from north to south and connects with paved U. S. Highway 62 on the south by way of The Potash Company of America's mine road, at a point 15 miles east of Carlsbad. On the north, the road through the area connects with paved State Highway 83 approximately 30 miles east of Artesia. Surface elevations within the area range from approximately 3,850 feet in the northeast corner to less than 3,400 feet in the southwest corner.

HISTORY

The first test drilled in the area, originally the R. A. Shugart No. 1 Coulthard, located 1,980 feet from the south line and 660 feet from the west line of sec. 35, T. 18 S., R. 31 E., was spudded July 30, 1937. Oil, encountered at a depth of 3,440 feet in sandstone, rose 500 feet in the hole in eight hours. The well was later deepened to 4,088 feet, the total depth. An additional show of oil was reported at 3,888 feet in sandstone. Water was reported from 4,068 feet to total depth. After plugging back to 3,920 feet, the interval from 3,400 to 3,470 feet was shot with 200 quarts of nitroglycerin, and from 3,870 to 3,900 feet with 90 quarts. With top of pay at 3,440 feet, the well was completed as a pumping producer.

Since discovery of oil in the general area by this well, several other productive localities have been found, mainly in the north township. Development of these localities has not been extensive, and up to the present time the producing area consists of a few small isolated groups of wells. In none of the groups has drilling been extensive enough to define productive limits completely.

The following summary gives the status of development as of November 1, 1941:

Drilling wells	1
Producing wells	28
Wells shut in	2
Dry holes	11
Total	42

[1] Geologist, The Atlantic Refining Company.

Production for 1941 totaled 215,991 barrels, while the production from discovery date to January 1, 1942, totaled 477,356 barrels.

STRATIGRAPHY

Owing to the large size of the area and the comparatively small number of wells drilled to date, discussion of subsurface formations is somewhat generalized. The surface is covered for the most part with Recent sands and caliche, though exposures of older sediments are present in places, especially toward the west.

TRIASSIC

Redbeds.—The red shale and sandstone succession of Triassic age, underlying the surficial deposits and extending downward to the Rustler formation, thins toward the west. In the northwest group of wells the average thickness is 500 feet, increasing to over 800 feet in the group of wells two miles to the east. The average thickness is approximately 725 feet in the south central group of wells. An undetermined thickness of red shale and sandstone at the base may represent the Dewey Lake formation of Permian age.

PERMIAN

Rustler.—The Rustler formation, so far as known, varies in thickness from 200 feet in wells in the north part of the area to more than 250 feet in wells toward the south. It consists principally of anhydrite, with included limestone, red shale, and sandstone. Salt members appear in the formation toward the south.

Salado.—The Salado formation averages 1,000 feet in the northwest group of wells, but is thicker toward the south and east. In the south central group of wells the thickness averages 1,300 feet ; it increases to approximately 1,400 feet in a well two miles to the southeast located in sec. 12, T. 19 S., R. 31 E. The three dry holes in the extreme south part of the area encountered thicknesses of the salt ranging from about 1,100 feet to 1,300 feet. The Salado, as the name implies, is composed mainly of salt, with a few included anhydrite members. The Cowden anhydrite member, 20 to 30 feet thick, is a persistent bed occurring at an average interval of 160 feet above the base of the salt in the area. The Salado includes 25 to 40 feet of anhydrite at the base.

Tansill.—The Tansill formation ranges in thickness from 140 to 180 feet. (See cross section, Plate 19.) In wells to the north the formation is almost entirely anhydrite with minor amounts of salt and silt. In some of these wells a thin stringer of dolomite marks the approximate top of the Tansill. Toward the south dolomite is more prominent. Wells in the extreme south show that the formation is nearly solid dolomite.

Yates.—The Yates formation varies somewhat in thickness over the area, though the base is not easily determined in wells to the north. Wells near the south border indicate a probable thickness of 250 feet, while toward the north it may be considerably greater. In the north wells the Yates consists mainly of anhydrite with a number of thin sandstone members. Some red shale and dolomite are usually present also. Toward the south dolomite and sandstone increase at the expense of the anhydrite. In the south central group of wells, the lower part of the Yates consists of 50 to 60 feet of sandstone, apparently not well represented by a comparable thickness in wells to the north. There are no wells at present to define the southward extent of the thick sandstone, but this member does not seem well developed in the dry holes in the extreme south. Several wells in the south central part of the area have found oil production in the sandstone.

Seven Rivers.—The thickness of the Seven Rivers formation ranges from approximately 600 feet in the south central group of wells to 800 feet or more in wells to the north. Generally it is difficult to place the boundary between the Seven Rivers and the overlying Yates because of lateral gradations in both formations from south to north. Wells to the north show the Seven Rivers to be chiefly anhydrite and dolomite with some silt and minor sandstone members. Dolomite content increases toward the south, and in the south central group of wells the upper and lower parts of the formation are mostly solid dolomite, with some sandstone. Remaining anhydrite within the Seven Rivers, seemingly interbedded with dolomite, is shown in this group of wells in the form of a southward thinning wedge between the dolomite above and below. On the accompanying cross section, Plate 19, the Keohane Coulthard and Carper Hinkle wells illustrate the thinning of the anhydrite to the south.

Queen.—The Queen formation ranges in thickness from about 425 feet to 475 feet. It contains a large percentage of sandstone, partly red in color, together with dolomite, red shale, anhydrite, and silt. Anhydrite content decreases toward the south. A prominent sandstone member at the top averaging 50 feet in thickness is known as the "Artesia red sand."

Grayburg.—The Grayburg formation has not been extensively explored by drilling. A few wells have penetrated the formation for considerable distances, with one or more possibly penetrating the entire formation. From the rather incomplete information compiled, the Grayburg appears to be principally dolomite with included sandstones. No appreciable amounts of anhydrite have been observed. In a deep well located in sec. 31, T. 17 S., R. 31 E., just outside the northwest corner of the area, the Grayburg is approximately 450 feet thick. Here it consists of dolomite, with included sandstones prominent in the lower 200 feet of the section. Several of the deeper wells in the north township of the area indicate that the Grayburg is more sandy toward the south, with probable increase in thickness.

San Andres.—The deep well outside the northwest boundary of the area encountered the San Andres formation at a depth of 3,645 feet. The San Andres in similar facies has not been recognized within the area proper. It is possible that beds equivalent to the San Andres have been penetrated by the deeper wells, particularly one located in sec. 12, T. 18 S., R. 31 E., which reached a total depth of 4,890 feet. Cuttings from this well have not been available for examination below 4,425 feet, at which point the hole was still in a succession of dolomite and fine gray sandstone. The top of the Grayburg in this well is placed at about 3,900 feet. The position and character of the San Andres in the area remain doubtful.

STRUCTURE

Due to the relative scarcity of wells in the area, comprehensive data relating to subsurface structural conditions are lacking. Formations below the Salado in the north part of the area apparently dip at a uniform rate of 80 to 100 feet per mile toward the southeast, with no known closures or marked interruptions. (See cross section, Plate 19.) There appears to be a shallow syncline plunging eastward across the central part of the area, with some evidence of abrupt deepening a short distance to the east.

The three comparatively shallow dry holes located in the extreme south part of the area give some indication of the presence of structural irregularities in contrast to the uniform southeast dip prevailing in the north part. Information to date is too meager for speculation upon the possible presence of marked structural relief within the area.

RESERVOIR ROCKS

The sandstone known as the "Artesia red sand," uppermost member of the Queen formation, is the principal reservoir rock in the area. Two small wells are known to produce from the Gray-burg, and several from a thin sandstone member of the Queen lower than the "red sand." The wells in the south central group produce from either the lower Yates or the uppermost Queen. No wells are known to produce from more than one formation.

DRILLING AND PRODUCTION METHODS

Nearly all of the wells have been drilled with cable tools ; on only two or three wells has rotary equipment been used. Common practice is to shoot pay zones with nitroglycerin to increase production. Since practically all producing horizons occur in fine-grained sandstones, most wells respond to some extent to shooting. Some few wells have had sufficient gas volume to flow upon completion, though the majority have been completed as pumping wells.

The area is principally served by the Texas-New Mexico Pipe Line Co.

FUTURE POSSIBILITIES

Inasmuch as the productive limits in most of the oil producing localities are still largely undefined, it seems reasonable to expect that a number of extension wells may yet be successfully drilled. In the south part of the area in particular, wildcatting has not been extensive enough to furnish much information concerning productive possibilities. There yet remain rather large unexplored areas both here and in the north township.

ACKNOWLEDGMENTS

The writer wishes to express his thanks to The Atlantic Refining Co. for permission to contribute this material, and to Messrs. Edgar Kraus, R. M. Knoepfel and Neil H. Wills for helpful criticism and discussion.

OTHER PRODUCTIVE AREAS IN EDDY COUNTY

Brief descriptions of several small productive areas in Chaves, Eddy, and Lea Counties are given on the chart, Plate 20.

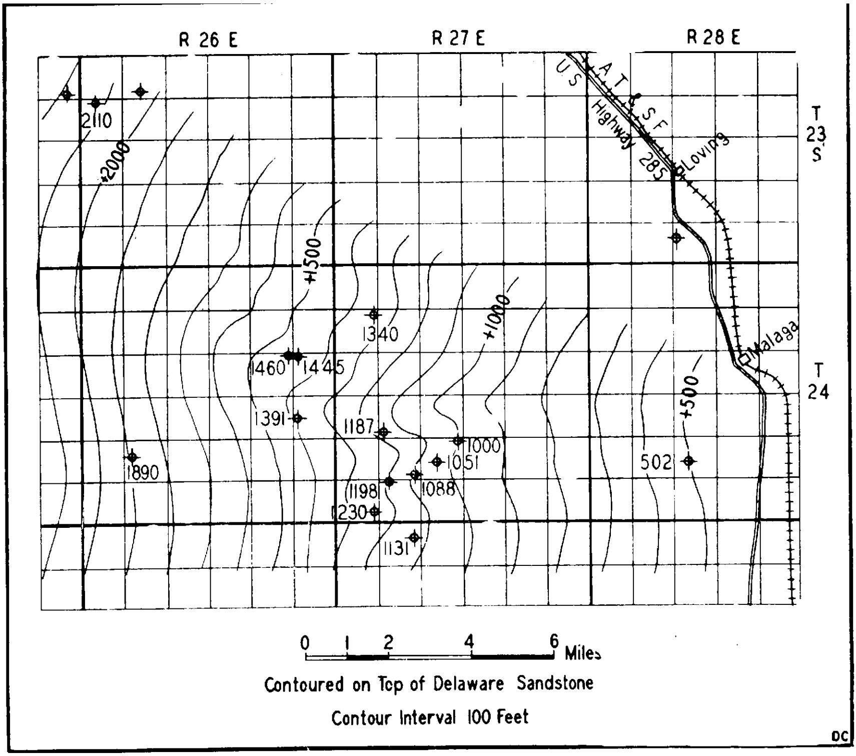


FIGURE 14.—Subsurface contour map of the Black River area, Eddy County.

Areas in Eddy County include Black River, High Lonesome, Leo, McMillan, Robinson, and Square Lake. A subsurface contour map of the Black River area is given in Fig. 14.

LEA COUNTY

ARROWHEAD POOL[1]

REUEL L. BOSS[2]
Hobbs, New Mexico

INTRODUCTION

The formational boundaries and nomenclature set forth in this report are not entirely accepted by the writer but have been adopted for the sake of uniformity throughout the Bulletin.

The writer wishes to acknowledge contributions or helpful information received from Mr. R. S. Knappen and Mr. D. C. Sears of the Gulf Oil Corporation, Mr. C. P. Miller of the Hobbs Proration Office, and Mr. R. K. DeFord of Midland, Texas.

LOCATION

The Arrowhead pool lies about five miles southwest of the town of Eunice. State Highway 8, connecting Monument and Eunice, approaches to within less than a mile of the northeast margin of the field. The geographic center of the pool lies in the northeast part of T. 22 S., R. 36 E., Lea County. (See map, Plate 21). As the axis of the structure trends northwest, the boundaries of the pool extend northwest into T. 21 S., R. 36 E., and southeast into T. 22 S., R. 37 E.

HISTORY

The discovery of the Arrowhead pool can be credited more to chance than to any premeditated exploratory program based on either geological or geophysical evidence. The structural data supplied by the older adjacent producing areas afforded only the slightest suggestion of the structure on which the field has been developed. In fact, on the basis of subsurface information the area appeared rather unpromising.

In order to validate an expiring lease, the Continental Oil Co. on April 22, 1938, spudded their No. 1 State "J-2" in the NW¼NE¼ sec. 2, T. 22 S., R. 36 E. Successive marker horizons disclosed the favorable structural position of the test, and with the penetration into the porous reservoir beds of the Grayburg formation, a producing well was assured. Unfortunately, the production casing had been cemented at the shallow depth of 3,497 feet (70 feet below sea level), and such an excessive volume of gas was encountered near the top of the oil pay that it was necessary to seal off the gas zone with a packer before the well could be completed with a favorable gas-oil ratio. On June

[1] Published with permission of Gulf Oil Corporation, Tulsa, Oklahoma.

[2] Resident geologist, Gulf Oil Corporation.

6, 1938, the well was completed at a depth of 3,800 feet for a calculated daily potential of 384 barrels of oil and 310,000 cubic feet of gas. Later, when production from deeper reservoir beds had been established, the well was depened to 3,847 feet and recompleted on November 24, 1940.

The Gulf Oil Corp. immediately offset the well to the north with the No. 3 W. A. Ramsay located in the SW¼SE¼ sec. 35, T. 21 S., R. 36 E., and completed the well on July 25, 1938, at a depth of 3,810 feet for a daily potential by natural flow of 528 barrels of oil and 1,940,000 cubic feet of gas. Before this well was completed, Gulf staked the location for the No. 1-E Mattern in the NW¼SW¼ sec. 1, T. 22 S., R. 36 E., two locations east and two locations south of the discovery well. The No. 1-E Mattern was higher structurally than either of the earlier wells and also produced more oil on initial potential tests. It was completed on August 4, 1938, at a total depth of 3,790 feet after flowing at the rate of 1,320 barrels of oil and 1,300,000 cubic feet of gas daily.

Flush production in an area of some size was indicated, and accordingly there followed an orderly development by several companies holding acreage in the area. Up to May 1, 1942, there had been 104 producing wells completed, and at that time one well was being drilled. There had been no dry holes drilled to that date.

STRATIGRAPHY

The stratigraphic section penetrated in the pool differs only in minor characteristics from typical back-reef sections in other areas of southeast Lea County. The columnar section, Plate 22, gives a description of the formations penetrated.

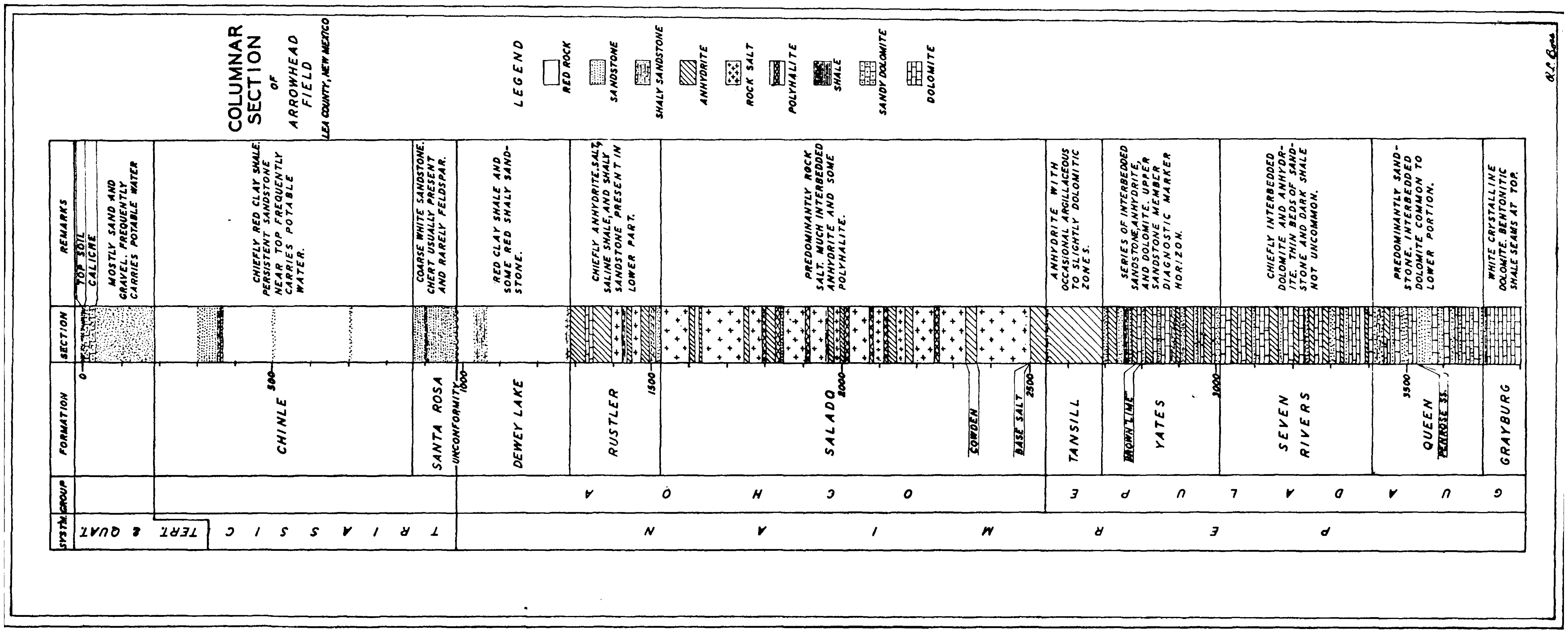
STRUCTURE

The Arrowhead structure, unlike such structures as Penrose, Skelly, Mattix, and others along the major back-reef axis, is a separate or somewhat isolated fold. Its origin is undoubtedly contemporaneous with that of the major trend. It is probably a secondary or echelon fold resulting from local deformation in the area where the major structural axis shows the greatest deviation from the normal strike.

The structure is a somewhat elongated asymmetrical anticline, the axis of which strikes northwest. (See map, Plate 21.) The steeper dips occur on the west flank, where differences in structural elevations from 75 to 80 feet between offset wells are not uncommon. Structure contours on the Rustler anhydrite show a closure of 100 feet. There is a pronounced westward thinning of the Salado formation over the structure, as shown on the cross section, Fig. 15.

RESERVOIR ROCKS

The main pay zones are found in the Grayburg formation. However, in structurally low wells, particularly on the west flank,


COLUMNAR SECTION
OF
ARROWHEAD FIELD
LEA COUNTY, NEW MEXICO
LEGEND
RED ROCK
SANDSTONE
SHALY SANDSTONE
ANHYDRITE
ROCK SALT
POLYHALITE
SHALE
SANDY DOLOMITE
DOLOMITE
SYSTEM
GROUP
FORMATION
SECTION
REMARKS
TOP SOIL
CALICHE
MOSTLY SAND AND GRAVEL. FREQUENTLY CARRIES POTABLE WATER
CHIEFLY RED CLAY SHALE. PERSISTENT SANDSTONE NEAR TOP FREQUENTLY CARRIES POTABLE WATER.
COARSE WHITE SANDSTONE. CHERT USUALLY PRESENT AND RARELY FELDSPAR.
RED CLAY SHALE AND SOME RED SHALY SANDSTONE.
CHIEFLY ANHYDRITE, SALT, SALINE SHALE, AND SHALY SANDSTONE PRESENT IN LOWER PART.
PREDOMINANTLY ROCK SALT. MUCH INTERBEDDED ANHYDRITE AND SOME POLYHALITE.
ANHYDRITE WITH OCCASIONAL ARGILLACEOUS TO SLIGHTLY DOLOMITIC ZONES.
SERIES OF INTERBEDDED SANDSTONE, ANHYDRITE, AND DOLOMITE. UPPER SANDSTONE MEMBER DIAGNOSTIC MARKER HORIZON.
CHIEFLY INTERBEDDED DOLOMITE AND ANHYDRITE. THIN BEDS OF SANDSTONE AND DARK SHALE NOT UNCOMMON.
PREDOMINANTLY SANDSTONE. INTERBEDDED DOLOMITE COMMON TO LOWER PORTION.
WHITE CRYSTALLINE DOLOMITE. BENTONITIC SHALE SEAMS AT TOP.
0
500
1000
1500
2000
2500
3000
3500
CHINLE
SANTA ROSA
UNCONFORMITY
DEWEY LAKE
RUSTLER
SALADO
COWDEN
BASE SALT
TANSILL
BROWN LIME
YATES
SEVEN RIVERS
QUEEN
PENROSE SS.
GRAYBURG
OCHOA
GUADALUPE
TERT. & QUAT.
TRIASSIC
PERMIAN

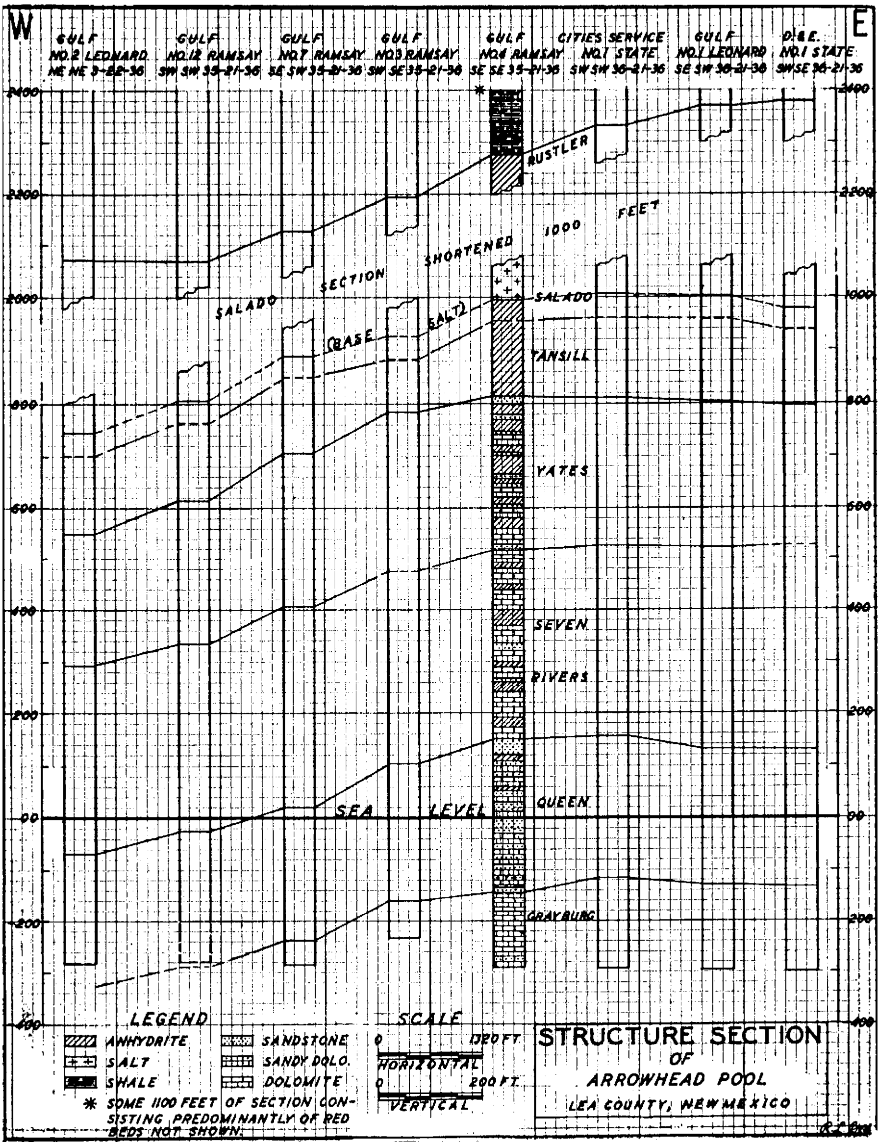


FIGURE 15.—Drawn along line D-D', Plate 21.

the oil-bearing rocks are the basal beds of the Queen formation. The reservoir rocks of both formations are generally porous dolomite. The sandy beds of the Queen are well cemented and do not constitute a suitable reservoir. The most productive zones, in the Grayburg dolomite, are highly oolitic and exceptionally porous and permeable.

As in most of the pools of the back-reef area in southeast Lea County, the general zone within which accumulation has occurred lies between 200 and 300 feet below sea level, rather than in intervals between stratigraphic horizons. Thus from the crest of the structure toward the flanks, progressively younger beds form the reservoir. This condition allows all wells to be drilled to approximately the same depth below sea level.

OIL

The characteristics of the crude oil produced in the Arrowhead pool are given in the following representative analyses.

Analyses of crude oil from Arrowhead pool

	Sample A			Sample B		
The Crude Oil						
Color	Brownish green			Brownish green		
Gravity (° A. P. I.)	34.9			35.7		
Viscosity at 100° F. (seconds)	45.0			40.3		
Flash, OC (°F.)	Below 60			Below 60		
Pour (° F.)	Below 0			Below -50		
Sulfur, B (percent)	1.31			1.29		
Water & Sed. (percent)	0.1			Trace		
Assay Distillation	Crude	Motor Gas Dist.	Light Gas Oil Dist.	Crude	Motor Gas Dist.	Light Gas Oil Dist.
Gravity	34.9	58.9	38.0	35.7	59.3	36.2
Over point	150	131	392	116	100	424
End point	-	424	569	-	395	546
Percent at 221° F.	-	31	-	-	34	-
284° F.	-	63	-	-	65	-
392° F.	-	94	0	-	98	-
10 percent at	-	176° F.	421° F.	-	162° F.	458° F.
50 percent at	-	257° F.	452° F.	-	252° F.	478° F.
90 percent at	-	364° F.	508° F.	-	348° F.	513° F.
Yield Summary						
Motor Gas Dist.	Over-392° F		33.3%	Over-392° F		36.2%
Gravity (° A. P. I.)	58.9			59.3		
Sulfur, L (percent)	0.24			0.15		
Octane No.	57.0 (CFR)			58 (CFR-ASTM)		
Heavy Blend Dist.	392°-428° F.		4.6%	392°-428° F.		3.8%
Gravity (° A. P. I.)	42.0			41.2		
Light Gas Oil Dist.	428-518° F.		10.0%	428-518° F		10.6%
Gravity (° A. P. I.)	38.0			36.2		
Sulfur, L (percent)	0.70			0.77		
Bottoms			51.5%			48.9%
Gravity (° A. P. I.)	21.3			20.7		
Viscosity at 100° F. (seconds)	352			461		
Pour (° F.)	Below 0			-5		
Carbon Residue (percent)	3.6			4.04		
Loss			0.6%			0.5%
			100.0%			100.0%

Sample A: Continental No. 1 State "J-2," NW¼NE¼ sec. 2, T. 22 S., R. 36 E.
Sample B: Gulf No. 1-C Christmas, NW¼NW¼ sec. 18, T. 22 S., R. 37 E.

GAS

The gas produced in the Arrowhead pool is sulfurous, having an average H_2S content of 700 grains per 100 cubic feet. However, the H_2S content is variable, from a minimum of 300 grains in one well to a maximum of over 900 grains in another within the same lease.

The gasoline content of the gas from this field is slightly above the average for the various fields of Lea County. Specific data relative to the gasoline content are shown in the following table.

Gasoline Content of Gas from Arrowhead Pool, in Gallons per Thousand Cubic Feet

	Lease A		Lease B		Lease C	
Test	1	2	1	2	1	2
Temperature (° F.)	82	66	88	60	68	62
Specific gravity	.860	.835	.990	.890	.830	.845
Gallons/1000 cu. ft.	.936	.779	.960	.893	.725	.982

Lease A: Gulf Mattern "E," secs. 1 & 12, T. 22 S., R. 36 E.

Lease B: Gulf Christmas "C," sec. 18, T. 22 S., R. 37 E.

Lease C: Gulf Ramsay, sec. 35, T. 21 S., R. 36 E.

WATER

The encroachment of water has offered no serious maintenance problem, possibly owing to the relatively youthful age of the field. Only four wells encountered bottom hole water initially. After completion, minor amounts of water have been reported in several wells along the southwest margin of the field. The initial water data are given on page 200.

DRILLING AND PRODUCTION METHODS

Rotary drilling equipment is used almost entirely in the Arrowhead field and both Diesel and steam rigs are used extensively. The most common casing practice is to use two strings of casing, a surface string cemented at approximately 300 feet in the top of the redbeds, and a production string cemented at the top of the pay. Occasionally an intermediate string is cemented between 1,100 and 1,400 feet in the Rustler anhydrite. Casing sizes vary but the 9 $^5/_8$-inch or 10¾-inch is most commonly used for surface casing and the 5½-inch size for the oil string. If the intermediate string is set, the 7$^5/_8$-inch size is normally run. To avoid excessive gas-oil ratios, it has proved expedient to use care in setting the production casing. The average depth at which this pipe is set is 200 feet below sea level, and penetration into the reservoir beds is normally carried to 300 feet below sea level. Tubing, usually of 2-inch size, is run to a point near total depth to facilitate normal flow of the wells. There were no wells pumping in the field to May 1, 1942.

Initial Water Encountered in Arrowhead Pool

Well and Location	Maximum subsea depth	Datum of water	Date	Initial amount	Remarks
Texas-Pacific No. 15 State. NE¼NW¼ sec. 11, T. 22 S., R. 36 E.	–295'	–292'	5/39	1 bailer per hour	Successful shut-off by plugging back to –290'
Gulf No. 3-D Mattern. SE¼NW¼ sec. 7, T. 22 S., R. 37 E.	–302'	–302'	2/40	63 barrels per day	Acidized into water. Produces maximum amount of water in pool.
Continental No. 5 Lockhart "B-1". SW¼SE¼ sec. 1, T. 22 S., R. 36 E.	–300'	–300'	6/40	3½ bailers per hour	Plugged back to –292' and tested 90% water. Plugged back to –248', drilled out to –270' and obtained shut-off.
Humble No. 3-M State. SE¼SE¼ sec. 18, T. 22 S., R. 37 E.	–301'	–301'	7/40	30 percent	Plugged back to –291' and tested 80% water. After 600-gal. acid treatment, tested only 30% water.

PRODUCTION

Throughout the entire history of the field oil production has been prorated, and the amount of oil produced has conformed, wherever possible, to allowables authorized by the State Oil Conservation Commission. The field produced a total of 1,421,912 barrels of oil from 101 wells during 1941, and the total cumulative production to January 1, 1942, was 3,017,810 barrels. Figures available from the semiannual bottom-hole pressure survey show an average field pressure decline of 18 pounds for the last half of 1941. The field average, calculated from 78 wells, dropped from 1,382 pounds to 1,364 pounds during that period. The oil produced during the period amounted to 657,783 barrels, giving a ratio of 36,544 barrels produced per pound of pressure drop.

Gas is found in several zones, particularly in the zone immediately overlying the oil pay. However, the only gas produced is that which accompanies the oil. In 1941 the field produced a total of 2,101,227,000 cubic feet, and during the period from January 1, 1939, to January 1, 1942, the cumulative total amounted to 4,406,915,000 cubic feet. Most of the wells are connected to a gathering system through which the gas is transported to the gasoline plant operated by Skelly Oil Co. in the nearby Penrose area.

LAND OWNERSHIP

There were 4,160 productive acres in the field to May 1, 1942 (calculated on the basis of 40 acres per well), of which 67 percent is State land, 32 percent patented land, and the remaining one percent Federal land. Eleven operating companies are represented in the field.

FUTURE DEVELOPMENT

Although the limits of the field have not been entirely defined, the character of the wells along the margins will not encourage the drilling of many offset tests. Undoubtedly economic conditions will largely control any future development in the field.

COOPER-JAL AREA

P. W. MILLER[1] and ROBERT L. BATES

LOCATION

The area designated as the Cooper-Jal area in this report is an elongate producing district, trending north, in southeastern Lea County. It includes four pools as defined by the State Oil Conservation Commission. (See map, Plate 23.) From south to north these pools are Eaves, Jal, Cooper, and Lynn. They are so closely related in the subsurface that it is thought advisable to treat them in a single discussion.

The town of Jal lies immediately east of the south central part of the area. State Highway 18 and the Texas-New Mexico Railroad, connecting Hobbs on the north with Monahans, Texas, on the south, parallel the area's eastern boundary. The surface, which is covered with caliche and loose sand, has an average elevation of about 3.100 feet.

HISTORY

The discovery of commercially important pools in Winkler County, Texas, prompted oil companies to extend their explorations northward into New Mexico along the general trend already established in Texas. Thus the first well in the Cooper-Jal area was located near the southern border. Discovery wells of the four pools are listed chronologically in the accompanying table, page 203.

As discovery came just before the start of the business depression, drilling was not extensive for about five years. Most of the drilling in the Cooper and Jal fields was not done until 1934 and 1935. At the end of 1941, there were 157 oil wells, 44 gas wells, and 9 dry holes in the area as a whole.

STRATIGRAPHY

From the surface to the base of the Salado formation, the geologic section in the Cooper-Jal area is essentially identical

[1] Geologist, Western Gas Co., Jal, New Mexico.

with that in the Langlie-Mattix area which adjoins it on the east (see page 205) .

Pre-Salado formations.—A comprehensive view of the formations below the Salado salt is given by the cross section, Plate 24. The Tansill consists of anhydrite and dolomitic limestone in about equal proportions. The limestone is more abundant toward the base of the formation. Thickness is 175 to 200 feet. The Yates, which is about 250 feet thick, is chiefly dolomitic limestone and gray sandstone, the latter carrying the characteristic frosted quartz grains. The Seven Rivers, the producing formation throughout the area, is highly porous tan to brown dolomitic limestone. Its thickness is approximately 400 feet. The Queen formation, which was partly penetrated in the area's deepest test, the Skelly No. 1 Combest in sec. 27, T. 23 S., R. 36 E., is dense light gray dolomitic limestone with sandstone stringers.

STRUCTURE

A long anticlinal ridge underlies the Cooper-Jal area. (See map, Plate 23, and cross section, Plate 24.) Its eastern limb descends only a short vertical distance into the shallow trough separating the Cooper-Jal and the Langlie-Mattix structures. The west limb of the anticline, however, coincides with the west edge of the Capitan Reef and drops off into the Delaware basin to a great depth. As the reef in this region is wider and less sharply defined than it is on the west side of the Delaware basin, the rate of dip on the west side of the Cooper-Jal anticline is only 300 to 350 feet per mile.

RESERVOIR ROCKS

In the south part of the area (Eaves pool), commercial amounts of dry gas are produced from sandstones in the Yates formation, and oil is yielded by very porous to cavernous dolomitic limestones of the basal Yates and uppermost Seven Rivers. Toward the north, oil and gas are found in progressively older strata. Thus in the Jal pool production is chiefly from the limestones of the middle Seven Rivers, and in the Cooper field most of the porous producing limestones are in the lower Seven Rivers, and possibly in the uppermost Queen formations.

In general the short eastern limb of the anticline is nonproductive. Gas is encountered along the crest, oil on the west limb, and oil and water low on the western flank.

FLUIDS

Like most of the oil that has accumulated in limestone, the oil in the Cooper-Jal area is sour. It has an average gravity of 30° A. P. I. The gravity and to some extent the characteristics of the oil vary with the zone of porosity from which it comes. Light oil tends to accumulate high on the flank of the structure, with heavier crudes farther down.

Gas is produced alone and with the oil. Both types are

Discovery Wells in the Cooper-Jal Area					
Pool	Well	Location (Sec., T.-S., R.-E.)	Total Depth, Feet	Date of Completion	Remarks
EAVES	Continental Oil Co. No. 1 Eaves	19-26-37	2,983	6-1-28	8,000,000 cubic feet of gas at 2,908 feet ; 62,000,000 at 2.927 feet; 90,000,000 at 2,968 feet. Initial production, 90,000,000 cubic feet.
LYNN	Continental Oil Co. No. 1 Lynn	26-23-36	3,930	3-1-29	15,000,000 cubic feet of "sulfur gas" at 3,091 feet ; 25,000,000 at 3,208 feet; 50,000,000 at 3,779 feet. Plugged back to 3,650 feet. Initial production, 30,000,000 cubic feet.
JAL	Skelly Oil Co. No. 1 Joiner	26-25-36	3,339	5-23-29	Initial production, 438 barrels of oil.
COOPER	Cranfill and Reynolds No. 1 Myers	22-24-36	3.438	7-18-29	Initial production, estimated, 90,000,000 cubic feet of gas.

sour. An analysis of a typical sour gas from this area is given on page 205. Gas-oil ratios for the various fields are as follows: Eaves, 7,000:1; Jal and Cooper, 10,000:1; Lynn, 5,000:1.

The field is under a strong water drive from the west. Flooding is taking place as fast as the oil and gas are withdrawn. In plugging back some wells to shut off the water, operators have found oil in porous zones which were dry when the hole was drilled ; this oil has been forced into such zones by the water drive. Many wells produce large amounts of water with the oil. In the Cooper area, more than eight times as much water as oil was produced during 1941. The water, which is high in hydrogen sulfide, is known as "sulfur water."

DRILLING AND PRODUCTION METHODS

Most of the drilling has been done with rotary equipment. Three strings of casing are employed, as follows: surface string of 12-inch at about 250 feet; salt string of $9^5/_8$-inch either above the salt (in the Rustler) or below it (in the Tansill); pay string of 7-inch at about 3,400 feet, just above the producing zone.

Wells are allowed to flow through 2-inch tubing until they begin to make large percentages of water. They are then put on pumps of various kinds, depending on the volume of water which must be raised in order to produce the required amount of oil. There are a number of gas-lift installations.

Especially in the Jal and Cooper fields, many wells have been plugged back to porous zones above the original pay, and re-completed by gun-perforating the casing.

PRODUCTION

Data on production of the four pools in the Cooper-Jal area are given in the following table.

	Oil (Barrels)		Gas (Thousands of Cubic Feet)	
Field	1941	To end of 1941	1941	To end of 1941
Cooper	1,032,739	13,096,849	6,739,727	106,156,727
Eaves	289,593	2,216,453	1,530,693	8,148,693
Jal	129,741	5,871,599	5,259,015	37,280,015
Lynn	347,384	1,647,295	2,288,437	7,537,437
Totals	1,799,457	22,832,196	15,817,872	159,122,872

LAND OWNERSHIP

Ownership of the land in the Cooper-Jal area was distributed approximately as follows at the end of 1941:

Field	Government Land (Percent)	State Land (Percent)	Patented Land (Percent)
Cooper	36.1	5.6	58.3
Eaves	48.5	48.5	3.0
Jal	55.5	11.2	33.3
Lynn	47.2	44.4	8.4

Most of the major companies and a number of independent operators are represented in the area.

FUTURE POSSIBILITIES

Dry holes among the producing districts of the area indicate that no new production will be secured within the pool limits from depths now exploited. No tests for deep production have been drilled. North of the Cooper-Jal area, oil is produced in great quantities from Permian formations lying below those which produce at Cooper-Jal; however, it is thought that this condition is a result of the normal tendency of the oil to accumulate in older formations toward the north.

Early in 1942 a wildcat, the Wilson No. 1 Saunders in the SE¼ sec. 11, T. 25 S., R. 35 E., was drilled to a depth of 5,158 feet. No oil or gas was secured.

Fractional Analyses of Gas from Southeastern Lea County

I. SOUR GAS

Sample taken at 495 lbs. pressure, 73° F. January, 1938.

Component	Percent by Volume	Gasoline, Gal. per Thousand Cu. Ft.
Air	Nil	
CO_2 and H_2S	1.20	
Methane	91.54	
Ethane	4.83	
Propane	1.89	
Isobutane	0.17	0.055
n-Butane	0.33	0.104
Pentanes plus[1]	0.04	0.015
Totals	100.00	0.174

Calculated specific gravity (air = 1): 0.614.
Calculated gross B.T.U. per cubic foot: 1,079.

II. SWEET GAS

Sample taken at 480 lbs. pressure, 75° F. January, 1938.

Component	Percent by Volume	Gasoline, Gal. per Thousand Cu. Ft.
Air	Nil	
CO_2 and H_2S	0.10	
Methane	90.69	
Ethane	6.01	
Propane	2.25	
Isobutane	0.21	0.068
n-Butane	0.39	0.123
Pentanes plus[1]	0.35	0.018
Totals	100.00	0.209

Calculated specific gravity (air = 1): 0.614.
Calculated gross B.T.U. per cubic foot: 1,107.

[1] Traces of light gasoline fractions calculated as isopentane.

CORBIN POOL

ROBERT L. BATES

LOCATION AND HISTORY

The Corbin pool lies in a single township in Lea County, T. 18 S., R. 33 E. (See map, Plate 14.) It is southeast of the Maljamar pool and southwest of the Vacuum pool. The northwest part of the township is crossed diagonally by Mescalero Ridge, the western edge of the Llano Estacado. Most of the area therefore is in the poorly drained sand-dune region on the east side of the Pecos Valley. Surface elevations range from 3,750 to 4,050 feet.

The discovery well of the Corbin pool was The Texas Co. No. 1 M. A. Corbin, in the NW¼SW¼ sec. 10, which was completed June 28, 1938. Total depth was 5,118 feet, but as large quantities of sulfur water were encountered at this depth the hole was plugged back to 4,320 feet. Top of pay is 4,258 feet. After shot with 240 quarts of nitroglycerin between top of pay and plugged-back depth, the well made 43 barrels of oil daily.

Since completion of the discovery well, Helmerich and Payne have drilled two additional wells, Nos. 2 and 3-A Corbin. The former, a direct west offset to The Texas Co.'s well, had an initial production of 70 barrels; the latter, a short distance to the northeast, is a gas well with an initial production of 13,500,000 cubic feet. These wells constitute the only producers in the field.

STRATIGRAPHY

Beneath the surface covering of windblown sand and caliche lie Tertiary, Triassic, and Permian shales and sandstones which aggregate 1,500 feet in thickness. The Rustler formation, next below, is dominantly anhydrite, with some sandstone and two prominent limestone zones. It is 200 feet thick. Fifteen hundred feet of salt makes up the Salado formation. It includes the Cowden anhydrite, 15 feet thick, about 150 feet above the base. The Tansill formation is anhydrite 150 to 200 feet thick. The Yates is largely red anhydrite, with a little red sand carrying a few frosted quartz grains, and some limestone. Total thickness is about 175 feet. The Seven Rivers is made up of limestone and anhydrite, the latter being especially prominent toward the base. It is 1,000 feet thick. The Queen contains at its top the "Artesia red sand," about 50 feet thick with many frosted quartz grains. The remaining 450 feet of the formation consists of sandstone, anhydrite, and limestone. The Grayburg, 350 feet thick, is light-colored dense limestone, in part oolitic, and gray calcareous sandstone.

No wells in the Corbin pool have entered the San Andres formation ; total depth of the discovery well is believed to lie just above this formation's top. However, the Henderson, Dexter, and Blair No. 1 Wyatt-Brown, dry hole in sec. 34 of the township to the north, penetrated 450 feet of sandstone and sandy limestone which is believed to be San Andres. Much chert was noted about 150 feet below the top of the formation.

STRUCTURE

The scarcity of control points for subsurface contouring makes it difficult to determine whether closure exists in the rocks of the Corbin area. Geophysical information indicates a structural high. It is thought that the structure is a southeastward-plunging nose, with little or no closure, on the south flank of the Maljamar-Vacuum trend.

RESERVOIR ROCKS

Reservoir conditions in the Corbin area are somewhat anomalous. The producing zone is the "Artesia red sand" member of the Queen formation. This sandstone showed no water in the discovery well, carried some sulfur water in the west offset, gave a show of oil in the Wyatt dry hole to the north, and yielded sulfur water in the Culbertson and Irwin No. 1 Wingfield, failure in sec. 4, T. 19 S., R. 33 E. The basal Grayburg sandy limestone, about 50 feet thick, produced a good oil show in the Wyatt-Brown well but carried salt water in The Texas Co. No. 1 Corbin. Further data are needed for an interpretation of reservoir conditions in the Corbin pool.

DRILLING AND PRODUCTION METHODS

The discovery well was drilled to 4,021 feet with rotary equipment and from that depth to 5,118 feet with cable tools. Most of the other wells of the area have also utilized both methods of drilling. Three strings of casing have been commonly set: a surface string at a depth of 250 to 500 feet; a second string in the Rustler formation at about 1,600 feet; and the production string close above the pay. In the discovery well the sizes of pipe in these strings were 13-inch, $9^5/_8$-inch, and 7-inch respectively.

The two oil wells are flowing. Production of oil in 1941 was 15,846 barrels, while total production to the end of that year was 26,624 barrels.

FUTURE POSSIBILITIES

Until more is known about the distribution of porous zones and contained fluids in the Corbin area, little prediction can be made. Whatever new areas are found to produce from depths now exploited are likely to be small. Whether or not oil occurs in commercial quantities in or below the middle part of the San Andres formation will not be determined till deep testing of the region is begun.

EUNICE POOL

EDGAR KRAUS[1]
Carlsbad, New Mexico

LOCATION

The Eunice pool is an important part of the almost continuous strip of productive territory extending from the Eaves pool

[1] Geologist, The Atlantic Refining Company.

to the Monument pool in Lea County, New Mexico. The north boundary of the pool is designated as within a narrow neck of productive land between the considerably wider main parts of the Monument and Eunice pools. (See map, Plate 21.) This line of demarcation was chosen for practical reasons to minimize conflicts between two different methods of proration, rather than on purely geologic grounds. However, low permeability, changing pressure conditions, and some structural differences have since indicated that the choice of this line is not unreasonable.

The wells in the south part of sec. 31, T. 21 S., R. 36 E., belong geologically with those in the South Eunice pool, but for the sake of convenience the pool boundary is made to coincide with the township line. On the east, a few wells of the Hardy pool come within T. 21 S., R. 36 E., but they are included in the Eunice pool only for proration purposes. They will be disregarded in the geological discussion that follows.

HISTORY

The discovery well of the Eunice pool was drilled in sec. 31, T. 21 S., R. 36 E., by the Marland Oil Co. (now the Continental Oil Co.), as one of a series of tests extending northwestward from the southeast corner of Lea County. Location was influenced somewhat by topography. This well was completed as the No. 1 Lockhart "B-31" on March 21, 1929, for a production of 250 barrels per day with some water. Shortly afterward the Continental No. 1 Meyers "A-17," in sec. 17, T. 21 S., R. 36 E., was completed in January, 1930, and was capable of producing 945 barrels in 18 hours. A gas well, the No. 1 State Ramsey, in sec. 34 of the same township, was completed by the Gypsy Oil Co. (now Gulf Oil Corp., Gypsy Division), late in 1929. This well considerably influenced early development by serving as a source of fuel.

The discovery, coming as it did in the early depression years, was followed by exceedingly slow development, and in June, 1932, 39 months after the completion of the first oil well, only nine wells were producing. During this period and for a time thereafter, daily production for most of the wells was limited to 45 to 50 barrels, the arrangement being entirely cooperative and voluntary.

In July, 1932, the Tide Water Associated Oil Co., because of drilling obligations, started its No. 1 State in sec. 8, T. 21 S., R. 36 E. By this time, Eunice operators had tentatively agreed with the State Geologist that optimum spacing allowed one well to each forty acres, and that a well drilled within 660 feet of a lease line constituted an offset. The completion of the Tide Water well in September, 1932, as a 500-barrel producer began the steady development of the field.

All wells are drilled either on regular 40-acre subdivisions or on lots, the smallest of which contains 33.24 acres. In September, 1941, there were 490 producing oil wells in the Eunice pool.

Eight wells have been abandoned after producing some oil. Five wells are designated as gas wells, although some have previously produced considerable oil.

STRATIGRAPHY

The surface, which is covered by Recent sand and caliche, gives no indication of geologic structure. It serves as poor grazing land, none of it having been cultivated.

TRIASSIC-PERMIAN

Redbeds.—The underlying redbed section consists in the upper part of Triassic formations, probably Santa Rosa and Tecovas (Dockum group), and in the lower part of Dewey Lake beds (Upper Permian).[2] The exact position of the unconformity between Triassic and Permian is not readily determinable, but in some wells a distinct color change is noted and harder drilling reported when the Permian is reached.

PERMIAN

Rustler.—The Rustler formation, 100-200 feet thick, is a tough white anhydrite in all parts of the field. It differs in lithology from the type Rustler, which is limy, especially near the top.

Salado.—An average thickness of 1,300 feet of salt and anhydrite underlies the Rustler. This corresponds to Lang's[3] Salado, or to the Upper Castile of the older literature. At least 30 feet of anhydrite lies beneath the lowest salt. A 20- to 30-foot bed about 100 feet from the base of the salt corresponds to the Cowden anhydrite[4] as described from the Cowden pool, west Texas.

Tansill.—The formation lying between the base of the Salado and the top of the Yates is now referred to as the Tansill.[5] It is not yet clear, however, whether this unit includes the anhydrite immediately below the salt or only that part of the formation which, in some areas, is largely limestone. The Tansill is limy in the western part of the Eunice pool, and contains more anhydrite eastward. In places on the extreme east edge it is entirely anhydrite.

Yates.—The Yates formation, the top of which is generally used as the contouring datum, is similar in characteristics to the Yates throughout southeastern New Mexico. A coarse sand containing large frosted quartz grains occurs at the top. Although in rotary-drill samples the frosted grains are not always found, the coarse sand is readily discernible. Fine silt, which lies above the coarse sand, is included in the Tansill. In addition to the

[2] Page, L. R., and Adams, J. E., Stratigraphy, eastern Midland basin, Texas: Bull. Amer. Assoc. Petrol. Geol., Vol 24, No. 1, pp. 52-64, 1940.3

[3] Lang, W. B., Salado formation of the Permian basin: Bull. Amer. Assoc. Petrol. Geol., Vol. 23, No. 10, pp. 1569-72, 1939.

[4] Giesey, S. C., and Fulk, F. F., North Cowden field, Ector County, Texas: Bull. Amer. Assoc. Petrol. Geol., Vol. 25, No. 4, pp. 593-629, 1941.

[5] DeFord, R. K., and Riggs, G. D., Tansill formation, west Texas and southeastern New Mexico: Bull. Amer. Assoc. Petrol. Geol., Vol. 25, No. 9, pp. 1713-28, 1941.

sand, the Yates contains dolomite which decreases toward the east and grades into anhydrite. The top of the Yates lies rather uniformly 190 feet below the base of the salt, but the base of the Yates is not so easily designated. A thickness of 300 feet for the Yates is considered average for the field.

Seven Rivers and Queen.—The underlying section, correlated with the Seven Rivers and Queen formations[6] of the standard section, is not easily subdivided. It consists chiefly of dolomite and anhydrite. The dolomite decreases eastward. Coarse sands, with many zones of large round frosted quartz grains, are more numerous in the Queen part of the section than in the Seven Rivers, but the exact point of demarcation is not clearly defined. The "Artesia red sand" zone, used as a marker in the oil fields of Eddy County and easily traced into northwest Lea County, is represented in the Eunice section by red and gray sands in the Queen, but it is neither uniform nor definite enough to serve as a marker.

Grayburg.—The Grayburg beds in the Eunice pool consist of sand, sandy dolomite, and dolomite, the first two materials becoming increasingly evident toward the east. The Grayburg correlates with the "Sandy Lime" section in the Hobbs field,[7] but whereas it contains little oil at Hobbs, it is the principal oil-producing formation in the Eunice pool.

San Andres.—The San Andres is a dark gray to white crystalline dolomite, in many places anhydritic. Few wells in the pool enter it. The Gulf No. 7 Bell-Ramsey-State, in sec. 9, T. 21 S., R. 36 E., at 4,015 feet entered beds correlated with the white crystalline lime of the Hobbs pool, which is considered San Andres. On the extreme west edge of the pool, the Shell No. 1 State, in sec. 12, T. 21 S., R. 35 E., is thought to have reached the San Andres at 4,350 feet. It was drilled to 4,404 feet. An unconformity of unknown magnitude is postulated at the top of the San Andres.

STRUCTURE

Dolomite reefs or limestone ridges, which parallel the eastern margin of the Delaware basin in almost unbroken succession, are the dominant structural features localizing production. These reefs or ridges developed during middle Permian time. In the region of the Eunice pool, active reef building was in progress with but few interruptions from San Andres to the close of Yates time. Evidence indicates that later reefs were built on the fore-reef detrital material of earlier reefs, so that, in general, later reefs project basinward (west at Eunice) over the lower earlier reefs or ridges.

[6] DeFord, R. K., and Lloyd, E. R., West Texas-New Mexico symposium, Part I; Editorial introduction: Bull. Amer. Assoc. Petrol. Geol., Vol. 24, No. 1, pp. 1-14, 1940.

[7] DeFord, R. K., and Wahlstrom, E. A., Hobbs field, Lea County, New Mexico: Bull. Amer. Assoc. Petrol. Geol., Vol. 16, No. 1, pp. 51-90, 1932.

A structure map of the pool, contoured on the top of the Yates formation (Plate 21), illustrates the small amount of actual reversal. The steep west dip is typical of the fields from Eaves on the south to Eunice, but little or no east dip exists on the Yates. Studies made by Anderson, Hinson, and Schroeder[8] lead them to the conclusion that there is reversal within the producing zone, but this opinion is based on configuration of zones of porosity rather than on stratigraphy.

The structure plunges south, the Yates being 500 feet lower on the crest at the south end than on the north. Contours on the top of the Rustler show a southward-plunging nose with steeper dip to the west than to the east. (See cross section, Plate 25.)

The main axis of production is almost exactly north-south, but a definite secondary northwest trend, reflected in both contouring and production, agrees with similar cross trends found in other oil fields of southeastern New Mexico. The major trend is unquestionably determined by reef building, while the northwest-southeast trend is a reflection of a deeper-seated "grain" of the region.

RESERVOIR ROCKS

Production has been attained in the Eunice pool, wherever porosity and permeability are sufficient, between about 190 feet below sea level and 360 feet below sea level. Above this zone, gas has been predominant; below it, sulfur water. As development and withdrawals have taken place, this zone has thinned, the reduced formation pressure has depressed the gas-oil contact, and the water replacing the displaced fluids has slowly raised the water-oil contact.

Through most of the field, the designated zone falls within the Grayburg section, but on the west side higher formations are productive. On the extreme west edge the production is from the Queen or Seven Rivers formations. The cross section, Plate 25, illustrates this condition. The gas-oil and water-oil contacts shown are those that existed early in the history of the field.

This remarkable segregation of gas, oil, and water in nearly horizontal zones, irrespective of stratigraphy or structure, indicates that enough intercommunication exists in the sediments to permit gravitational forces to be effective over long periods of geologic time.

It is noteworthy that the water-oil contact, originally estimated in the Eunice pool at 360 feet below sea level, is at essentially the same elevation as that estimated for many other southeastern New Mexico fields. At Monument, water was found wherever porosity was obtained below –360 feet. Corresponding figures for neighboring pools are: South Eunice, –350 feet; Lynn, –360 feet; Eaves, –300 feet. This indicates that equilibrium was

[8] Anderson, C. C., Hinson, H. H., and Schroeder, H. J., Reservoir characteristics of the Eunice oil field, Lea County, N. Mex.: U. S. Bur. Mines Report of Investigations No. 3456, July 1939.

reached over a large area and that the accumulation of oil must have been early, perhaps almost contemporaneous with deposition of the sediments.

Because the reservoir transgresses stratigraphic boundaries, the reservoir rock varies in character depending on which formation lies at the productive level. In most of the wells this happens to be the Grayburg. The producing section is made up of gray and white dolomite which is commonly oolitic, sandy in a few places, and rarely anhydritic, and shows porosity varying from pin-point to cavernous. A pink dolomite 5 to 10 feet thick is recognized in parts of the field, and provides an aid to correlation within the producing zone. Where formations higher than the Grayburg come within the zone, gray, white, and buff dolomite and sandy dolomite are productive. The dolomite is less commonly oolitic in these higher strata.

The aggregate thickness of the pay in any well is not easy to determine. Coring has proved little except that the best part of the pay section usually is marked by that part of the core which is not recovered; however, it has not been entirely safe to assume that all core lost is necessarily pay. Of the 150 to 170 feet within the oil-producing zone, not over 40 to 50 feet in any well has been thought to contribute to the total production. In a great many wells there is not more than 10 to 20 feet of actual pay.

Because drilling is more rapid in porous than in dense dolomite, drilling time has been found a reliable index of pay section. Streaks of shale or silt are probably drilled more rapidly than dense dolomite and may introduce some error, but in general the drilling-time curve has proved the most consistent means of predicting final production. Size of bit, weight on bit, and type of drilling fluid vary the absolute drilling time, but relative changes great enough to indicate pay streaks have generally been easily discerned. Usual practice has been to time one- or two-foot intervals as drilling progressed below the oil string.

The limits of present production have been determined with the drilling of a gratifyingly small number of exploratory or limiting dry holes. On the west, only one dry hole a mile from production has been drilled. On the south, Atlantic No. 1-F State, in the SW cor. sec. 29, T. 21 S., R. 36 E., was completed as a failure; and subsequent abandonment, after small production, of wells three quarters of a mile farther south, has limited development in that direction. On the east and southeast, decreased porosity yielded poor wells, and some producing wells drilled in sec. 28 were abandoned because of rapid encroachment of water. Devonian Oil Co. No. 2 State-Evans, on the east edge of sec. 3, T. 21 S., R. 36 E., was a small producer which was later abandoned; and similar small producers all along the east edge of the area now developed discouraged further extension eastward. To the north, the Eunice field merges with Monument, so that no dry holes have been drilled. However, some wells with low porosity and small production have been completed in the connecting neck between the fields.

Over 200 oil wells are now producing from two to 98 percent water. Encroachment by water has been most uniform on the west and south, while the east edge, because of lower permeability, is less evenly flooded. As might be expected, the central part of the pool has the largest percentage of oil wells still free from water.

GAS RESERVOIR

As almost all drilling has been by the rotary method, information on gas zones is not accurate. On the basis of gas shows, accidental gas blowouts, and gas production developed behind the oil string and bradenheaded, principal gas zones appear to be in the Grayburg formation immediately above the oil zone (originally higher than 190 feet below sea level) , and in the lower Tansill ("Brown Lime") and upper Yates sections. This Tansill-Yates zone extended from about 150 feet to 300 or 400 feet below the base of the salt. The gas from this zone, which is in general sweeter than that associated with the oil lower in the section, has often been bradenheaded and used for lease and fuel purposes. In the Gulf No. 1 Mattern, sec. 24, T. 21 S., R. 36 E., the principal gas zone appears to be in sand and sandy dolomite in the lower Queen section. In the Gulf Ramsey-State gas well in sec. 34, the gas is principally from the Yates zone, with possibly some from the lowermost Queen and upper Grayburg.

OIL

Typical Eunice oil shows the following general characteristics.

Analysis of Oil from Eunice Pool

Gravity	30.0 to 34.5° A. P. I.
Sulfur content	1.10 to 1.65 percent
Saybolt Universal viscosity at 100° F.	42 to 56 sec.
Pour point	0° F.

Distillation

Fraction	Percent
Motor stock, octane no. 58[9]	35.0
Gas oil	43.6
Tar	20.0
Loss	1.4
Total	100.0

Too few analyses of oils from individual wells are available to determine whether oils coming from different parts of the stratigraphic section vary in any definite way.

DRILLING AND PRODUCTION METHODS

As previously indicated, with few exceptions the wells in the Eunice field have been drilled with rotary tools. As it was found

[9] At end point of 420° F. If the motor stock is carried to a 300° F. end point, it will yield 21.9 percent; but the octane number will be increased to 66.

that the injurious effect of water or mud on the pay was out of proportion to the high formation pressure, some early wells were drilled-in with cable tools. Because of the expense and delay occasioned by rigging up cable tools to accomplish this 100 to 150 feet of final drilling, a substitute method of drilling-in, with oil as the circulating fluid, was adopted by many operators. The use of oil, together with gas to lighten the column, permitted the formation to produce normally even while being drilled-in, and avoided the necessity of cleaning the wells by washing or acid treatment. Many wells were drilled-in with rotary tools using light mud or water, and then brought into production by swabbing or by treating with acid. It was found that an acid wash resulted in undoing the damage referred to, and yielded a well of potential similar to that which would have been obtained had oil fluid been used.

Casing programs of two general types have been followed. The most common arrangement provides for a string to shut off surface water, set anywhere from 75 to 350 feet below the surface, but generally between 250 and 300 feet; an intermediate string set in the Rustler anhydrite; and a production string set near the top of the producing zone.

Another popular program, used frequently in attempting to bradenhead gas from the Yates and other gas zones, has been to set surface pipe as indicated and then set the intermediate string through the salt and into the upper part of the Tansill formation. When the production string was then set as usual, gas could be bradenheaded and produced between the intermediate and production strings without injury to the salt section.

Early in the development program, usual pipe sizes for the surface, intermediate, and production strings were 12½-inch, $9^5/_8$-inch, and 7-inch respectively, or even 15½-inch, 10-inch, and 7-inch; but later practice, which reduced drilling and casing expenses and proved entirely satisfactory, has been to use smaller sizes, namely 12½-inch, $8^5/_8$-inch, and 5½-inch, or 10¾-inch, 7-inch, and 5½-inch. The smaller well bore is practical at Eunice because potential is not used in allocating production.

Cementing and casing regulations and practices have been designed (1) to protect surface waters, (2) to protect the salt and potash beds, and (3) to protect the producing zone from upper waters and exclude as much free gas as possible. Many operators set the production string only after taking drill-stem tests to determine the gas-oil contact. After the elevation of this interface had been determined, most of the production strings were cemented at about 200 feet below sea level. Some operators have preferred to set the pipe higher and control the free gas by setting packers on the tubing. This procedure has not always proved successful. During the early development of the field, 3-inch and 2½-inch tubing were commonly used, but later, with lower allowables prevalent, much 2-inch tubing was run.

Many wells have been acidized immediately upon completion.

A few operators have acidized whether the wells were capable of making their prorated allowable or not. Acid used in a single treatment is commonly 1,000 gallons, although larger amounts have frequently been used. Acid treatment has also been used either to revive declining production or to reduce high gas-oil ratios. By acidizing the lower part of the producing section, an operator could often increase oil production without proportionately increasing the gas.

A few wells have been shot with nitroglycerin, but this practice has not been common because of resulting cleanout delay and because shooting destroys possible packer seats, making future remedial work expensive or impossible.

Throughout the productive history of the field, all wells except marginal ones have been restricted in flow. Allocation has been on an acreage basis only, with adjustments penalizing high gas-oil ratios. The effectiveness of the field's water drive is shown by the relatively small decrease in bottom-hole pressures. From an estimated original average of 1,500 pounds static bottom-hole pressure at 250 feet below sea level, the average in July, 1941, had fallen to 1,017 pounds, or a drop of 9.6 pounds per million barrels.

As the bottom-hole pressures dropped and gas came out of solution, a gas cap formed in the central part of the field and in general the gas-oil contact was depressed. This caused a gradual increase in gas-oil ratios for many wells. Much remedial work has been done to correct this increase. The most successful method has been to set packers on tubing in dense lime streaks below the new gas-oil contact. Acidizing below the packer was frequently necessary to increase oil yield partly shut off by the packer setting. The recent gas-oil ratio for the field as a whole averages about 3,500 cubic feet of gas to one barrel of oil.

OWNERSHIP

Two hundred ninety-eight (61 percent) of the producing wells are on State of New Mexico land; one hundred wells (20 percent) are on Government land; and the remainder are on fee lands. Operators in the field include nearly all the major companies active in southeastern New Mexico.

PRODUCTION

Production from the Eunice pool has been as follows:

Period	Barrels
Prior to 1935	1,822,229
During 1935	3,207,460
1936	7,444,756
1937	11,107,688
1938	8,841,388
1939	7,823,026
1940	6,540,417
1941	6,644,181
Total	53,431,145

FUTURE POSSIBILITIES

Few if any additional wells will be drilled to the present producing zone. As only a few wells have tested the upper part of the San Andres formation, some future drilling intended to explore this section more completely may be attempted. The present accumulation is associated with reefs, and there may or may not be true folding underlying the field. It is not likely that deep exploration for Pennsylvanian or Ordovician production will be started at Eunice until areas more attractive for such exploration have first been tested.

ACKNOWLEDGMENTS

The petroleum geologists and engineers in southeastern New Mexico have so generally exchanged information, experiences, and ideas, that it would be impossible to give credit to all those whose data or conclusions have been included in this report. Specific thanks are due, however, to R. E. Morgan for the preparation of the cross section and to R. M. Knoepfel for the drafting of the contour base map.

HALFWAY POOL

RONALD K. DEFORD[1]

Midland, Texas

LOCATION AND HISTORY

All the wells in the Halfway pool are in sec. 16, T. 20 S., R. 32 E., Lea County, except one in sec. 9 of the same township. The pool is about three miles northwest of Halfway station on U. S. Highway 62, about half way between Carlsbad and Hobbs. (See map, Plate 14.)

Oil was discovered in a test drilled by the Westlea Oil Co. in the NE¼ SW¼ sec. 16 on October 6, 1939, at a depth of 2,627 feet. This well was also known under the name of Frank Farley or Peck and Croft; it is now called the Argo Oil Corp. No. 1-B Texas-State. The initial potential, without acidizing or shooting, was 1,000 barrels in 24 hours, based on an 18-hour swabbing test.

Between October, 1939, and August, 1941, Argo Oil Corp. drilled six more oil wells, and the North Shore Corp. drilled two oil wells. These, with the discovery well, constitute the nine producing wells of the Halfway pool.

Prior to the discovery of oil, a 4,000-foot dry hole was drilled in the northeast corner of sec. 16, another test was drilled in the SE¼ sec. 20, and a third in the southeast corner of sec. 8. After the discovery of oil six more dry holes were drilled in or directly offsetting sec. 16.

The 1941 production of the Halfway pool was 112,318 barrels of oil, and its cumulative production to the end of 1941 was 177,988 barrels.

[1] Geologist, Argo Oil Corporation.

STRATIGRAPHY

The following classification of the rock section penetrated in the discovery well summarizes the stratigraphy of the Halfway pool.

Age	Formation	Lithology	Interval and Thickness	
QUATERNARY		Caliche.	.0-10	(10)
	Gatuña	Reddish sandstone.	10-35	(25)
TRIASSIC	Chinle	Red shale and red sandstone.	35-105	(70)
	Santa Rosa	Fine to coarse red sandstone; some red shale, little gray sandstone.	105-395	(290)
PERMIAN	Dewey Lake	Red siltstone.	395-873	(478)
	Rustler	Anhydrite, salt, dolomite, and red sand.	873-1235	(362)
	Salado	Salt, with anhydrite and polyhalite members. Cowden anhydrite member, 2160-85; "Base of salt," 2285; Fletcher anhydrite member, 2285-2330.	1235-2330	(1095)
	Tansill	Dolomite; Ocotillo silt member, 2360-70.	2330-2430	(100)
	Yates	Dolomite and sandstone. "First sandstone" (gray), 2430-70; "Second sandstone" (red and gray), 2500-27; "Third sandstone" (buff), 2585-95. Base of formation not reached.	2430-2629	(199)

The foregoing log may be supplemented as follows by correlation with the Western Drilling and Engineering Co. No. 1 State, a 4,000-foot dry hole located about 4,100 feet northeast of the discovery well. The depths are given as they would be in the discovery well if the thicknesses were the same.

Age	Formation	Lithology	Interval and Thickness	
PERMIAN	Yates	Dolomite and sandstone.	2430-2730	(300)
	Seven Rivers	Light-colored dolomite and limestone.	2730-3650?	(920?)
	Queen (?)	Light-colored limestone and dolomite, and light gray fine sandstone	3650-3955	(305)

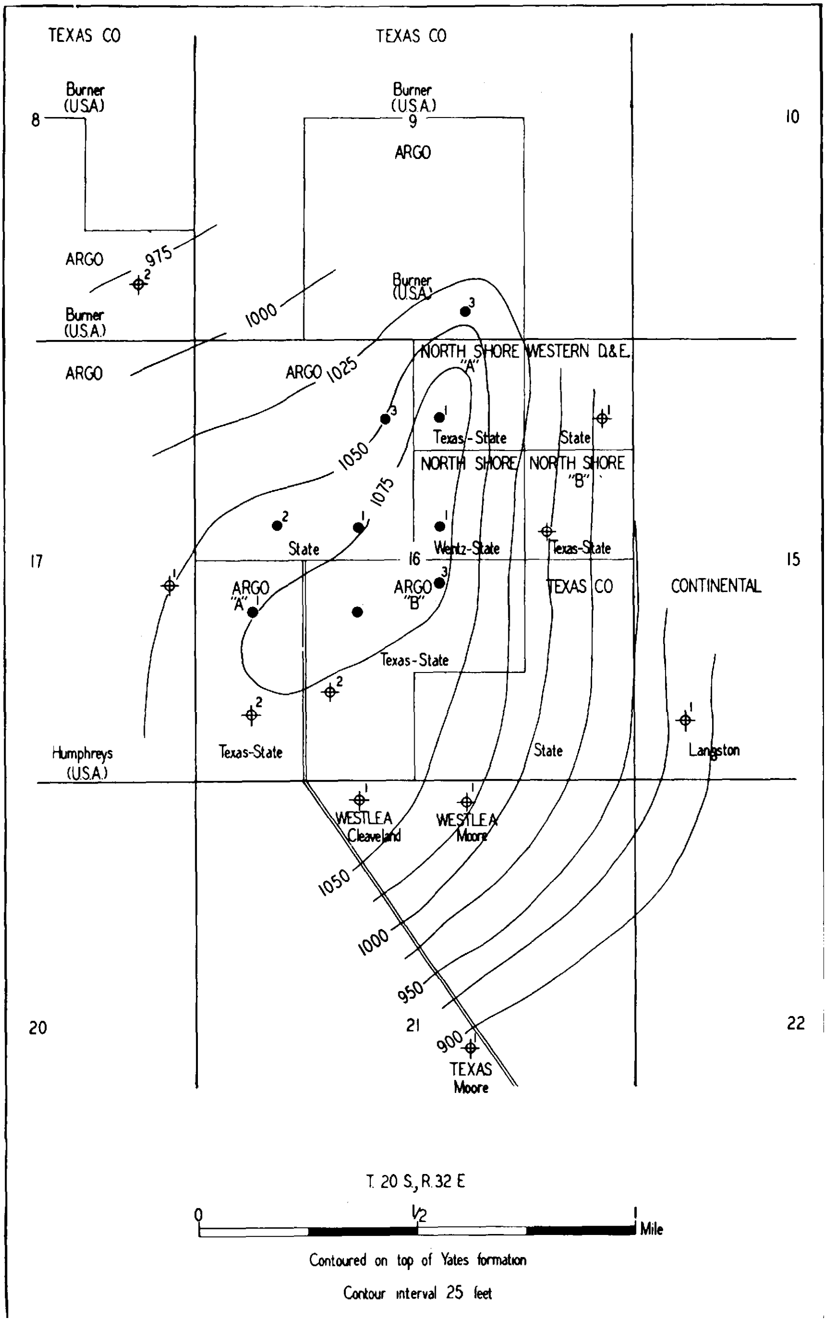


FIGURE 16.—Subsurface contour map of the Halfway pool, Lea County.

The Permian system is composed of the Ochoa series—depths 395 to 2,330 feet, thickness 1,935 feet; and the Guadalupe series—depths 2,330 to 3,955 feet, incomplete thickness 1,625 feet. The complete thickness of the Guadalupe series in this vicinity is probably more than 5,000 feet. Starting at the top of the Tansill formation, a test well would drill about 2,800 feet of light-colored limestone and dolomite, underlain by about 2,400 feet of calcareous sandstone. At a depth of about 7,500 feet the drill would enter the dark limestone of the Leonard series.

STRUCTURE AND RESERVOIR ROCKS

The subsurface structure map, Fig. 16, shows the attitude of the top of the Yates formation by means of 25-foot contours.

The oil reservoirs are lenses of porous crystalline dolomitic limestone. These lenses are members of the Yates formation.

FLUIDS

Only the North Shore Corp. No. 1-A Texas-State in the SW¼NW¼NE¼ sec. 16, structurally the highest well in the pool, produces an appreciable amount of gas with the oil. This gas is nearly 90 percent nitrogen and is non-inflammable.

The average gravity of the oil is 26° A. P. I. The salinity of the water associated with the oil is from 16 to 20 grams per liter.

DRILLING AND PRODUCTION METHODS

The wells are drilled with cable tools, mostly with No. 3 National machines. The North Shore Corp. No. 1-A Texas-State is flowing; the remainder of the wells are pumping. Most of the wells produce water with the oil. The water is separated by chemical treatment and settling.

HILL POOL

ROBERT L. BATES

The producing district here termed the Hill pool is situated in sec. 36, T. 20 S., R. 37 E.; sec. 31, T. 20 S., R. 38 E.; sec. 1, T. 21 S., R. 36 E.; and secs. 5 and 6, T. 21 S., R. 37 E. (See map, Plate 21.) The three westernmost wells are included by the Oil Conservation Commission in the Eunice pool, and the remainder in the Hardy pool. As the district is a geological unit, not directly connected with any other pool, it is treated separately. The Hill pool lies 12 miles south of Hobbs and four miles west of State Highway 18.

The discovery well was The Texas Co. No. 1 Alexander, located 3,300 feet from the south line and 1,980 feet from the west line of sec. 5, T. 21 S., R. 37 E. It was completed May 27, 1937, for an initial production of 50 barrels of oil and 200,000 cubic feet of gas daily. Total depth was 3,755 feet. The well was shot with 160 quarts of nitroglycerin from 3,704 feet to total depth. An east offset to this well was completed by Stanolind on their E. C. Hill lease in September, 1937 Its initial production was 30 barrels of oil per day, pumping. The field now has 39 wells, most of which were drilled in 1938, 1939, and 1940.

The stratigraphic section is similar to that penetrated in the Eunice pool to the west. This section is discussed in some detail on pages 208-210.

The pool lies in a structural saddle between high relatively flat areas to north and south. It is separated by a syncline from the Eunice pool to the west, and is bounded on the east by the wide structurally low middle part of the Central Basin Platform. The reservoir rock is the Shipley sand of the upper Grayburg formation.

Drilling has been chiefly with cable tools. In the discovery well, casing was cemented at 120 feet, 1,572 feet, and 3,535 feet. The majority of the wells are on the pump.

In 1941 the Hill pool produced 280,930 barrels of oil, and its cumulative production to the end of 1941 was 1,148,465 barrels.

Most of the information in this brief report was received from W. W. West of the Skelly Oil Co., to whom the writer expresses his thanks.

HOBBS POOL

R. G. SCHUEHLE[1]
Houston, Texas

INTRODUCTION AND HISTORY

The Hobbs pool is located on the Llano Estacado physiographic province in Tps. 18 and 19 S., Rs. 37 and 38 E., Lea County, five miles west of New Mexico's eastern boundary. (See map, Plate 14.) Outcrops and surface indications of geologic structure are lacking. Geophysics is credited with the discovery of the field.

Interest in southeastern New Mexico was aroused in the middle 1920's, after discovery of the fields to the south in Winkler County, Texas. The Midwest Refining Co. (now Stanolind Oil and Gas Co.) conducted a magnetometer survey which outlined a possible structure in the Hobbs area. Later gravimetric work verified the magnetometer interpretation, and Midwest acquired a large block of acreage on the geophysical high. In October, 1927, Midwest spudded its No. 1 State, the discovery well, in the NE¼NE¼ sec. 9, T. 19 S., R. 38 E. Oil first entered the hole in June, 1928, at a depth of 4,065 feet, and the well was completed at a depth of 4,220 feet with an average daily flow of 700 barrels of oil. Because this well's potential was small as compared with wells in nearby Texas fields, and neither market nor transportation facilities were available, the

[1] Geologist, Shell Oil Company.

discovery aroused little interest. However, in June, 1929, in order to protect a permit on Government-owned minerals, the Humble Oil and Refining Co. began its No. 1-A Bowers test in sec. 30, T. 18 S., R. 38 E., three miles northwest of the discovery well. Notwithstanding the geophysical surveys' indication of the structural high as being in the vicinity of the Midwest No. 1 State, the Humble test proved to be much higher on the structure. It was completed in January, 1930, for an average of 7,275 barrels of oil per day, open flow, over a 23-day test period. Total depth was 4,106 feet. A drilling campaign was initiated by this well, and by January 1, 1931, 141 wells had been completed, proving 5,080 acres productive. A market for the oil was secured through pipe lines brought into the field by the Atlantic, Humble, and Shell companies, and a railroad connection was provided by April, 1930. However, business conditions became unfavorable, the drilling campaign ceased, and Hobbs was on a settled producing basis from January 1, 1931, to early 1934. Only 57 wells were drilled on proved acreage during this period. Bettering of business conditions, and an enhanced value of areas of naturally low potential through increased productivity by acid treatment of the producing formation, caused resumption of drilling which lasted till the field was fully developed. By the end of 1941, there were at Hobbs 265 wells on 10,080 productive acres.

STRATIGRAPHY

The wells in the Hobbs pool penetrate a typical Permian Basin sedimentary sequence. As much has been written about the regional stratigraphy, the following discussion will cover in detail only those features peculiar to Hobbs. The formations penetrated are described in the accompanying table.

LITHOLOGY OF PRODUCTIVE ZONES

Whitehorse.—Approximately 125 feet below the top of the Whitehorse is a bed of buff dolomitic limestone associated with permeable sand layers. This unit is here called the 2,800-foot lime.[2] Near the middle of the Whitehorse is the Bowers sand, generally a soft, fine-grained, silty, red and gray sandstone, at places interbedded with anhydrite and containing irregular bodies of salt. The third Whitehorse reservoir, comparable lithologically to the Bowers sand, is the Big Gas sand. It occurs approximately 325 feet above the base of the Whitehorse. The lowest accumulation in the Whitehorse is an oil-bearing sandy lime representing the group's basal phase. The Sandy lime section consists of dense, earthy gray, sandy dolomitic limestone, with minor beds of anhydrite near the top and calcareous sandstone and pure crystalline limestone beds at the base. There is a general thickening of this section from south to north and also

[2] This zone has been commonly designated the "Brown lime." As there are a number of "brown limes" in Permian Basin oil fields, the term 2,800-foot lime will be used to refer to the one at Hobbs.

toward the edges of the field. Along the central part of the field the Sandy lime varies in thickness between 50 and 110 feet, and on the extreme edges of the structure from 130 to 150 feet. Although predominantly a dense unit, the Sandy lime has a few erratic and poorly developed porous streaks containing some oil and gas. (See Fig. 17.)

Age		Formation	Lithology and Productive Zone	Interval and Thickness	
RECENT			Caliche and windblown sand.	0-200	(200)
TERTIARY		Ogallala	Sand and gravel.		
TRIASSIC		Chinle	Red shale.	200-1350	(1150)
		Santa Rosa	Red sandstone.		
PERMIAN		Dewey Lake	Red, blue, and gray shale and sand.	1350-1550	(200)
		Rustler	Anhydrite with some dolomitic limestone, and red shale and sand.	1550-1700	(150)
		Salado	Massive salt beds with thin layers of red shale and sand.	1700-2600	(900)
	White-horse	Tansill	Salt and anhydrite.	2600-2690	(90)
		Yates	Anhydrite, sand, and limestone. "2800-foot lime."	2690-2950	(260)
		Seven Rivers	Anhydrite and thin sand beds. "Bowers sand" near middle.	2950-3400	(450)
		Queen	Anhydrite, sand, and limestone. "Big Gas sand."	3400-3800	(400)
		Grayburg	Dolomitic limestone, sandy toward base. "Sandy lime."	3800-4000	(200)
			Unconformity		
		San Andres	White and light gray crystalline dolomitic limestone with a few thin beds of sand and shale. "White Crystalline lime."	4000-	?

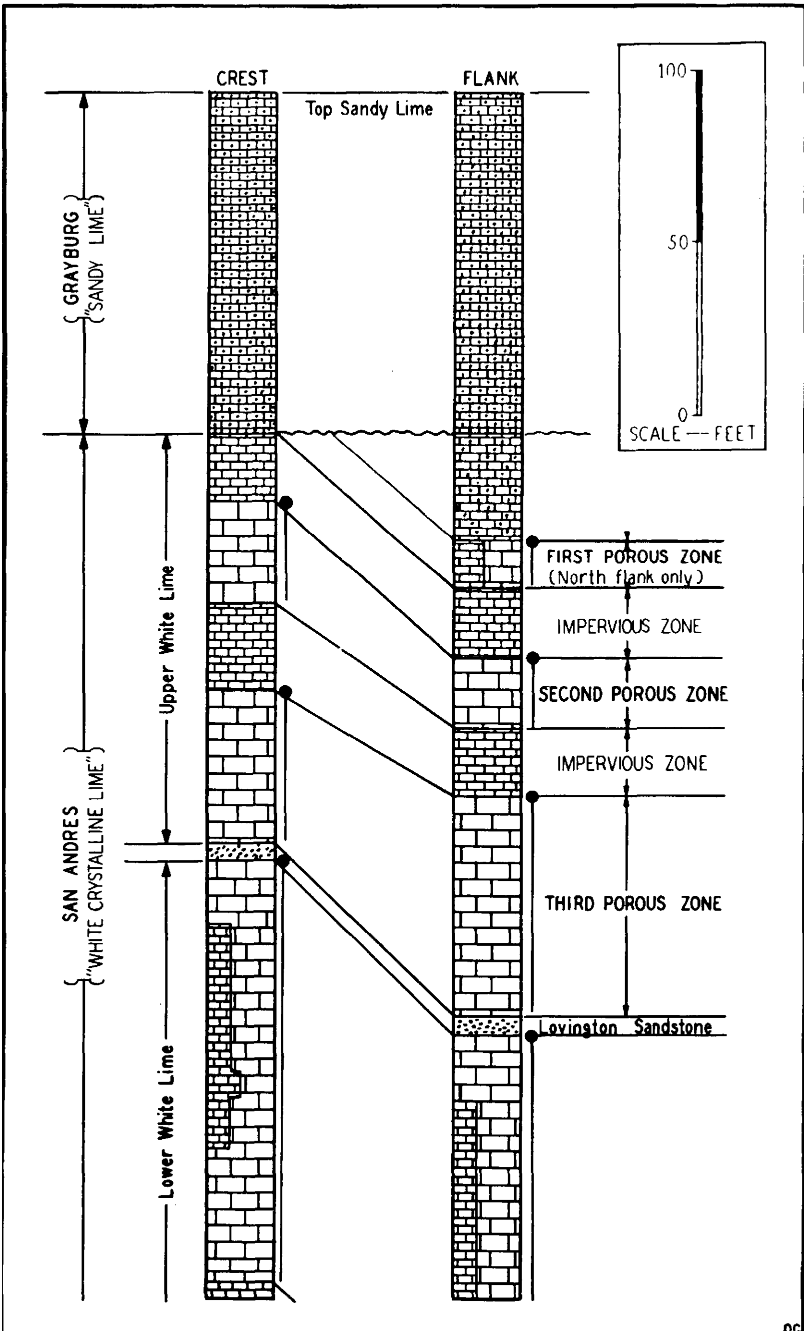


FIGURE 17.—Columnar section of the pay zones, Hobbs pool, Lea County.

Unconformity.—In the central part of the field there is a well-defined contact, with evidence of an unconformity, between the Sandy lime and the underlying White Crystalline limestone of San Andres age. On the extreme edges of the field the Sandy lime appears to grade into the White Crystalline lime without abrupt lithologic change. Although it is possible that the unconformity is also present on the edges of the field, it apparently represents such a short time interval that for practical purposes its presence can be ignored.

San Andres.—The White Crystalline lime, the present producing formation of the Hobbs field, is a white to blue-gray crystalline dolomitic limestone. Although a few minor beds of gray and black shale and gray sand are present, the formation is exceptionally pure. There is one persistent thin bed of impervious sandstone within the White Crystalline lime, named by Hills[3] the Lovington member of the San Andres formation, which has considerable effect on the producing characteristics of the reservoir. This bed, which separates the formation into upper and lower units, is a fine-grained, dense, silty sandstone averaging five feet in thickness. The upper unit of the White Crystalline lime increases in thickness from 80 feet at the south end to a maximum of 140 feet at the north end of the structure.

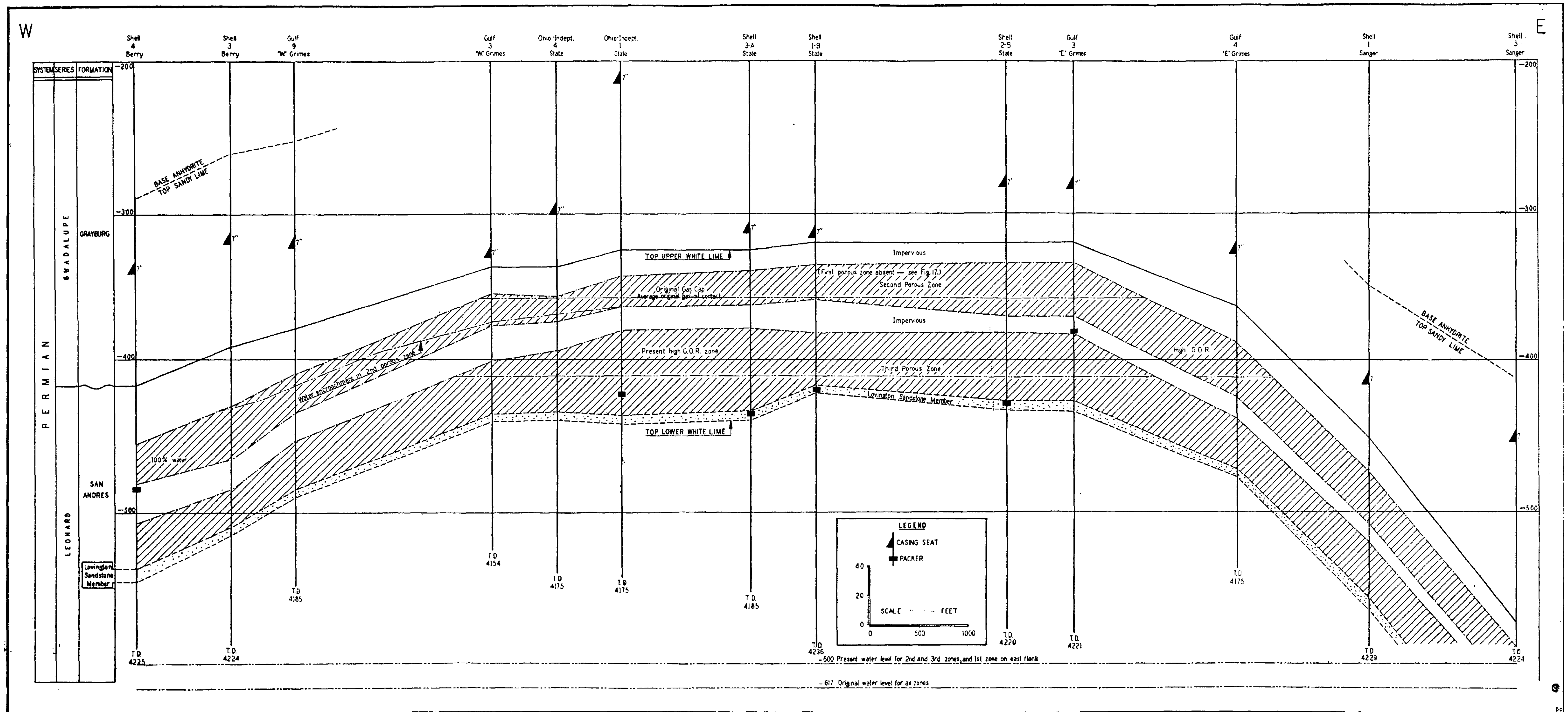
The upper unit of the White Crystalline lime contains three porous layers, and the lower unit contains one. (See Fig. 17.) The First zone is present only on the northern extremity of the structure. Its areal extent is outlined on the map, Plate 26. Permeability of this zone is normally low and erratic. The Second and Third zones, averaging 30 and 45 feet thick respectively, persist over the entire structure. They are sufficiently permeable for commercial production. On the north one-third of the structure the Third zone exhibits the greater permeability, but over the remainder of the field the Second zone is more permeable. Throughout the field both zones are less permeable on the east flank of the structure than elsewhere.

Although its normal degree of permeability is known to be somewhat less than that of the Upper White lime, the Lower White lime throughout the field is capable of commercial production. Some indications of porosity zoning in the Lower White lime are found, but the number of wells drilled into this unit is too small and the pentrations are too meager for delineation of permeable layers.

STRUCTURE

The Hobbs structure as depicted by the top of the White Crystalline lime (see map, Plate 26) is a northwest-trending elongated asymmetrical anticline with a maximum closure of 305 feet above the original oil-water contact. Due to the unconformity discussed above, some of the section is missing from the

[3] Hills, J. M., South Lovington poo : This bulletin, p. 270. The Lovington member has previously been referred to as the "inter-White Lime sand break."



West-east cross section of the Hobbs pool, Lea County. Along line A-A', Plate 26 top of the White Crystalline lime. The true structure of this formation, as shown by contours on the Lovington sandstone member, is similar in general outline to the structure on the top of the White Crystalline lime. Plate 27 shows the structural and stratigraphic features of the White Crystalline lime. In the formations younger than the White Crystalline limestone, structural closure diminishes progressively upward.

ACCUMULATIONS

2,800-foot lime.—The limestone occurring at an average depth of 2,775 feet contains a relatively low volume of dry, sweet gas accumulated under a reservoir pressure of approximately 1,400 pounds per square inch. Initial tests of 4,000,000 to 5,000,000 cubic feet per day are not uncommon, but the volume declines rapidly and usually settles at less than 500,000 cubic feet per day under regular production. Present indications are that this gas reservoir will not be attractive for commercial development. The productive area of the 2,800-foot lime has not been established and the presence of water has not been determined. Thus, until more data are available, the value of this accumulation cannot be estimated.

Bowers sand.—The Bowers zone, occurring at an average depth of 3,200 feet and comprising two sand beds having an average total thickness of 18 feet, contains some gas and the greatest unexploited known reserve of oil in the Hobbs structure. Approximately 5,500 acres are inside the productive limits of this reservoir; however, in view of highly variable results secured from tests of the Bowers sand, not all the foregoing area can be considered promising. The maximum rate of production that has been obtained from any one well is a natural flow of 413 barrels of 40° gravity paraffin-base sweet oil per day; but some wells favorably located on structure have found the Bowers sand non-productive. Although this erratic productivity has been ascribed to lenticularity of the sands, it is possible that salt which is intercrystallized in the sand has locally eliminated permeability and thus prevented oil from entering some of the wells. In addition to the oil, the Bowers sand probably has a small free gas cap of minor importance on the crest of the structure where several wells have produced an appreciable volume of gas. Considerable value is attached to the oil accumulation. However, because of erratic initial productivity, lack of adequate data to estimate the volume of recoverable oil, and low rate of production compared to the deeper White Crystalline lime, the Bowers sand has not been considered a justifiable objective for new development. Rather, it is a valuable reserve to be secured by recompletion of present wells when the White Crystalline lime is exhausted.

Big Gas sand.—The Big Gas sand, found at an average depth of 3,700 feet, appears to be a prolific source of sweet gas accumulated under a pressure of 1,600 pounds per square inch. This zone, which is productive over approximately 3,600 acres, has on short-duration open-flow tests afforded individual well potentials as high as 85,000,000 cubic feet per day, and one well produced in excess of 50,000,000 cubic feet of gas per day for seven days without a noticeable decline. In spite of the initial high well potentials, which indicate an appreciable reserve, the available data are too meager to evaluate this accumulation.

Sandy lime.—The Sandy lime contains a small amount of low gravity (25° corrected) brownish-black sour crude oil. Natural flow has not been established from this zone, and the maximum initial capacity determined to date is four barrels of oil per hour swabbing. Only one well, Sun No. 1-B McKinley, which secured an initial potential of 25 barrels of oil per day pumping, has been completed in the Sandy lime. The potential of this well soon settled to a maximum of five barrels per day, and the well during its 69-month life has produced only 7,300 barrels of oil. Such production is considered typical of the Sandy lime, and demonstrates that a commercial accumulation of oil is not present.

White Crystalline lime.—The White Crystalline lime, found at an average depth of 4,025 feet, contains the Hobbs field's major accumulation of oil and gas. This reservoir has 10,080 producing acres, and the oil originally occurred over a maximum vertical interval of 275 feet in all four of the porous zones. In addition, free gas was also present in the First zone, occupying a maximum vertical interval of 30 feet under 1,000 acres on the crest of the structure. The original water level in the reservoir, between 617 and 619 feet below sea level, was uniform in all porous zones.

Although all the porous zones in the White Crystalline lime are productive, over most of the field the Second zone affords the highest potentials, with the Third, Lower White lime, and First zones having lesser capacities in the order named. Over the north one-third of the field, the Second and Third zones exchange places in terms of capacity to produce. These four porous layers function as separate reservoirs, but since oil is produced from all of them simultaneously, little is known of their separate characteristics. The oil, however, is identical in all porous zones. It has an average gravity of 34°, is brownish-green in color, and is saturated with gas under reservoir conditions.

The White Crystalline lime, as a whole, is classified as a water-drive reservoir. However, as demonstrated by certain changes in reservoir conditions, the water has not been able to keep pace entirely with the withdrawals of oil and gas. The original average reservoir pressure of 1,500 pounds per square inch has been reduced to the present average pressure of 1,163 pounds per square inch. The original free gas cap has expanded until it now occupies a maximum vertical interval of 85 feet, and is present over 2,050 acres on the crest of the structure. Furthermore, a secondary free gas cap, or area of high gas-oil ratios, occupying 1,050 acres on the crest of the structure, has formed in the Second porous zone. In addition, the oil while still saturated with gas is now calculated to contain only 560 cubic feet per barrel measured under surface conditions, as compared with the original ratio of 720 cubic feet per barrel. Other changes which have taken place during the reservoir's 12-year producing life include a rise in the water level from between 617 and 619 feet below sea level to between 600 and 610 feet below sea level.

Invasion of water, aside from the general rise in water level, has become a serious problem in some areas. Such up-structure encroachment of water in individual porous zones from the flanks of a reservoir may be expected in a water-drive field where the oil has accumulated in a series of unconnected layers. Differential well penetrations and varying permeability between zones control the relative withdrawals from the several porous zones, thus aggravating edge-water movement. The White Crystalline lime in the Hobbs field is an excellent example of the foregoing condition and has had a heavy influx of edge-water in the Upper White lime. Lesser permeability of all porous zones on the east flank of the structure has prevented entrance of edge-water from that side; however, early in the life of the field, edge-water entered the Second zone from the southwest and moved up and across structure until at the present time this zone, except for a narrow belt on the east flank, has become flooded over the entire south half of the field. While there is little conclusive evidence of edge-water encroachment in the Third zone in the south part of the field, this zone is the most seriously affected on the north end, where the water also entered from the west flank of the reservoir; in this part of the field, the water moved east and southeast across the structure and down the east flank. Various data have proved that in the north end of the reservoir, water has invaded all three porous zones of the Upper White lime. Because of the differential permeability previously discussed, the water appears first in the Third zone and successively later in the Second and First zones. Edge-water encroachment comparable to that in the Upper White lime may also take place in the Lower White lime; however, lesser permeability and relatively small well penetrations have prevented this phenomenon from being noticeable to date.

PRORATION

Since early in the life of the Hobbs pool, all operations have been effectively regulated and little of the hazardous, wasteful development characterizing some older areas has been permitted. The value of the rigid control exercised over the field both by the State regulatory body and by the operators is demonstrated by the fact that although the field is 12 years old, high-potential natural flow still predominates. A proration plan became operative on July 16, 1930. At first proration was effected by agreement of the operators, but it is now enforced by State regulations.

The initial drilling at Hobbs followed a plan of one well to every 10 acres. With the advent of proration, the 40-acre lot of government survey was made the basic factor or unit of proration, and development of the field was completed with one well per unit. Until January 1, 1937, 25 percent of the field's daily oil outlet was distributed equally among all units, and 75 percent was distributed in proportion to the respective units' average potential or ability to produce, irrespective of the number of wells contained by the unit. From January, 1937, until February, 1941, 60 percent of the field outlet was distributed equally among all units, and 40 per cent on the units' respective average potentials. The unit potential was established by a one-hour open-flow test taken under standard conditions, and when more than one well was drilled on a unit, the mathematical average of the potential of all wells was assigned to a unit as its potential. When proration first went into effect in the Hobbs field, the unit potentials were re-established every three months by flow tests. It was soon found that this periodic retesting of the well was detrimental, as it was followed immediately by an abnormal drop in reservoir pressure and a heavy influx of water. Therefore, in lieu of the quarterly flow tests, and based on the assumption that maintenance of uniform static reservoir pressure would enable each operator to secure the recoverable oil under his leases, the following formula, tending to attain the desired pressure uniformity, was put into effect.

Let P= present individual well-pressure;
P_f = average field-pressure of previous survey;
V_o = old well potential; and
V_n = new well potential.

Then

$$V_n = \frac{P - 2/3\ P_f}{1/3\ P_f} V_o$$

In February, 1941, all consideration of unit potential was eliminated from the proration plan, and the field's outlet of oil was thereafter allocated by the following formula which distributes 80 per cent of the oil equally among all units and 20 percent in proportion to the relative bottom-hole pressure of each unit.

Let F = total field allowable;
U = unit bottom-hole pressure;
U_s = sum of all units' bottom-hole pressures; and
A = unit bottom-hole pressure allowable.

Then

$$A = 0.20 \frac{FU}{U_s} .$$

Since the inception of proration, serious and successful efforts have been made to eliminate excessive production of free gas. Generally, formation packers have been used to shut off the layers containing free gas. The corrective measures were designed to keep the volume of gas produced with a barrel of oil under 5,000 cubic feet. This Emit, established by the operators, was used until February, 1940, when a statewide ruling went into effect limiting the average volume of gas produced to 4,000 cubic feet per barrel of oil.

RECOVERIES

Production of Oil and Gas from the Hobbs Pool

Period	Oil (Barrels)	Gas (Thousands of Cubic Feet)
1941	3,624,159	5,153,057
Cumulative to end of 1941	97,876,942	204,989,057

The ultimate recovery estimate for the White Crystalline lime has varied from 150,000,000 to 175,000,000 barrels. It is now conservatively estimated, based on present known reservoir data, that accumulative production from this formation will amount to 165,000,000 barrels of oil. This figure indicates that the White Crystalline lime is 59.3 percent depleted, and the average per acre recovery will be about 16,400 barrels.

METHODS OF PRODUCTION

Hobbs after a 12-year life is still rated a naturally flowing field. Present indications are that natural flow will predominate during the greater part of the producing life of the White Crystalline lime. The active water drive, restricted production rates, and various conservation measures, such as prevention of excessive gas production, have permitted nearly 60 percent of the recoverable oil to be secured with a drop in reservoir pressure of only one pound per square inch for every 290,801 barrels of oil produced. Therefore, unless unforeseen factors seriously disturb the reservoir, it can be expected that most wells will approach exhaustion before natural flow ceases. Irregular water encroachment and local depletion of the reservoir in areas of low permeability, however, have already caused some wells to cease flowing and have necessitated artificial lift. In a number of other wells natural flow has been continued only through the shutting off of watered layers with formation packers. It is expected that entrance of large volumes of water, not loss of pressure, will be the determining factor in installation of lifting equipment in nearly all wells which will require artificial producing methods.

Some pumping equipment has been installed, but in view of the large volume of water which will have to be lifted in the later life of the wells and of the anticipated high final reservoir pressure, gas lifting appears to be the more practical method of artificial production. There is some difficulty at the present time in procuring an adequate supply of gas for this purpose, but several sources, including compression of residue gas from the field's two gasoline plants, should ultimately supply the demand for an economical source of energy.

FUTURE POSSIBILITIES

The Hobbs structure contains three known oil- and two known gas-bearing zones. Only one, the most prolific oil-bearing zone, is being exploited at the present time; however, one of the two unexploited oil accumulations offers good recompletion possibilities after the present producing reservoir is exhausted. Both of the two gas accumulations might be profitably developed if an outlet for the gas were available. There has been no deep drilling in or adjacent to the Hobbs field, but since a structure suitable for the accumulation of oil and gas is present, deeper zones will undoubtedly be explored.

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LANGLIE-MATTIX AREA

P. W. MILLER[1] and ROBERT L. BATES

LOCATION

The Langlie-Mattix area as designated in this report is the southeasternmost producing district in Lea County. (See map, Plate 23.) It includes the Rhodes, Langlie, and Mattix pools as defined by the Oil Conservation Commission. These lie in Tps. 24, 25, and 26 S., R. 37 E. Six sections in the southwestern part of the Skelly pool, T. 23 S., R. 37 E., are also included. The area is discussed as a unit because of the relative uniformity of geological conditions throughout.

The western side of the area is traversed by State Highway 18 and the Texas-New Mexico Railroad, connecting Hobbs on the north with Monahans, Texas, on the south. The town of Jal is situated in the west central part of the area. The land surface is gently rolling and is covered with sand dunes and caliche which make it unsuitable for cultivation.

[1] Geologist, Western Gas Company, Jal, New Mexico.

HISTORY

A list of the discovery wells in the Rhodes, Langlie, and Mattix pools is given in the accompanying table. The earliest well, The Texas Co. No. 1 Rhodes, was drilled as part of the general attempt to extend production north along the trend discovered in Winkler County, Texas. Although the attempt was successful, little further drilling was done in the Langlie-Mattix area for about eight years. The impression appears to have been held among oil operators that the newly discovered productive trend in southeastern Lea County was oriented northwesterly rather than northerly. Consequently the Cooper-Jal area to the west was developed in 1934 and 1935, before attention was paid to the Langlie-Mattix area. Most of the drilling in the latter area was done between 1936 and 1939, with a few wells being completed in 1940 and 1941. In general, drilling progressed from south to north. At the end of 1941, the area contained 311 oil wells, 52 gas wells, three abandoned oil wells, and 12 dry holes.

STRATIGRAPHY: POST-PERMIAN

Caliche and windblown sand of Recent age are at the surface, and they conceal all indication of subsurface structure. Beneath them lies soft buff sand of Tertiary age to a thickness of about 50 feet. Thence in descending order the Triassic consists of the Chinle red shale, the Santa Rosa red sandstone, and the Tecovas red shale. They total about 950 feet in thickness.

PERMIAN

Dewey Lake.—The uppermost Permian formation consists of fine red sand and sandy shale 150 to 200 feet thick. The calcareous content of these beds distinguishes them from the overlying Triassic redbeds.

Rustler.—The Rustler is 200 to 300 feet thick and consists chiefly of anhydrite. Thin beds of red shale are found, and in places limestone is present near the top of the formation.

Salado.—This formation is 1,200 to 1,500 feet thick. Its upper half is chiefly anhydrite with beds of red shale and salt. Its lower half is chiefly salt. The Cowden anhydrite member, 30 to 50 feet thick, lies about 150 feet above the base.

Tansill.—Anhydrite and brown dolomitic limestone make up the Tansill formation. It is 180 feet thick.

Yates.—Gray sandstone, with frosted quartz grains 30 to 50 feet below the top, characterizes the Yates formation. Anhydrite occurs erratically, and in many wells gray and brown dolomitic limestone is prominent. The Yates is the major gas-bearing formation of the area. Its thickness is 300 feet.

Seven Rivers.—Gray dolomitic limestone is the dominant constituent of the Seven Rivers. Associated thin beds of sandstone are considered to be lenses because they cannot be traced

Discovery Wells in the Langlie-Mattix Area

Pool	Well	Location (Sec., T.-S., R.-E.)	Total Depth, Feet	Date Completed	Initial Production
Rhodes	The Texas Co. No. 1 Rhodes	22-26-37	3,213	11-1-27	300 barrels of oil and 22,500,000 cubic feet of gas per day.
Langlie	Continental Oil Co. No. 1 Sholes "A-19"	19-25-37	3,035	1-8-29	60,000,000 cubic feet of gas per day.
Mattix	Amon G. Carter No. 1 Mattix	3-24-37	3,940	7-25-35	160 barrels of oil per day.

very far laterally. The sandstones in the lower part of the formation are an important oil reservoir. The Seven Rivers is 400 to 450 feet thick.

Queen.—The Queen formation is chiefly light gray dense dolomitic limestone with sandstone lenses. At the top of the formation locally there is a prominent gray sandstone containing many frosted quartz grains, which is thought to be the equivalent of the "Artesia red sand" of Eddy County. The Queen is about 350 feet thick. Most wells do not reach its base.

STRUCTURE

The anticline trending slightly west of north under the Langlie-Mattix area (see map, Plate 23), is not considered to have been formed by compressional folding. Sandstone beds on the west 'flank do not continue across the structure, but wedge out up-dip, forming stratigraphic traps. Furthermore, younger sandstones are found progressively farther off the structure toward the west. (See cross section, Plate 24.) Thus it is thought that sands were deposited against a low ridge on the site of the present anticline. This ridge rose slowly during late Queen and early Seven Rivers time.

RESERVOIR ROCKS

The reservoir rocks in the Langlie-Mattix area are sandstones of the Yates, Seven Rivers, and Queen formations. In the southern part of the area, the Yates and upper Seven Rivers sandstones are the main producers; in the central part of the area, the lower Seven Rivers; and on the north, the upper Queen. This tendency of the oil and gas to occur in stratigraphically lower zones toward the north is also shown in the Cooper-Jal area to the west, where, however, the accumulations are in limestone rather than in sandstone. Oil has accumulated in the up-dip parts of sandstone lenses. The area is under an active gas drive.

FLUIDS

Most of the gas produced in the southern part of the area is sour, while that produced from deeper horizons to the north is sweet. Analyses of both types of gas are given on page 205. There is enough gas to allow more than 85 percent of the wells to flow, and more than half of the gas recovered is produced with the oil.

The oil is sweet, has a paraffin base, and averages about 37° gravity. Water is encountered only in small local reservoirs and gives little trouble in the Rhodes and Mattix pools. In the Langlie pool, however, nearly three times as much water as oil was produced in 1941.

DRILLING AND PRODUCTION METHODS

Wells have been drilled with cable tools, rotary equipment, or a combination of the two. Rotary tools are of course in general use in districts where high gas pressures are likely to be encountered.

Three strings of casing are generally cemented: a surface string in the redbed section at 250 to 300 feet, an intermediate or "salt string" in the Tansill formation at 2,600 to 2,800 feet, and the production string above the pay at 3,200 to 3,400 feet. Two and one-half inch tubing is used, often with a packer to separate oil and gas zones.

Most of the wells flow. The average gas-oil ratio is approximately 7,000:1. There are about 15 pumping wells and seven gas-lift installations. The area is served by four oil pipe lines, by a small gas line which carries gas to the towns of Eunice and Hobbs, and by the El Paso Natural Gas Co.'s pipe line which takes most of the gas westward to serve the city of El Paso and the towns and copper smelters of southwestern New Mexico and southern Arizona.

PRODUCTION

Production of oil and gas from the pools in the Langlie-Mattix area is given in the following table.

Field	Oil (Barrels)		Gas (Thousands of Cubic Feet)	
	1941	To end of 1941	1941	To end of 1941
Rhodes	144,054	397,501	9,169,184	39,343,184
Langlie	1,368,092	6,770,435	20,409,237	62,236,744
Mattix	1,395,718	6,101,710	11,304,700	32,394,700
Skelly [2]	135,772	251,253		
Totals	3,044,636	13,520,899	40,883,121	133,974,628

OWNERSHIP

Ownership of land in the Langlie-Mattix area was distributed approximately as follows at the end of 1941:

Field	Government Land (Percent)	State Land (Percent)	Patented Land (Percent)
Rhodes	88.0	9.0	3.0
Langlie	36.1	11.2	52.7
Mattix	33.3	8.4	58.3

Both major operators and independent concerns are active in the area.

FUTURE POSSIBILITIES

As is the case in a number of other Lea County fields, the Langlie-Mattix area will probably see little further development of productive zones now being exploited. Discovery in 1937 of a small west extension of the Mattix pool (the so-called Toby area in sec. 12, T. 24 S., R. 36 E., and secs. 7 and 18, T. 24 S., R. 37 E.) indicates that other small producing areas on the west fringe of the main trend may be developed. No deep drilling

[2] Southwestern six sections, T. 23 S., R. 37 E. Figures for gas production are not available.

has been done. It is believed that prospects for deep production are relatively good.

LANGLIE UNITIZED REPRESSURING PROJECT

W. K. DAVIS[1]
Bennett, New Mexico

The Langlie Unitized Repressuring Project commenced operations on April 1, 1941. It involves 13 wells in a more or less isolated group in secs. 5, 8, and 9, T. 25 S., R. 37 E., in the Langlie pool, Lea County. (See maps, Plate 23 and Fig. 18.) The five companies which own an interest in these wells entered into an agreement forming the Repressuring Project. These are Anderson-Prichard Oil Co., Stanolind Oil and Gas Co., Illinois Oil Co., R. Olsen Oil Co., and El Paso Natural Gas Co. The operator of the project is the Anderson-Prichard Oil Co. It supervises the accounting and field operations and makes monthly or quarterly reports to the Planning Committee, which is composed of one member from each of the companies listed above.

A Field Engineering Committee of three members meets each month. Its functions are to make individual well curves and unit curves of production; to study the results of the repressuring; to supervise field surveys; and to make recommendations to the Planning Committee concerning future operation of the project.

As shown on the subsurface contour map, Fig. 18, the structure underlying the area is a southward-trending nose. The producing zone includes two medium fine-grained sands separated by approximately 15 feet of dense dolomite. The thickness and character of the sands vary with structural position. Cuttings from non-productive wells near the lower limit of the structure have shown that there the sands are shaly and impervious. The fact that the pay sands grade into impervious shaly sands toward the east, south, and west, and probably in the undrilled area to the north, should eliminate any movement of injected gas away from the area involved in repressuring.

The Anderson-Prichard No. 2 Langlie and No. 1 Jal wells were chosen as input wells because they have high positions on the structure, are centrally located, and had large initial potentials indicating better than average porosity and permeability of the pay section. In the early stages of injection, the gas was returned to the pay zone at the rate of approximately 200,000 cubic feet per day. The rate was gradually increased to about 1,185,000 cubic feet per day in the No. 2 Langlie and 1,070,000 cubic feet per day in the No. 1 Jal. In the latter well the two pay sands are separated by an anchor packer, set at a depth of 3,458 feet. The lower sand is rather poorly developed in this well, and takes only 141,000 cubic feet per day compared with

[1] Superintendent, Western Gas Company.

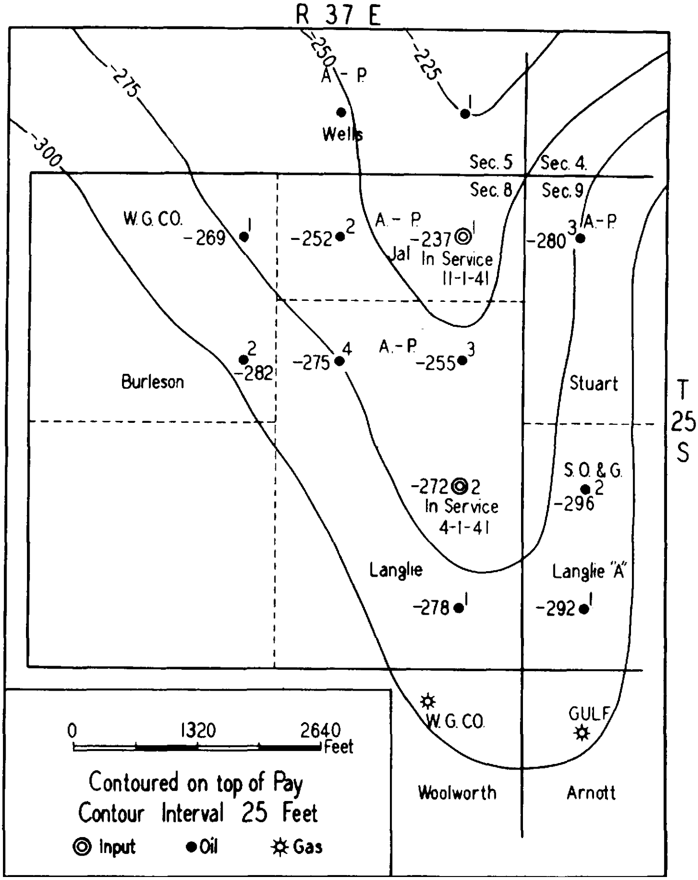


FIGURE 18.—Subsurface contour map of the area included in the Langlie Unitized Repressuring Project, Langlie pool, Lea County.

929,000 taken by the upper sand. It is planned to shoot the lower sand with nitroglycerin to make it more responsive to gas injection.

The table on page 237 shows a comparison of bottom-hole pressures, injection rates, and volumes injected for the two input wells.

In April, 1941, the average bottom-hole pressure of all the wells in the project was 555.74 pounds absolute. By August, 1941, the average had increased to 588.51 pounds, and by May, 1942, to 671.13 pounds. The gas-oil ratios of some of the wells offsetting the input wells have shown a definite increase, thought to be due to revived movement of gas which had dropped out of

Comparison of Data on *Input Wells,*
Langlie Unitized Repressuring Project

Well	Bottom-Hole Pressure lbs. per sq. in.		Average Daily Volume Injected, thousands cu. ft.		Injection Pressure, lbs. per sq. in.		Total vol. Injected to Apr. 1,1942 1,000s cu. ft.
	Before Injection	In May, 1942	April, 1941	March, 1942	April, 1941	March, 1942	
No. 2 Langlie	505	915	200	1,185	625	990	310,818
No. 1 Jal							
Upper sand	375	680	200	929	530	810	100,047
Lower sand	628	690	161	141	1,140	1,230	18,470

solution as the bottom-hole pressure declined and was more or less dormant in the pay surrounding the bore holes. The space filled by the volume of gas injected daily in May, 1942, was approximately 70 percent of the total space voided by withdrawals of gas, oil, and water.

A comparison of the daily potential-decline curve in the later months of the repressuring operations with the estimated potential-decline curve without repressuring indicates a substantial increase in daily potentials due to repressuring. The Stanolind No. 1-A Langlie may be taken as an example. In April, 1941, its average daily production was 15 barrels of oil, cut with two percent water, pumping, and its bottom-hole pressure was 263 pounds per square inch. In March, 1942, the average daily production was 40 barrels per day, flowing, with 225 pounds back pressure on the tubing, and the bottom-hole pressure was 650 pounds per square inch.

The gas used for injection is supplied by the El Paso Natural Gas Co. from its low-pressure gasoline plant in the Mattix pool, Lea County. The company utilizes one 300-horsepower single-stage compressor with a capacity of 3,000,000 cubic feet per 24 hours at 500 pounds intake pressure and 2,000 pounds discharge pressure.

LYNCH POOL

ROBERT L. BATES

LOCATION AND HISTORY

The Lynch pool, in Lea County, includes all or part of secs. 26, 27, 34, and 35, T. 20 S., R. 34 E., and secs. 1 and 2, T. 21 S., R. 33 E. (See map, Fig. 19.) Total area is four and one-half square miles. The pool lies 12 miles west of the Eunice field. Elevations range from 3,750 to 3,800 feet.

The discovery well of the Lynch pool is The Texas Co. No. 1-A Beulah Lynch, located in the NW¼SE¼ sec. 34, T. 20 S., R. 34 E. This well, completed on April 11, 1929, had an initial production of 1,072 barrels per day pumping, at a total depth of 3,731 feet. It is of interest to note that this well is situated at a higher position structurally than any of the wells drilled later. Successful completion of the first well precipitated the drilling of 17 more wells between 1929 and 1934. At the end of 1941 the pool had 12 producers, four abandoned producers, and two dry holes.

A discussion of the Lynch pool, under the name "Lea pool," is given by Winchester.[1]

STRATIGRAPHY

Surface materials and redbeds.—Caliche and windblown sand at the surface are underlain by red sand and shale of Triassic and Permian ages to a depth of about 1,600 feet. Sands containing water lie at depths of 250 feet and 950 feet.

[1] Winchester, D. E., The oil and gas resources of New Mexico : N. Mex. Bur. Mines Bull. 9, pp. 170-172, 1933.

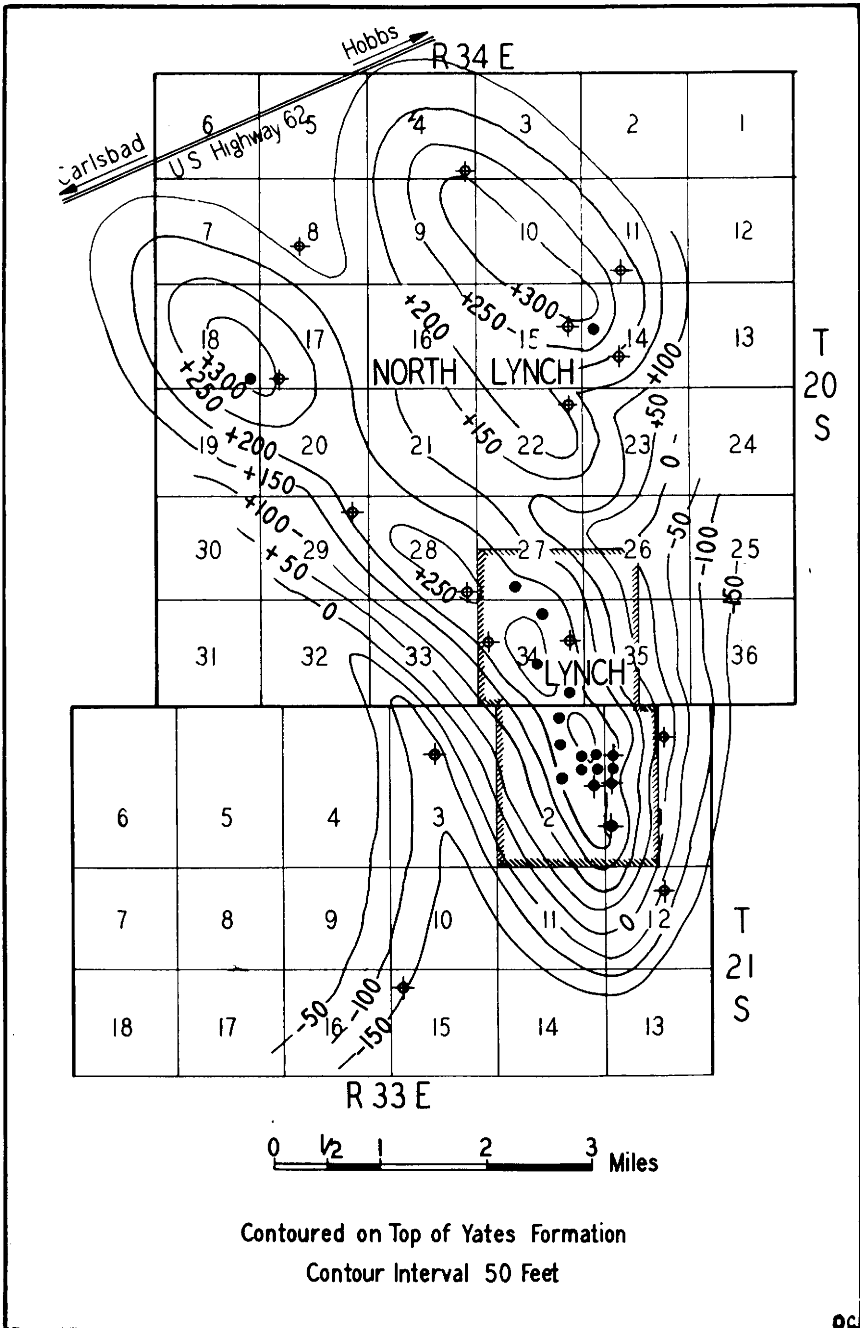


FIGURE 19.—Subsurface contour map of the Lynch and North Lynch areas, Lea County.

PERMIAN

Rustler.—This formation, which is about 150 feet thick, consists of anhydrite with gray and brown sandy dolomitic limestone.

Salado.—Beneath the Rustler is a 1,500-foot thickness of salt. A prominent anhydrite zone is encountered 80 to 100 feet below the top of the salt, and the widespread Cowden anhydrite, which here carries some dolomitic limestone, lies about 150 feet above the base of the Salado.

Tansill.—The Tansill formation is anhydrite and brown dolomitic limestone to a thickness of about 150 feet.

Yates.—The Yates consists of red and gray sandstone with frosted quartz grains. Greenish-gray shale and anhydrite are also present. Thickness is about 150 feet.

Seven Rivers.—Most of the wells in the Lynch pool have penetrated approximately 200 feet of white and buff dense dolomitic limestone, with some bentonitic shale, which is believed to be Seven Rivers.

STRUCTURE

The contour map. Fig. 19, indicates that the structure in the Lynch pool is a sharp northwest-trending high. It lies above the Capitan reef, yields oil from massive dense limestone of the reef type, and hence is thought to be a "reef bump" or depositional ridge rather than a true anticline. Similar "reef bumps", mentioned by Wills[2] and shown in Plate 15, are found farther to the west in the same relative position on the reef. It is of interest to note that the structures shown by Wills have a northwest trend similar to that of the Lynch structure.

RESERVOIR ROCKS AND FLUIDS

Oil in the Lynch pool comes from the Yates and Seven Rivers dolomitic limestones. Porous zones extend through a vertical range of 250 feet, but probably the net thickness of pay for any given well is considerably less than this figure. A single well, The Texas Co. No. 2-B Lynch, produces from sandstone beds in the Yates formation. The oil, which is sour and has a gravity of about 29° A. P. I., is undersaturated with gas.

All the wells except The Texas Co. No. 2-B Lynch produce water with the oil; in fact, more than five times as much water as oil was produced in 1941. The active character of the water drive has necessitated plugging back several wells and abandoning others.

Oil production for 1941 was 153,248 barrels; cumulative production through the end of that year was 6,848,453 barrels.

DRILLING AND PRODUCTION METHODS

Most of the wells, including the discovery well, have been drilled with cable tools. Three strings of casing are generally

[2] Wills, N. H., Getty-Barber area: This bulletin, p. 174.

set : a surface string at 100 to 150 feet, a string in the Rustler anhydrite, and the production string below the base of the salt. Several wells have been subjected to shooting with 50 to 130 quarts of nitroglycerin, and a few wells have been acidized. The wells have been on the pump since completion.

OWNERSHIP

The land in the northern township is Government-owned; that in the southern is owned by the State of New Mexico. Two companies, The Texas Co. and the General Crude Oil Co., were operating in the Lynch pool in 1941.

FUTURE POSSIBILITIES

Unless deep production is shown to be likely for areas above the Capitan reef front, possibilities for future production in the Lynch pool are not great.

MALJAMAR POOL[1]

JOHN A. BARNETT[2]
Roswell, New Mexico

LOCATION

The Maljamar pool is located in T. 17 S., R. 32 E., Lea County. (See map, Plate 14.) It is at the eastern end of a trend of almost continuous production that begins with the Red Lake pool, in T. 17 S., R. 27 E., Eddy County, and extends easterly to include the Leonard, Grayburg-Jackson, and Maljamar pools. From the standpoints of geography, geology, methods of operation, and ownership of producing acreage, the Maljamar pool is closely related to the adjoining Eddy County pools. It is located immediately south of State Highway 83, approximately 40 miles east of Artesia and 25 miles west of Lovington, the county seat of Lea County.

HISTORY

First commercial oil production was established by the Maljamar Oil & Gas Corp. No. 1 Baish, which was spudded during November, 1925, and completed on July 16, 1926. This test, which is located 250 feet from the north and east lines of sec. 21 on a public-land lease, was drilled to a total depth of 4,140 feet and plugged back to 4,117 feet. It found 10,000,000 cubic feet of gas per day in the "Red Sand" at 3,115-3,155 feet, shows of oil in alternating sands and sandy limestones at 3,590-3,738, 3,783-3,788 and 3,796-3,816 feet, oil pays in dolomitic limestone at 4,002-4,040 and 4,105-4,132 feet and salt water at 4138-4,140 feet. Shooting of the oil-bearing formations resulted in an initial flowing production of 100 barrels of oil per day.

[1] Published by permission of the Director, Geological Survey, United States Department of the Interior.

[2] District Engineer, Oil and Gas Leasing Division, Conservation Branch, Geological Survey.

Due to poor roads, inaccessibility from developed market outlets, lack of knowledge regarding the extent of the productive area, and other factors, development of the field was slow. Four producers were completed prior to 1930, and by the end of 1938 only 22 oil wells and one gas well had been drilled. However, the year 1939 marked the beginning of more aggressive exploitation of the area, resulting in extensions to the south, east, and west of the discovery area. On January 1, 1942, there were 151 oil wells and three gas wells. Of this total, all are on public lands, except 10 oil wells and one gas well on State lands. The following table indicates the production of the field, by years.

Oil and Gas Production, Maljamar Pool

Period	Oil, Barrels	Gas, Cubic Feet
1926-1937	795,030	
1938	236,174	
1939	372,114	15,000,000,000[3]
1940	775,008	
1941	1,638,031	1,553,689,000
Totals	3,816,357	16,553,689,000[3]

Development has been orderly and the spacing pattern of well locations has been uniform. With seven exceptions, every well is located in the center of a 40-acre subdivision. Production in early years was restricted on a voluntary basis, and the field was later included with others in the general proration plan for all oil fields in the State. Such constructive operating practices should prove to be important in obtaining a greater ultimate oil recovery from the field.

SURFACE FEATURES

The surface in the Maljamar field is largely covered by sand in small shifting sand hills that form a relatively even terrain, with surface altitudes ranging from 3,925 to 4,050 feet above sea level. Only a short distance to the east, an escarpment rises some 200 feet to the western edge of a level plains area long known as the Llano Estacado or Staked Plains. This escarpment, probably the most striking topographic feature of the region, follows a northwesterly direction from southeast of Hobbs to a point about midway between Fort Sumner and Tucumcari, and thence eastward into Texas. The surface of the plains area east of the escarpment slopes southeasterly at about 15 feet per mile.

STRATIGRAPHY

Subsurface studies, based on information from wells drilled in the Maljamar area, disclose that the surface sand is underlain by approximately 800 feet of sandstone and red shale generally classified as belonging to the Dockum group of Triassic age, with

[3] Estimated figure.

a possibility that the lowest 50 feet of sandstone may be the Dewey Lake (?) redbeds of Permian age. Due to indefinite contacts between lithologic units in the Dockum, it is practically impossible to subdivide the group.

All formations drilled in this area below the Dockum are of Permian age. Subsurface geological determinations for the Maljamar field, currently used by the Southwestern District supervisory office of the Geological Survey for petroleum engineering work and related matters, are shown in detail on the accompanying type log and correlation chart, Plate 29, for the section below the Dewey Lake (?) redbeds. The nomenclature, correlations and formation intervals are based on studies of the Permian formations of West Texas and southeast New Mexico by Dickey[4] and King[5]. The structural relationships and relative depths of the formations in various parts of the Maljamar field are shown on the west-east cross section, Plate 30, and on the north-south cross section, Plate 31.

There are usually four distinct sandstone beds or sandy zones within the Yates formation, of which two or more have yielded shows of oil or gas in many wells. It is the second of these sands which has yielded oil in commercial quantities and is the pay zone of the Maljamar Oil & Gas Corp. No. 5-A Baish in the SW¼NE¼ sec. 21, and No. 7-A. Baish in the SE¼NW¼ sec. 21.

The upper member of the Queen formation is the so-called "Red Sand," which varies from 20 to 45 feet in thickness. The sand is of reddish color, and is in part fairly well cemented with calcareous material; and in places it lies above, below, or between layers of gray sand a few feet thick. Nine oil wells in the southern part of the field and two gas wells along the northeastern edge have been completed in the "Red Sand" as commercial producers.

As will be noted from the correlation chart, Plate 29, oil is found in four different zones within the Grayburg formation, but the different zones are productive in different parts of the field. The upper two zones are sandy dolomite; the third contains a greater percentage of sand although still classified as sandy dolomite; and the fourth zone, essentially the basal sand member of the Grayburg formation, grades into a sandy dolomite in only a few places. This fourth or lowest zone, generally called the "Maljamar Sand Pay," is the most prolific oil producer over the largest part of the field, especially the central and southern portions.

The San Andres formation, which underlies the Grayburg, is of undetermined local thickness, since only the upper part has been drilled. The top of the San Andres is apparently marked by an unconformity.[6] The upper beds are commonly white or light

[4] Dickey, R. I., Geologic section from Fisher County through Andrews County, Texas, to Eddy County, New Mexico: Bull. Amer. Assoc. Petrol. Geol., Vol. 24. No. 1, pp. 37-51, January 1940.

[5] King, P. B., Permian of West Texas and southeastern New Mexico: Bull. Amer. Assoc. Petrol. Geol., Vol. 26, No. 4, April 1912.

[6] Dickey, R. I., Op. cit., p. 47.

gray hard dolomite. No sandstone beds are present in the upper 300 or 350 feet. Oil is obtained from dolomite in which three separate producing zones are found in various parts of the field. The discovery well, as well as several later producers in the immediate area, is obtaining most of its oil from the third or lowest zone in the San Andres formation. The deepest test in the area, Southern Union Production Co. No. 2-B Pearsall, located in sec. 34, was drilled to a total depth of 5,150 feet. Since this well penetrated only about 1,122 feet into the San Andres formation, possibly to near its base, little is known of the deeper Permian and older rocks.

For convenience and simplicity, the Roswell office of the Oil and Gas Leasing Division, Geological Survey, and the operators in the field, apply a system of numbers for the nine known producing zones, which are locally used for engineering and production purposes. By this scheme, which is indicated on the correlation chart, Plate 29, the second sandstone in the Yates is Zone 1 and the "Red Sand" is Zone 2. Zones 3, 4, 5, and 6 are the four pays in the Grayburg, and the three oil producing zones in the San Andres are designated Zones 7, 8, and 9.

STRUCTURE

The Maljamar pool is located mainly on the crest and south flank of an eastward-plunging anticline which has little or no closure. (See map, Plate 28.) The regional dip of Permian beds in northeast Eddy County is generally toward the east or southeast at the rate of 50 to 75 feet to the mile. Along the south and southeast flanks of the Maljamar field, however, the dip ranges from 200 to 500 feet per mile ; the dip along the southern tier of sections in the township is somewhat steeper in the lower beds, due to down-dip thickening of all formations below the Tansill.

As in most fields of southeastern New Mexico, the geologic structure appears to have been an important determining factor in the accumulation of oil, but accumulation appears to have been locally determined in part by the lithologic character of the deposits, such as irregular calcareous cementation of sandy zones and irregular zones of porosity in dolomite.

RESERVOIR ROCKS

The nine known oil-bearing zones are very irregular in porosity and texture, both with respect to each other and in themselves. Zones 1, 2, 5, and 6 (see Plate 29) are essentially sands with varying degrees of lenticularity and cementation. Zones 3, 4, 7, 8, and 9 are dolomite or sandy dolomite. Each of the producing zones varies in favorable reservoir qualities to such an extent that normal movement of oil, gas, or water is restricted, with the possible exception of zone 6, the basal sand in the Grayburg, which produces a major portion of the oil in the field. Zone 6 probably permits oil movement with greater ease than any of the other oil-bearing zones, even though found to grade almost wholly into dolomite in local areas. No gas caps are known to exist in the Maljamar field.

No information is available regarding the original source of the oil accumulated in the Maljamar pool and surrounding areas.

Although the productive zones are relatively thick, estimates of expected ultimate recovery under usual operating methods should include consideration of low permeability and only fair saturation as evidenced by a study of core analyses, logs made from a study of cuttings, electrical logs, and production data. Connate water is known to be present with the oil in amounts estimated to vary from 15 to 35 percent. One analysis of a core taken from Zone 6 indicates a porosity of approximately 18.5 percent, and an average permeability of 50 millidarcies. In order to obtain a satisfactory rate of oil production, it is necessary to acidize producing zones in the dolomite and to shoot the sand and sandy dolomite zones in most wells.

OIL ANALYSES

The following analyses were made by the Malco Refinery at Artesia, New Mexico, and each is believed to be representative of the indicated oil-producing zone. The tests were run in accordance with A. S. T. M. distillation D-158-41 except iced condenser 200 cc. distilled.

Oil Analyses, Maljamar Pool

	Barney Cockburn No. 10-A Pearsall Sec. 33 Zone 2	Kewanee Oil Co. No. 16-B Baish Sec. 28 Zone 6	Maljamar Oil and Gas Corp. No. 2-A Baish Sec. 21 Zone 9
A. P. I. gravity	37.7°	38.0°	37.0°
Salt per 1,000 bbls.	2 lbs.	8 lbs.	20 lbs.
Bottom sediment and water	None	Trace	Trace
Initial boiling point	130° F.	94° F.	96° F.
5%	200	160	180
10%	220	210	208
15%	246	244	234
20%	280	275	264
25%	312	304	290
30%	350	340	330
35%	392	380	370
40%	436	416	412
45%	484	462	460
50%	530	512	510
55%	572	554	546
60%	612	572	590
65%	650	612	636
70%	670	650	664

GAS ANALYSIS

Five fundamental analyses of gas taken from Zones 5, 6, 7, and 9 in the Maljamar pool, under average trap pressures of two pounds, were made by Sidney Born of Tulsa, Oklahoma. The following composite of these analyses is representative of the gas produced from the Grayburg and San Andres formations.

Composite Gas Analysis, Maljamar Pool

Methane	55.97	
Ethane	16.37	
Propane	14.60	
Iso-Butane	1.83	
N-Butane	5.87	1.843
Iso-Pentane	1.15	.418
N-Pentane	1.62	.591
Hexanes and heavier	2.59	1.113
Totals	100.00	3.965

Carbon dioxide (including hydrogen sulfide) --------------------------------- 3.01 percent
Oxygen --- .63 percent
Air equivalent --- 2.69 percent
Hydrogen sulfide per 100 cubic feet ------------------ 435 grains

Individual analyses indicate that the gas from Zones 6 and 9 contains slightly less methane, but more ethane and propane than the average figures shown above. Also, all liquid products contained in the gas produced from these two zones is ordinarily slightly in excess of the above figures.

WATER

Water is known to have been encountered below the Seven Rivers formation in 19 wells. Of this total, water was found in Zone 2 (the "Red Sand") in one well in the southwest quarter of sec. 35, in Zone 8 in another well in sec. 26, and in the San Andres formation below Zone 9 in two other wells located in secs. 5 and 18. Water in the other 15 wells, including several in the north half of sec. 21, has been found in Zone 9 at depths ranging from 85 to 468 feet below sea level. Water found in the several oil reservoirs appears to be locally trapped and of limited areal extent. As a result, there is believed to be no effective water drive which might be considered as a factor in the recovery of oil, and no definite oil-water contact. Although water has been found with the oil in Zone 9 in a few wells along the crest of the structure, it has generally been possible to plug back a short distance and to produce the oil with only a small amount of water or with none.

[7] Equivalent to gas volume percent.

DRILLING AND PRODUCTION METHODS

Until 1939, all wells in the field had been drilled with cable tools. Standard derricks were used in the earlier development, but heavy-duty types of portable machines have become more popular during the past four years. Also, a number of wells have been drilled with rotary rigs—at least until the oil string of casing has been set and cemented. In most rotary wells, the pay section is drilled with cable tools. In the few wells completed with rotary equipment, oil has been used as a circulating medium instead of mud or water. Because of low initial reservoir pressures, and possibly other reasons, the use of mud for circulation is known to affect adversely the producing zones by infiltration of mud and the restriction of oil recovery. However, the use of rotary equipment for drilling the oil-producing section, together with electrical logging to obtain necessary formation details, has proved successful as a completion procedure.

The standard casing program begins with setting of casing, usually $8^5/_8$-inch, in the anhydrite immediately above the top of the Salado or "salt section," and cementing with approximately 50 sacks of cement, preceded by mud circulated to surface. This casing is necessary in order to protect the potash-bearing salt section from contamination by water from upper sands, to act as an anchor string in case of blowouts, and to eliminate mechanical difficulties by upper formations caving in on the tools. The production string of casing, ordinarily 7-inch O.D. or $5\ ^3/_{16}$-inch I.D., is then set at a point about 100 feet above the first producing zone, and cemented with 100 sacks of cement or more, preceded by mud circulated to surface.

In most rotary-drilled wells it has been possible to economize on the above casing program. One or two joints of large casing are cemented at the surface as a "conductor string." No more casing is set until the depth is reached for the oil string, where 7-inch or $5\ ^3/_{16}$-inch casing is cemented by the "two-state" method. About 200 sacks of cement are pumped back of the lower portion of casing in the usual manner, and about 250 sacks behind the upper portion, extending from near the base of the Rustler to the surface, by injecting the cement through a multiple-stage cementing tool or through perforations in the casing at a point immediately above the "top of salt."

Water for drilling purposes is obtained from beds of the Dockum group from wells drilled to depths of 600 to 800 feet, but is found only in certain local areas. In most of the field no water is encountered in the Dockum group or Dewey Lake (?) redbeds.

Of the total of 151 oil wells completed by January 1, 1942, nine were being pumped by individual units powered by gas or gasoline engines, and the other 142 wells were flowing. No commercial oil producers have reached the abandonment stage, and the bottom-hole pressure decline has not been excessive. Present bottom-hole pressures average more than 1,000 pounds per square inch, and the gas-oil ratios of all wells in the field in March, 1941, averaged 965 cubic feet per barrel.

Oil from the Maljamar field was first sold to the Continental Oil Co. refinery at Artesia, and transported from the field through the New Mexico Pipe Line Co.'s line to the refinery. In 1931 an additional market outlet was provided by the erection of the Malco Refinery at Artesia, which is independently owned. Oil was then moved to the Malco Refinery by means of the Murchison & Closuit pipe line. During more recent years, an additional outlet for the Maljamar and Eddy County crude has been provided by the Texas-New Mexico Pipe Line Co., which includes a gathering system and trunk line connections to an inter-state pipe line system in Lea County, and enables operators to sell crude oil for delivery to Gulf Coast points.

The operators in the field have formed a cooperative pressure-maintenance agreement, and are operating the field under a cooperative method of pressure-maintenance by gas injection. Operation of the plant was commenced in April, 1942, and a total of 12 gas-injection wells are being used. It is contemplated that additional input wells will be added later. A gasoline-extraction plant is being operated in connection with the pressure-maintenance unit. The gasoline is being sold to a local refinery, and other liquid by-products suitable for use in the manufacture of aviation gasoline and synthetic rubber are sold to Phillips Petroleum Co.

LAND OWNERSHIP

About 92 percent of the productive area is public land, under oil and gas lease from the Federal Government and under general field supervision of the Oil and Gas Leasing Division, Geological Survey. The remainder is State land under the jurisdiction of the New Mexico Oil Conservation Commission.

There is a total of 13 operators in the field, but 80 percent of the productive acreage is held by Maljamar Oil & Gas Corp., Carper Drilling Co., Barney Cockburn, and Kewanee Oil Co. The first three operators are largely responsible for the development of the area, and Kewanee Oil Co. acquired a substantial interest in the field by purchase from Mr. Cockburn in September, 1941.

FUTURE POSSIBILITIES

Since January 1, 1942, 10 oil wells have been completed, bringing the field total to 161 oil wells and three gas wells. The total developed area amounts to 6,560 acres. With some possible development to be expected to the northwest, east, and possibly southwest of the known productive area, it is possible that the field may eventually cover a producing area of 8,000 to 9,000 acres. The major portion of the field in the known productive zones appears to have been developed, and future possibilities for maximum exploitation of the reserves lie largely in the continued successful operation of the pressure-maintenance project.

ACKNOWLEDGMENT

Acknowledgment is made of the cooperative assistance of the Maljamar field operators, and of R. O. Anderson of Malco Refineries, Inc., in releasing for publication certain data which have been used in the preparation of this report. The writer is also indebted to Ernest A. Hanson and Foster Morrell, of the Geological Survey, for valuable assistance and constructive review of the manuscript.

MONUMENT POOL

ROBERT L. BATES

LOCATION

The Monument pool lies in east-central Lea County. It includes about 30 sections of land centering around the common corner of Tps. 19 and 20 S., Rs. 36 and 37 E. (See map, Plate 14.) The pool lies 10 to 15 miles southwest of Hobbs. State Highway 8, connecting U. S. Highway 62 on the north with the town of Eunice on the southeast, passes through the eastern part of the field.

The southwestern edge of the Llano Estacado crosses the northern part of the field, so that some wells are located on the flat treeless plain of the Llano while others are situated on the sand-dune wastes below and on the intervening slope. The dune area supports a scant desert vegetation and provides poor forage land.

The Monument pool is the northernmost producing area of the long Hendricks-Jal-Cooper-Eunice trend. More specifically, it is the northern part of the continuous producing area, 18 miles long and several miles wide, that includes the South Eunice, Eunice, and Monument pools. Geologically it occupies the northwest part of the Central Basin Platform (see map, Plate 13).

HISTORY

The name Monument was taken from a post office and general store located in what is now the east-central part of the field. In turn this post office derived its name from a monument or rock pile which served to guide Indians to a spring, the only surface water to be found in the region.

Four wells were drilled in this general area several years before the discovery of the Monument pool. These included the Marland (now Continental) No. 1 Myers, a small gas well one and one-half miles southeast of the present southeast limits of production; the Marland (now Continental) No. 1 Reid, dry hole a mile southwest of the southwest corner; the Exploration No. 1 Record, dry hole four miles west of the pool; and the National Securities No. 1 Linam, about midway between the north end of Monument and the Hobbs pool. Geological studies based on these four wells indicated that the intervening area was likely to show a structural high. In 1932-33, Amerada Petroleum Corp. made seismograph surveys of the area, and drilling was undertaken on the basis of the results.

The discovery well, the Amerada No. 1-D State, located in the NW¼NW¼ sec. 1, T. 20 S., R. 36 E., was spudded on December 14, 1934. As was expected, it had a structurally high position. At a depth of 3,929 feet it flowed 945 barrels in 24 hours. The well was deepened to 3,954 feet, but encountered water and was plugged back to 3,945 feet with a packer set at 3,929 feet. After a 2,000-gallon acid treatment, the well was completed on March 29, 1935, for an initial production of 3,552 barrels of oil per day.

Other wells were immediately started. Three and one-half miles to the northeast, The Texas Co. completed its No. 1 Saunders in July, 1935, for an initial production of 743 barrels daily after acid treatment of 2,000 gallons. In November of the same year, Barnsdall Oil Co. brought in its No. 1 Cooper two miles southeast of the discovery. This well, first completed for 110 barrels per hour natural, was later treated with 5,000 gallons of acid and re-completed for a potential of 1,178 barrels in one hour, flowing.

The completion of these wells indicated a field of major importance. Soon after the discovery, more than 50 rigs were in operation. A rig-builders' strike in 1936 temporarily slowed development, but most of the field had been drilled by the end of 1937. At the close of 1941, the field contained 497 oil wells, five abandoned oil wells, two gas wells, and seven dry holes.

STRATIGRAPHY

Recent.—Deposits of Recent age include a thin soil cover and a few feet of caliche on the Llano Estacado, and dune sand, caliche, and re-worked Tertiary shales to the south.

Tertiary.—Buff to pink sands and gravels with thin beds of shale make up the Tertiary section, which is 50 to 200 feet thick. On the Llano Estacado, sand and gravel beds at a depth of 100 feet yield large quantities of water well suited for camp and drilling purposes.

Triassic.—The Triassic section consists of red shale, in part sandy, which is of Chinle age. This is underlain by 190 feet of red sand which is thought to represent the Santa Rosa formation. Beds of Tecovas age have not been recognized, but are probably present in thin development below the Santa Rosa. Total thickness is 400 to 450 feet.

PERMIAN

Dewey Lake.—Beneath the Triassic beds lies compact sandy red shale which carries some anhydrite in the lower part. This shale, which is considered to be Dewey Lake, is about 100 feet thick.

Rustler.—The Rustler formation is about 100 feet thick. The upper and lower parts are pure hard anhydrite, separated by light-colored limestone 20 feet thick.

Salado.—The Salado consists of salt, polyhalite, and anhydrite. The anhydrite decreases with depth, and is essentially absent in the lower half of the formation except for the widespread Cowden anhydrite, 20 feet thick, which occurs about 160 feet above the base of the salt. Total thickness of the Salado is approximately 1,200 feet.

Tansill.—Between the base of the salt section and the top of the Yates sandstone is the Tansill anhydrite, 170 to 200 feet thick. It carries thin stringers of salt in the upper part and of limestone in the lower part.

Yates.—The Yates consists of anhydrite, sandstone, and thin limestone beds. The sandstone is greenish-gray and contains numerous frosted quartz grains. Thickness of the formation is difficult to estimate, as its base is not readily recognizable. It is probably 250 to 300 feet thick.

Seven Rivers, Queen, and Grayburg.—The geologic section between the base of the Yates formation and the top of the San Andres dolomitic limestone cannot be readily subdivided in the Monument area and hence is treated as a unit. It is some 1,100 feet thick. Anhydrite is prominent in the upper 100 or 200 feet, but decreases with depth and disappears about 500 feet below the base of the Yates formation. Sandy dolomitic limestone with thin beds of sandstone makes up the lower part of the section. Sandstones that are prominent to the west, such as the "Artesia red sand" at the top of the Queen formation, are present only as thin stringers at Monument and may lens out entirely in places.

San Andres.—This formation consists of massive dolomitic limestone which is finely crystalline to dense in texture and white to gray and tan in color. Some zones carry a few anhydrite inclusions and thin shale seams. On the west side of the field the upper part of the formation appears to grade laterally into sandy limestone and sandstone. The deepest wells have penetrated about 500 feet of the San Andres.

STRUCTURE

The structure at Monument is a broad anticlinal fold with considerable relief. A structure map with contours on the top of the Rustler formation shows a decided north-trending axis with a structural relief through the producing area of about 400 feet. Structure as shown by the top of the Yates, however, includes a subsidiary northwest-trending axis (see map, Plate

21), which is a feature of the other pools to the south and east. Relief on the Yates surface in the producing area is greater than that on the Rustler, being about 500 feet. The steep west dip is characteristic of the structures along the west edge of the Central Basin Platform, and makes the eastern limb of the deep San Simon syncline (see map, Plate 13). The Monument structure seems to be located approximately at the place where the north trend of the Capitan Reef, which orients production to the south, was intersected by the northwest trend prominently shown in pools to the east and southeast.

An isopach map of the Salado formation shows abnormal thinning of this formation over the crest of the Monument structure. The axis of greatest thinning closely parallels the axis of Yates folding.

RESERVOIR ROCKS

The zone that produces oil at Monument occupies a definite position between a depth of 200 feet below sea level and a common water table at 360 feet below sea level. In this respect the pool is similar to a number of other pools to the south, including the Eunice pool (see pages 207 to 216). Probably in no well does the entire 160 feet produce oil, but all productive zones fall within this interval.

In the structurally higher parts of the field, gas has been found in the lower part of the Yates formation, at intervals throughout the Seven Rivers-Queen-Grayburg section, and in the upper San Andres limestone. In fact, any part of the section may be expected to produce gas if sufficient porosity and permeability exist above the top of the oil zone at 200 feet below sea level. Gas blow-outs, gauging from 50,000,000 to 100,000,000 cubic feet per day, have been common in wells on the structurally higher parts of the pool.

The fact that the fluids have been so well segregated with respect to sea level indicates a high degree of permeability in all formations that fall within the producing interval. On the flanks of the structure, the interval containing oil lies within the sandy limestones of Grayburg age above the San Andres formation. In the central part of the pool, the San Andres dolomitic limestone produces oil.

Oil has been found to occur in porous limestone. The sands of the Grayburg formation have their interstices filled with crystalline dolomite, and therefore, although they may be saturated with oil, are neither porous nor permeable enough to act as good reservoirs. The sandy limestones of the Grayburg yield oil which occurs in either oolitic or granular porosity. The oolitic type is the more productive. A treatment with acid is generally found effective in cleaning out secondary lime carbonate in the pore spaces between the oolites. The limestone with coarse-grained or granular porosity in most places has insufficient permeability to produce natural flow, but has been found to respond fairly well to acid treatment.

The massive, relatively uniform San Andres limestone forms the best reservoir. Porosity is of two types: oolitic and honeycomb or cavernous. The oolitic type is similar to that in the Grayburg section, but generally contains less secondary calcite. The honeycomb or cavernous type is by far the more productive; however, little is known of it at first hand. Cores cannot be taken in such soft material, and rotary drilling fluid is generally lost so that cuttings fail to return to the surface. The material is so soft that a rotary bit has been known to drill three feet of it in less than one minute.

OIL

An analysis of oil from the Monument pool follows.

Analysis of Oil from Amerada No. 1-D State
Sec. 1, T. 20 S., R. 36 E.,
Monument Pool

Gravity	29.8° A.P.I.
Sulfur	1.37 percent
Saybolt Universal viscosity at 100° F.	55 sec.
Pour point	0° F.
Color	Brown

Distillation

Fraction	Percent
Motor stock, octane No. 58	26.2
Light gas oil	11.9
Heavy distillate	4.1
Tar	57.5
Loss	0.3
Total	100.0

WATER ENCROACHMENT

Water encroachment at Monument has been relatively slow, probably in part due to the strict proration imposed on the field throughout development. The west and southwest edges appear to show some effect of a water drive. Practically all the wells producing water are located on the edges of the field. During 1941, 26.7 percent of the oil wells at Monument produced some water. The average amount of water produced per well in 1941 was 3,354 barrels.

DRILLING AND PRODUCTION METHODS

Drilling in the Monument pool has been almost entirely with rotary equipment, utilizing steam power where water was plentiful and Diesel units in other places. Cable tools have been used only in the upper 3,000 feet of one of the early wells and for drilling into the pay section in a few structurally low wells. With rotary tools, heavy mud has generally been used as circulating fluid in the central part of the field where high gas pressures exist. Oil or water has been in common use in other parts of the pool. Some operators have drilled all their wells using oil as fluid; where high gas volumes were encountered, drilling and running of tubing was carried on under pressure. This procedure avoided the possibility of sealing off valuable porosity with mud, and the necessity of having to "kill" the well. Only one destructive blow-out and fire has resulted.

In compliance with New Mexico law, enough surface casing has been used to reach the redbed section and seal off fresh-water sands. This has generally amounted to about 200 feet, and has been cemented for its entire length. Diameter commonly used has been 12½-inch. Two general casing programs were used below the surface string. In the first, 8⅝-inch or 9⅝- inch casing was cemented below the base of the salt section at about 2,500 feet, and the production string of 5½-inch, 6⅝-inch, or 7-inch casing was cemented above the pay, at a depth of about 3,800 feet. This program was used by practically all operators during the early development of the field. The second casing program originated as an economy measure during later development. It consisted of cementing 7-inch casing in the Rustler anhydrite at 1,000 to 1,300 feet and cementing a 5½-inch oil string at the top of the pay section. This program was less expensive not only because it required smaller casing sizes, but also because it took 1,200 to 1,500 feet less of intermediate-size casing. Two disadvantages, however, are apparent. When drilling with the entire salt section open, there was more danger of twisting off drill pipe with resulting fishing jobs and danger of losing the hole. Secondly, as no protective string of casing separates the production string from the corrosive salt, there is more likelihood of the production string being eaten through, causing leaks, before the end of the life of the well. Furthermore, because of the small size of the oil string used, there is generally not space enough for a second oil string inside the first one.

More than half the wells in the Monument pool have been treated with acid. The limestone is 100 percent soluble in the acid used, and contains little anhydrite or shale to interfere with its action. The dolomitic sandstone does not respond to acid treatment. Very few wells have been shot with nitroglycerin, as it was early found that this method is not well adapted to reservoir conditions.

PRODUCTION

The Monument field went on production in April, 1935, and was prorated from the start. Until early 1937 The Texas Co.'s pipe line was the field's only outlet, with a daily capacity of about 10,000 barrels. Therefore, as drilling continued the field allowables were constantly decreased. After several other companies constructed pipe lines into the field, the well allowable was raised to about 125 barrels per day. This figure has been lowered in recent years.

During 1941 the Monument pool produced 6,973,808 barrels of oil and more than 16 billion cubic feet of gas. Cumulative production to the end of 1941 was 46,289,201 barrels of oil and 126 billion cubic feet of gas. Per acre yield is 2,305 barrels.

OWNERSHIP

Forty-one percent of the land at Monument is owned by the State of New Mexico, 40 percent by the Government, and 19 percent by individuals. Amerada Petroleum Corp. operates about 25 percent of the acreage, with most of the other major companies also well represented.

FUTURE POSSIBILITIES

Development of oil and gas production from depths now exploited is considered to be about at its maximum. As the field is one of the largest New Mexico structures, it is thought that chances for deep Permian and possibly pre-Permian production are relatively good.

NORTH LYNCH AREA

ROBERT L. BATES

LOCATION AND HISTORY

The North Lynch area includes all of T. 20 S., R. 34 E., Lea County, except sec. 34 and parts of secs. 26, 27, and 35, which are included in the Lynch pool. (See map, Fig. 19.) U. S. Highway 62, connecting Carlsbad and Hobbs, crosses the northwest corner of the township. Elevations average about 3,650 feet.

On July 12, 1929, Henderson, Dexter and Blair completed their No. 1 McDonald-Jewett, located in the SE¼SE¼ sec. 18, for an initial production of 66 barrels daily from a depth of 3,587 feet. The well was plugged back from 3,612 feet, at which depth sulfur water was encountered. This well, the only producer in the west half of the township, was offset early in 1942 by the Cities Service Oil Co., who drilled a dry hole in the SW¼ sec. 17.

The area's second producer, The Texas Co. No. 1 J. S. Lea, was completed in 1934. It is located in the SW¼NW¼ sec. 14. This well made 77 barrels of oil in 6¼ hours from a plugged-back depth of 3,622 feet. Total depth was 3,688 feet. The well remains the only producer in the east half of the township north of the Lynch pool.

Numerous dry holes have been drilled in the area, most of which encountered sulfur water. Three failures have been drilled within three-fourths of a mile of the producer in sec. 14.

STRATIGRAPHY AND STRUCTURE

The geologic section underlying the North Lynch area in most respects closely resembles that of the Lynch pool (see page 238). Red beds of Triassic and Permian ages are penetrated by the drill to approximately 1,500 feet; salt and anhydrite of the Rustler-Salado-Tansill section to about. 3,400 feet; and red and gray sandstone of the Yates formation, with abundant frosted quartz grains, to total depth.

Datum points on the top of the Yates formation indicate the presence of at least two small anticlinal structures in the township exclusive of the Lynch pool. Oil is now produced from one well on each of these structures. The history of these small highs appears to be depositional rather than dynamic. They were probably formed during medial Permian time in the sandy region back of the Capitan reef.

RESERVOIR ROCKS

Oil in the North Lynch area comes from sandstones of the Yates formation, and possibly from the uppermost Seven Rivers sandstone. Most of the porous section contains sulfur water; the oil appears to have been trapped in two small pockets above the water surface. Small size of the eastern oil pocket is indicated by the closeness with which the producing well is surrounded by dry holes.

The oil, as in many areas of "sand production," is relatively sweet. It has a gravity of 35-38° A. P. I. Some gas is produced with the oil in The Texas Co. No. 1 Lea, and some water in the Henderson, Dexter and Blair well to the west.

PRODUCTION

Except for The Texas Co. No. 1 Jackson, which was drilled with rotary equipment, all the wells in the area have been drilled either with cable tools or with a combination of both types. Three strings of casing are generally set: a surface string, a string in the Rustler formation below the redbeds, and the production string in the Tansill formation below the salt section. No shooting or acid treatment has been employed. The wells are pumping.

Oil production during 1941 was 8,418 barrels; cumulative production through 1941 totalled 154,505 barrels.

FUTURE POSSIBILITIES

Other small depositional highs like those now producing may be discovered in the township. Confidential geophysical surveys may already indicate such structures. Presence of oil at greater depths than have been explored so far is entirely problematical.

SALT LAKE POOL

CHARLES P. MILLER[1]
Hobbs, New Mexico

LOCATION

The Salt Lake pool, in T. 20 S., R. 33 E., is situated in western Lea County approximately midway between Hobbs and Carlsbad. (See map, Plate 14.) U. S. Highway 62, connecting these two towns, diagonally crosses the area. The surface is of low relief,

[1] Engineer, Lea County Operators Committee.

and precipitation drains into a shallow, highly saline lake in the northwest part of the township. This lake is believed to overlie a part of the oil-producing structure.

HISTORY

The first test well in the area of the Salt Lake pool was the Marland Oil Co. (now Continental Oil Co.) No. 1 Brooks, in the NW¼SW¼ sec. 8. This well, which reached a total depth of 4,041 feet, was completed as a dry hole on April 16, 1929. Shows were reported as follows: oil-3,020-3,050, 3,080; gas-3,0253,050; salt water-3,210-3,220; sulfur water-3,455, 3,475, and 3,710-3,730. Another dry hole, Western Drilling Co. No. 1 State, was completed in 1931. It was located in the NE¼ sec. 16, T. 20 S., R. 32 E. Discovery of large amounts of sulfur water led to its abandonment at a total depth of 4,005 feet.

The two wells just described showed regionally high structural positions on the Yates sandstone and Seven Rivers limestone. Furthermore, a study of the Salado salt section in these two tests and in nearby dry holes indicated a thinning in the salt section, the axis of thinning bearing northwesterly. On October 6, 1939, commercial quantities of oil were discovered in the Seven Rivers limestone by a well located in sec. 16, T. 20 S. R. 32 E. This discovery, which led to the development of the Halfway pool, provided the necessary impetus for re-investigation of the Salt Lake area; structural and isopach information was reviewed, and torsion balance and geochemical surveys were completed. Results of the torsion balance survey are shown in Fig. 20.

The discovery well of the Salt Lake field was drilled by Harry Leonard and Van S. Welch on a State lease in the NW¼- NW¼ sec. 18, T. 20 S., R. 33 E. It was completed on June 22, 1941, for an initial production, pumping, of 240 barrels per day of 26° gravity oil from a total depth of 3,102 feet.

STRATIGRAPHY: POST-PERMIAN

Gypsite, weathered caliche, and gypsiferous sandy redbeds, of Recent and Tertiary (?) ages, extend from the surface to a depth of about 70 feet. Below this material lie red shales and varicolored quartz sands of the Dockum group (Triassic) , about 960 feet thick. In the upper part of this section a sand, which contains some calcareous material, may be the Santa Rosa sandstone or its equivalent.

PERMIAN

Dewey Lake.—The uppermost Permian formation consists of red shales with pink and red sands, to a thickness of about 70 feet.

Rustler.—This well known and easily recognized unit is made up chiefly of anhydrite. It also carries a few thin beds of salt, shaly limestone, and red sand. Thickness of the formation is about 325 feet.

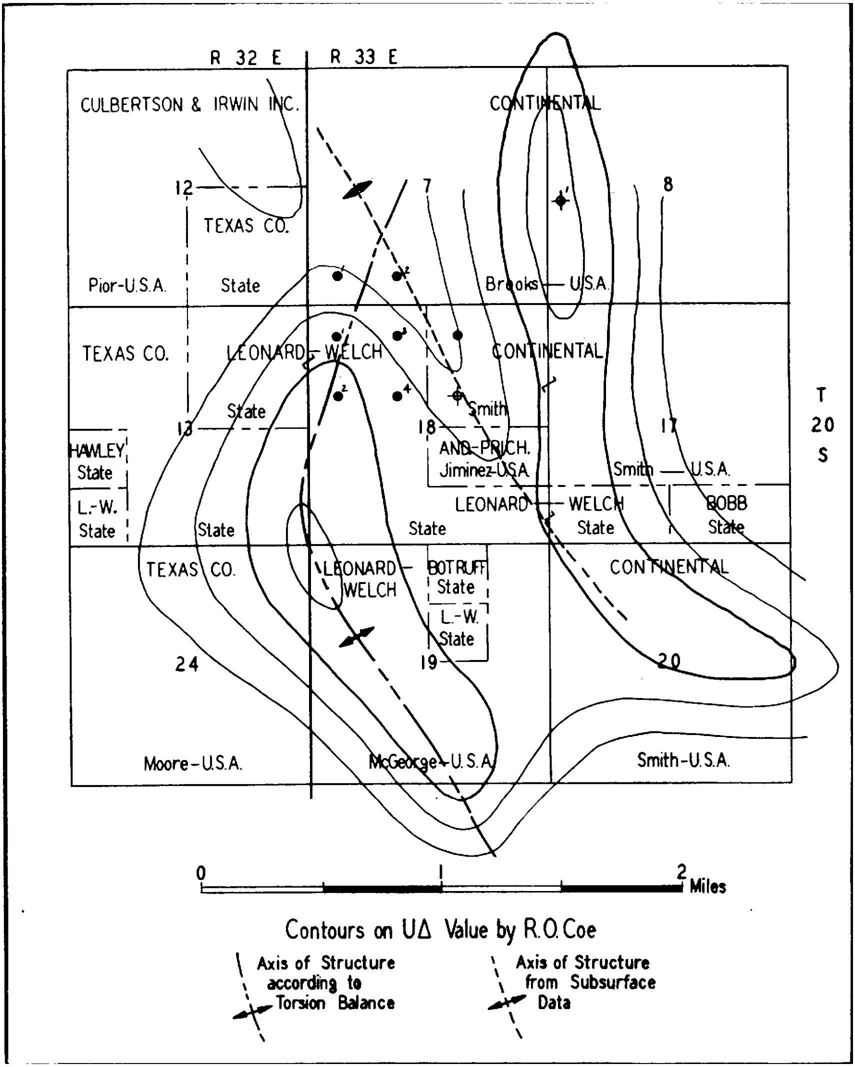


FIGURE 20.—Torsion-balance map of the Salt Lake pool, Lea County.

Salado.—This formation consists chiefly of salt and is about 1,175 feet thick. The Cowden anhydrite member, which has a thickness of 25 to 30 feet, is found about 90 feet above the base of the salt.

Tansill.—The thickness of the Tansill is 150 feet. Its upper part is anhydrite, but there is a downward gradation into anhydritic dolomite. A few thin beds in the upper dolomite section are red. Stringers of red sand and shale are found in the lower part of the formation.

Yates.—Sandstone with characteristic frosted quartz grains makes up the Yates. The top of the formation is easy to determine, but its lower contact, with the Seven Rivers, is not clear-cut. Thickness averages about 265 feet.

Seven Rivers.—This formation, so far as it has been penetrated in this area, is white and gray dense dolomitic limestone, with porous zones in the upper part. Its full thickness has not been determined.

STRUCTURE

Due to the small amount of subsurface information now available, it is impossible to make an accurate interpretation of geologic structure. However, it is believed that the structure will be shown to be anticlinal, the axis bearing about N. 30° W. from a point near the southeast corner of sec. 18 (see map, Fig. 20). Much of the structural movement is believed to have taken place during early Salado time.

RESERVOIR ROCKS

Oil is found in sandstones in the basal Yates formation, and in porous zones in the upper part of the Seven Rivers limestone. Evidence is lacking as to possibility of production from deeper strata.

FLUIDS

Oil analyses are not available. However, the oil apparently has a mixed paraffin and asphalt base. Oil from the basal Yates has a corrected gravity of 30°, while that from the upper Seven Rivers has a gravity of 26° to 27°. As free gas is present in insufficient quantity to produce natural flow, artificial methods of lift are used. Both tubing and casing pumps have been employed successfully. On account of the erratic distribution of the zones of porosity, which is reflected in the fact that initial productions have varied from 50 to 750 barrels daily, it is impracticable to make an estimate of percent of saturation or ultimate recovery. The Salt Lake pool had produced 14,030 barrels of oil at the end of 1941.

DRILLING AND PRODUCTION METHODS

All drilling has been done with cable tools. Average cost per well for drilling and completion is about $8,000. Casing requirements and costs are reduced to a minimum by the fact that the surface string, at about 400 feet, and the intermediate string, at 700 to 750 feet, are recovered prior to cementing the 8¼-inch string in the Rustler anhydrite at about 1,100 feet. The pay string, of either 7-inch or 5-inch diameter, is generally set about 80 feet below the top of the Yates formation.

LAND OWNERSHIP

All leases are on either Federal or State land, the proportions being about equal. More than 900 acres are believed proved for production.

SKELLY-PENROSE-HARDY AREA

ROBERT L. BATES

LOCATION

The Skelly-Penrose-Hardy area as defined in this report includes the south half of T. 21 S., R. 37 E. (Hardy pool); all of T. 22 S. R. 37 E. except that part in the Arrowhead field (Pen- rose pool); and the north half of T. 23 S., R. 37 E. (Skelly pool). (See map, Plate 14.) Similarity in subsurface conditions throughout the area makes it advisable to treat it as a unit.

The town of Eunice is situated in the north central part of the area. State Highway 8 extends northwest from Eunice to the Eunice and Monument pools, and east to the Texas line. State Highway 18 and the Texas-New Mexico Railroad extend the entire length of the area, connecting Hobbs on the north with Jal on the south. The land surface is nearly flat and supports scant vegetation.

HISTORY

Oil was sought in the Skelly-Penrose-Hardy area as a part of the campaign to explore the great Hendricks-Eunice trend toward the north and east. The discovery well, in the NW¼SW¼ sec. 5, T. 23 S., R. 37 E., was completed by the Skelly Oil Co. as their No. 1 B. F. Harrison early in March, 1936. The well was drilled to 3,794 feet and plugged back to 3,762 feet. Initial production was 224 barrels of oil per day, pumping, after shot with 870 quarts of nitroglycerin from 3,490 to 3,762 feet. Development progressed northward from the discovery well. Most of the drilling was done in 1937 and 1938, although a few rigs were kept busy until late 1941.

STRATIGRAPHY

The geologic section penetrated in the area is similar to that of the Langlie-Mattix area to the south (see pages 230 to 235). Discussion of the stratigraphy in the Arrowhead pool, immediately to the west, will be found on pages 195 to 201.

STRUCTURE

Structure of the southern half of the area is a series of relatively low, irregular uplifts with a long narrow ridge on the west side of the productive area. (See map, Plate 21.) In the north half, the structure more nearly approaches anticlinal form, although the flanks are irregular and closure to the north is lacking. The trend as a whole is separated from the Arrowhead pool to the west by a shallow syncline. The general structural high underlying the area carries on toward both the north and south, although reservoir conditions have not allowed oil to accumulate for some distance in those directions. To the east the structure slopes off into the low middle part of the Central Basin Platform.

RESERVOIR ROCKS

Wells in the south half of the Skelly-Penrose-Hardy area produce from a sandstone, known locally as the Shipley sand, near the top of the Grayburg formation. The sandstone occurs as stringers and lenses in cream-colored dense dolomitic limestone. Frosted quartz grains are common near the top of the zone. Total thickness of the pay is about 150 feet. Oil accumulation is controlled both by structural position and by lensing and permeability of the sandstone. Boundaries of the productive area to the east, south, and west are determined by the places at which .the permeability of the sandstone decreases to a negligible amount.

In the north half of the area the Shipley sand is thin and serves as a gas reservoir. Oil is found below the sand, in porous light-colored oolitic limestone of the middle Grayburg formation. Zones carrying oil are found in an interval of approximately 100 feet. Accumulation is controlled by structural position, and also by distribution of porosity, which depends largely on extent of oolite development.

The sandstone and limestone reservoirs interfinger in the central part of the area. Several wells, among them the Skelly No. 1 Danglade in the SW^1/4 sec. 22, T. 22 S., R. 37 E., have secured oil from the limestone zone on deepening after depleting the Shipley sand.

FLUIDS

The amount of gas varies from low to excessive. In the area of sand production, control of gas-oil ratios is difficult, as it is not feasible to run pipe and perforate, or to set packers, because of the necessity of shooting the sand zone with nitroglycerin.

Both gas and oil are sweet. The oil has a gravity of 36° to 40°, depending in part on the structural position from which it comes. There is no water drive, and only a small amount of water is produced with the oil. In the Skelly pool, 70 barrels of oil are produced for one barrel of water ; in the Penrose pool the ratio is 110 to one, and in the Hardy pool 127 to one.

DRILLING AND PRODUCTION METHODS

In the south part of the area, most of the wells are drilled with cable tools, whereas in the north part high gas pressures in the Shipley sand have necessitated much rotary drilling.

If drilling is with cable tools, five strings of casing are employed, as follows: surface string at 100 to 150 feet; intermediate strings at 400 to 450, 700 to 750 and 1,100 to 1,200 feet; and the production string at 3,500 to 3,550 feet. After the production string is cemented, the other strings are pulled. In the case of rotary drilling, one string is cemented either near the surface or in the Rustler anhydrite, and the production string is cemented above the pay.

Thin beds of bentonite, which are found in a section 15 to 20 feet thick beneath the Shipley sand, have caused some trouble by swelling and caving. For this reason a few wells have been plugged back to above the bentonite.

Wells producing from the sandstone zone are generally shot with 400 to 500 quarts of nitroglycerin. Those producing from the limestone are treated with 2,000 to 3,000 gallons of acid.

PRODUCTION

Oil production of the three pools in the area is as follows:

Field	1941	To End of 1941
Hardy[1]	497,132	2,801,052
Penrose	1,203,831	6,931,070
Skelly [2]	401,303	2,445,951
Totals	2,102,266	12.178,073

[1] South half of T. 21 S., R. 37 E.
[2] Except southwest quarter of T. 23 S., R. 37 E.

At the end of 1941 the area contained 340 oil wells, five gas wells, five abandoned oil wells, and 10 dry holes.

OWNERSHIP

The largest part of the land is owned either by the State or by individuals. Leases are held by most of the major companies, and by a few independent operators.

FUTURE POSSIBILITIES

Development of the sandstone and limestone pays in the Grayburg formation has practically reached its limit. Possibilities for production from lower beds, possibly even pre-Permian formations, are unknown but believed relatively good.

ACKNOWLEDGMENTS

The writer wishes to express his appreciation to W. F. Bailey and W. W. West, of the Skelly Oil Co., for furnishing much of the material on which this report is based.

SOUTH EUNICE POOL

DELMAR R. GUINN[1]
Tyler, Texas

LOCATION

The South Eunice pool, which lies approximately eight miles southwest of the town of Eunice in Lea County, includes T. 22 S., R. 36 E., with the exception of seven sections in the northeastern part which are included in the Arrowhead pool. The area thus defined is the one used for proration purposes and is outlined by survey boundaries rather than by geologic structure. (See map, Plate 14.)

HISTORY

The first drilling within the present boundaries of this field was undertaken with the idea in mind that the trend which had already been found productive in the Jal and Hendricks fields

[1] Geologist, Cities Service Oil Company.

might extend farther north. The first well was drilled by Empire Gas and Fuel Co., now Cities Service Oil Co., on their Tom Closson federal permit. This well was spudded May 5, 1929, in the NE¼NW¼SE¼ sec. 6, T. 22 S., R. 36 E. The well was drilled with cable tools and after considerable difficulty in drilling through the "Big Gas" was finally completed May 29, 1930. Total depth was 4,237 feet, but the well was plugged back on account of water to 3,831 feet, from which depth it is still producing. This is the only well completed through the "Big Gas" in this field with cable tools. A water supply sufficient for rotary rigs was developed, and all later drilling has been by the rotary method. In spite of the fact that rotary rigs have been used, several wells have blown out while drilling through the "Big Gas" zone. At the close of 1941 a total of 83 holes had been drilled. Of this number 75 were oil wells; five were gas wells, three of which were shut in and two of which were connected with the Lea County Water Co.'s gas line; and two are dry holes. One former producer has been plugged and abandoned. Fifty-eight wells are capable of producing top allowable, and 17 are marginal.

Practically all of the production has been prorated on a straight acreage basis. Due to limited pipe line facilities very little oil was taken from the few wells drilled in the field before it was prorated. In 1941 two pipe lines were serving the field. The Texas-New Mexico Pipe Line Co. takes the major part of the oil and the Shell Pipe Line Co. a small amount.

STRATIGRAPHY: RECENT AND TERTIARY

No rock crops out in this field, the surface being covered with windblown sand of Recent age. The underlying Tertiary rocks, which have a thickness of about 175 feet, in general consist of buff to pinkish calcareous sandstone, in most places very poorly cemented.

TRIASSIC

Triassic red shale and sandstone about 1,300 feet thick underlie the Tertiary. Few samples are saved in drilling through this zone and even fewer have been examined, so that very little detail is known.

Chinle.—The upper 750 feet of the Triassic consists chiefly of red shale. It has been correlated as Chinle by DeFord and Lloyd.2

Santa Rosa.—A 250-foot thickness of sandstone with a few red shale breaks, lying directly below the Chinle, should probably be considered as Santa Rosa. This sandstone carries considerable water.

Tecovas.—Below the Santa Rosa are red shale, silt, and sandstone which characteristically contain some mica. These beds, which are about 300 feet thick, belong in the basal Triassic Te-

[2] DeFord, R. K., and Lloyd, E. R., West Texas-New Mexico symposium, Part 1 Editorial introduction: Bull. Amer. Assoc. Petrol. Geol., Vol. 24, No. 1, p. 4, Fig. 2, January 1940.

covas formation. It is difficult to differentiate between basal Triassic and upper Permian in rotary samples.

PERMIAN

Dewey Lake.—Below the Tecovas and above the Rustler anhydrite lies red shale of Dewey Lake age. The formation may be somewhat thicker than the 75 to 100 feet commonly assigned to it, but in the subsurface it is difficult to place the upper contact due to the fact that the diagnostic Tecovas mica may lag in rotary samples.

Rustler.—The Rustler formation, the top of which is commonly known in subsurface parlance as the "top of anhydrite," in this field is approximately 250 feet thick. The upper 100 feet is mainly anhydrite, some of which is limy ; in some places 10 to 20 feet of salt is present near the middle. Below the anhydrite is salt about 100 feet thick. The lower part, in general, consists of anhydrite with brown dolomite. In some places the brown dolomite in the basal part of the section is prominent.

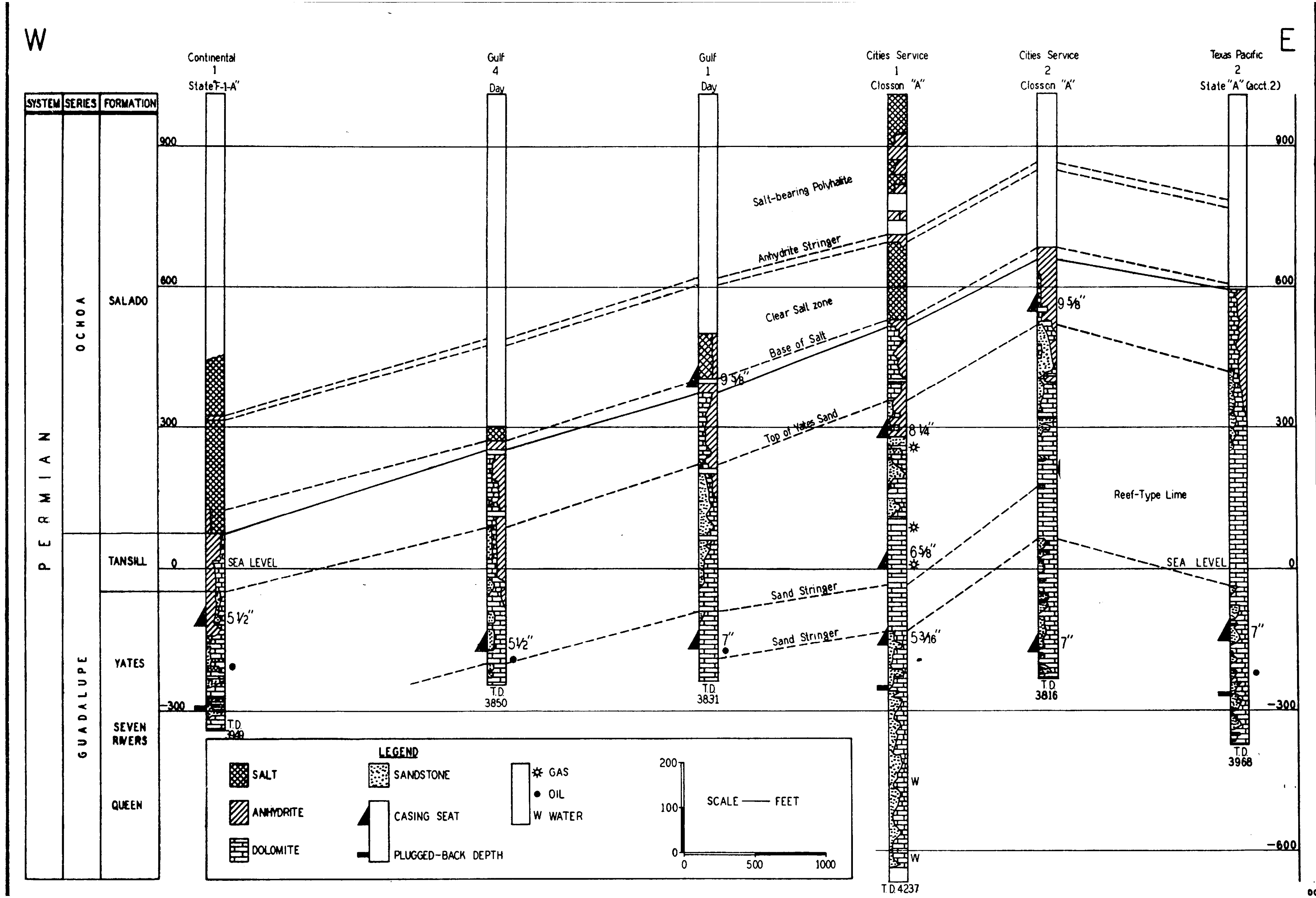
Salado.—Below the Rustler is the "Salt Section," which is approximately 1,300 feet thick. The upper 900 feet carries considerable polyhalite in places and several stringers of anhydrite. The lower part, which is predominantly clear salt bearing no poly-halite, is separated from the upper by a 30-foot bed of anhydrite. The basal 20 feet of the Salado is also anhydrite.

Tansill.—The Tansill formation, which ranges in thickness from 145 to 200 feet, is a body of brown dolomitic limestone with silt and anhydrite. In the west part of the field the top of the formation can usually be picked as the top of the brown dolomitic limestone. However, toward the east this horizon becomes less distinct. The differences in thickness assigned to the formation in the various wells is probably partly due to differences in the way samples were obtained. General stratigraphy of the Tansill and older beds is shown on the cross sections, Plates 32 and 33.

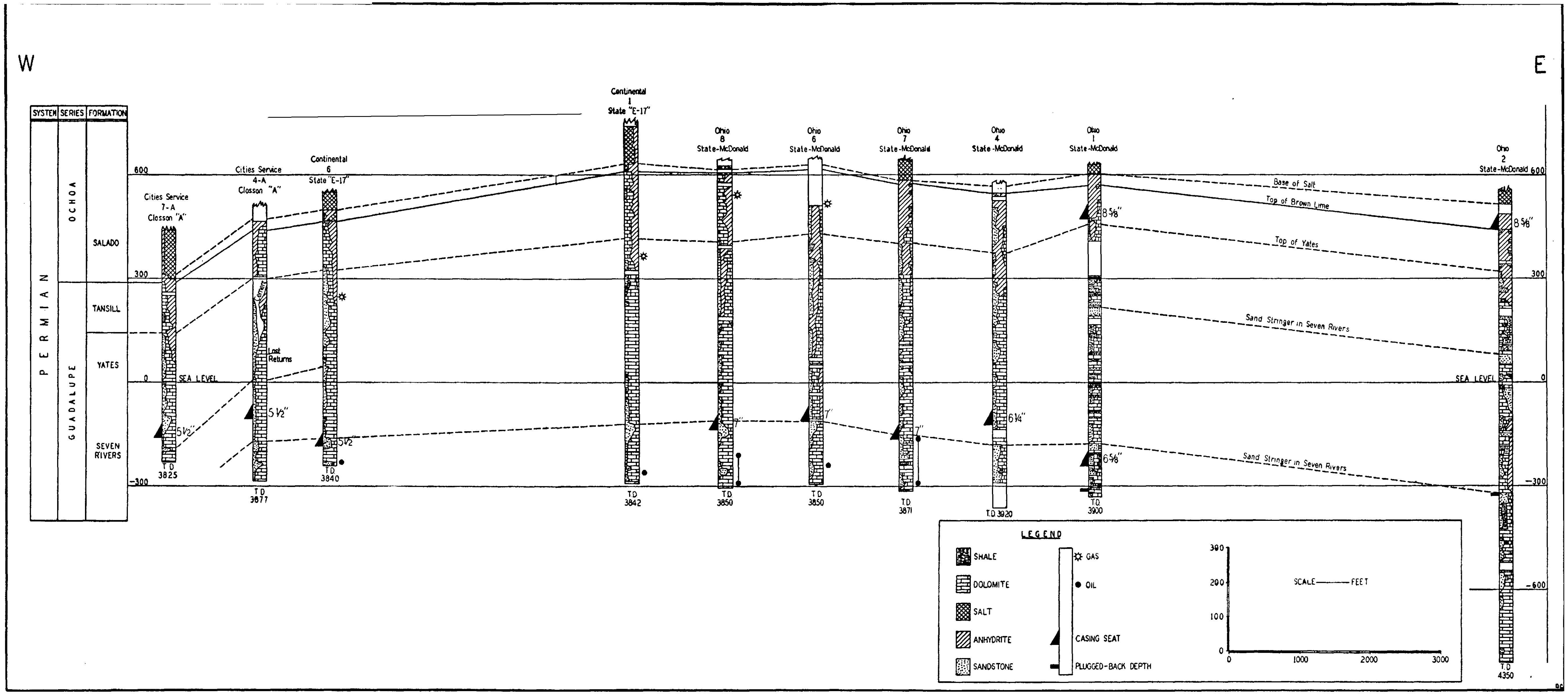
Yates.—This formation consists of sand, silt, anhydrite, and dolomitic limestone. The Yates, the top of which is in wide use by many geologists as a subsurface contouring horizon, is a gray sandstone, with frosted quartz grains generally appearing 20 feet below the top.

Seven Rivers.—Below the Yates is a section consisting chiefly of limestone and sand lenses, with a little anhydrite found in some wells in the upper part of the section. In this field this formation is probably about 600 feet thick. The pay in all wells is in the Seven Rivers formation.

Only one well, the Ohio No. 5 State-McDonald, has been drilled to sufficient depth to penetrate the section below the Seven Rivers. For this reason, the following stratigraphic descriptions are based entirely on samples obtained from this well.



West-east cross section at the north end of the South Eunice pool, Lea County. Along line B-B', Plate 21



West-east cross section at the south end of the South Eunice pool, Lea County. Along line C-C', Plate 21

Queen.—The strata below the Seven Rivers are very similar to those within it. It is believed that the Queen formation is about 400 feet thick in this area. The upper and lower parts of the formation carry considerable amounts of sand, whereas the middle part is predominantly limestone.

Grayburg.—This formation consists of about 300 feet of limestone with a little sand. No shows of oil or gas have been reported.

LEONARD SERIES

A thickness of approximately 1,500 feet of Leonard was drilled in the Ohio No. 5 State-McDonald. The San Andres formation at the top is predominantly limestone and is 1,200 feet thick. A sandy zone occurs about 250 feet below the top.[3] Approximately 300 feet of the middle part of the San Andres is shaly and anhydritic. The top of the Glorieta sandstone was picked by Woods [4] on a sandstone break. Below the point picked as the top of the Glorieta is a 150-foot thickness of limestone carrying considerable sand, beneath which lies limestone 150 feet thick, with one sand break and a little anhydrite in the last 20 feet of samples. Apparently 250 to 300 feet of the Yeso formation was penetrated in the Ohio test.

STRUCTURE

Structural conditions in the South Eunice field are not reflected at the surface. While a general idea of the structure can be obtained from the attitude of the top of the Rustler anhydrite, the best markers are the top of the Tansill and the top of the Yates. Either of these markers is fairly easy to pick in this field, and, in general, lower sand-breaks seem to conform to them reasonably well.

Along the west edge of the field, extending in a direction slightly west of north, is the thick limestone section of the Capitan Reef. About three-fifths of the oil comes from this trend, with the major part of the pay being on its west flank. There is slight closure to the east. This feature is a continuation of the trend which produces in the Cooper and Jal fields of New Mexico and the Hendricks field of Winkler County, Texas. To the east is a small dome which formed in the lagoonal area back of the reef. About two-fifths of the production in the field is from this dome.

RESERVOIR ROCKS

Most of the oil and gas in the South Eunice pool is found in a white crystalline dolomitic lime which in some places is very porous. A few wells east of the reef front have been completed in sandstone beds. The wells with the largest potentials have generally been found on the west flank of the reef. The upper part

[3] This is undoubtedly the Lovington member of the San Andres formation, named by Hills. See pp. 270-271. this bulletin.—Compiler's note.

[4] Woods, E. Hazen, South-north cross section from Pecos County through Winkler County, Texas, to Roosevelt County, New Mexico: Bull. Amer. Assoc. Petrol. Geol., Vol. 24, No. 1, pp. 29-36, Fig. 1, January 1940.

of the crystalline lime is more cavernous than the lower part. For this reason some bad blow-outs have occurred when the upper zone was encountered high enough to be in the gas cap. Where this zone was encountered below the gas-oil contact, wells were completed with large natural flow.

The gas-oil contact and the oil-water contact seem to follow the sea-level datum more nearly than stratigraphic lines, but do not conform entirely to either of them. In the west part a reasonable gas-oil ratio can generally be obtained by setting casing at 160 feet below sea level. The datum at which water is encountered varies considerably. In general, on the west side of the field most wells have been completed at a depth of 230 feet below sea level without encountering water. In the eastern lagoonal area many wells have been drilled more than 300 feet below sea level without encountering water.

FLUIDS

Although gas from some of the upper shows seems to be sweet, most of the gas encountered in and below the blow-outs contains sulfur and is fairly sour. All of the oil is sour. Its gravity, which varies somewhat between wells and in different parts of the field, ranges from 31° to 33°.

Many of the wells are now making water, although not in large quantities. Some have produced water from the beginning and others have started since completion. The west part of the field has a rather effective water drive, and also a gas drive which no doubt will aid considerably in the production of the oil.

DRILLING AND PRODUCTION METHODS

The discovery well was drilled with cable tools but all later drilling has been with rotary equipment. Both heavy and light rotary equipment have been used. The majority of the rigs use steam power, due to its advantages in case of a gas blow-out, but some Diesel rigs are used.

Different companies have used different casing programs. The tendency has been to use less and smaller casing on recent wells. In the original program, 12½-inch casing was cemented in the redbed section from 250 to 300 feet. The second string, $9^5/_8$-inch, was cemented below the base of the salt from 3,200 to 3,300 feet. A 7-inch oil string was cemented at about 3,750 feet. Economy was effected by substituting 10¾-inch for 12½-inch casing, $7^5/_8$-inch for $9^5/_8$-inch, and 5½-inch for 7-inch.

Satisfactory results have been obtained through a method of completion inaugurated by the Texas Pacific Coal and Oil Co. for some of their wells on the west side of the field. After the 10¾-inch casing was cemented in the redbeds at a depth of about 400 feet, a 5½-inch oil string was set through the pay to total depth and then gun-perforated in the pay zone.

Many of the wells have been completed on natural flow. The majority of those not completed naturally were acidized. A few wells in the eastern part of the field, especially those completed in sand, have been shot with nitroglycerin. Most of the wells are flowing. Only a very few, on the eastern side, are on the pump.

Drilling costs have varied considerably for three reasons. First, the development has extended over a long period of time and actual drilling costs have decreased considerably. Second, the casing program has been changed. Third, the amount of trouble in drilling through the "Big Gas" has a direct bearing on the amount, quality, and cost of drilling-mud required. With the exception of the discovery well, which cost approximately $125,000.00, the early wells drilled with rotary equipment cost about $50,000.00. An extra $10,000.00 was spent on those wells which blew out. Costs on later wells run from $20,000.00 to $25,000.00 per well.

LAND OWNERSHIP

Practically all of the acreage in this field is controlled by major companies, of which the Federal unit and Continental are most prominent. The Federal unit, which is operated by Continental, is composed of Continental, Atlantic, Stanolind, and Standard of Texas. Other companies in order of their interest in the area are as follows: Ohio, Cities Service, Texas Pacific, Gulf, Western Gas, Repollo, Mid-Continent, Tide Water, Sun, Atlantic, and Skelly. Approximately 44 percent of the leases are on State land, 29 percent on Government land, and 27 percent on patented land.

PRODUCTION

Total oil production from the South Eunice field through December 31, 1941, was 4,659,706 barrels. Production during 1941 was 961,631 barrels.

FUTURE POSSIBILITIES

Some undrilled 40-acre tracts in this field will probably be productive from the present pay zones. As only one test has been drilled below the present productive zones, little is known regarding deeper possibilities. Deeper zones, however, in the eastern part of the field are worthy of consideration. The lower Permian, as well as sedimentary formations below the Permian, are considered possibilities.

SOUTH LOVINGTON POOL

JOHN M. HILLS[1]
Midland, Texas

LOCATION

The South Lovington pool lies in central Lea County, ten miles northwest of Hobbs. (See map, Plate 14.) It comprises 1,760 acres proved for oil production and 80 acres for gas production, centering about the corner common to Tps. 16 and 17 S.

[1] Consulting geologist.

and Rs. 36 and 37 E. The Texas-New Mexico Railroad and State Highway 18, connecting Hobbs and Lovington, cross the northeast part of the pool.

HISTORY

The first well drilled in the pool was the Westmount No. 1 Amerada-State, in sec. 12, T. 17 S., R. 36 E., which was spudded with rotary tools in November, 1938. It encountered numerous shows of gas in several porous dolomites and sandstones throughout the Whitehorse group. At a depth of 3,956 feet, gas was gauged at 7,000,000 cubic feet per day; as it was under high pressure it caused a number of blowouts and fishing jobs. The well was finally bottomed at 3,986 feet in the upper part of the Queen sandstone. Here the gas was gauged at 12,800,000 cubic feet per day open flow, with a shut-in pressure of 2,000 pounds per square inch. Due to lease requirements, the well was completed at this depth on December 14, 1938. The gas was used for fuel in later drilling operations.

The first two oil wells completed in the pool were the Amerada No. 1-LA State, a diagonal northwest offset to the Westmount well, and the Skelly No. 1-N State two miles to the north. In January, 1939, both of these wells were completed as small flowing producers from the upper part of the San Andres dolomite, some 900 feet below the horizon at which the Westmount well was completed. A third well, the Stanolind No. 1-E State, north offset to the Westmount well, found neither oil nor gas in the San Andres and was plugged back to make a gas well in the upper Queen sand.

Lease requirements forced fairly rapid development of the pool throughout 1939 and the first part of 1940. By the end of March, 1940, 36 wells had been drilled. Most of them were rather small producers, the average daily potential approximating 400 barrels. The majority of the wells had to be shot with nitroglycerin or treated with acid in order to attain flowing production. Therefore, when lease requirements had been met there was no further immediate development. In the second half of 1941, six wells were completed, five of which were on the west side of the pool. On January 1, 1942, 40 oil wells and two gas wells were producing. Of the oil wells, eight were being pumped and two were being operated on gas lift. The remainder were flowing.

STRATIGRAPHY

The accompanying table gives a summary of the stratigraphy, which is similar to that of the Vacuum and Hobbs pools and is typical of the back-reef area of the Permian Basin.

Age		Formation	Lithology	Interval and Thickness	
RECENT			Caliche.	0-30	(30)
TERTIARY		Ogallala	Coarse sand and gravel carrying fresh water.	30-160	(130)
CRETACEOUS		(?)	Red and gray clays and marls	160-320	(160)
TRIASSIC		Chinle	Dark red shales and clays with thin chalky gypsum beds and lenses of gray sand. Few light-colored fresh-water limestones.	320-1590	(1270)
		Santa Rosa	Red sandstone.	1590-1730	(140)
		Tecovas	Orange-red shale with a coarse angular basal conglomerate.	1730-1820	(90)
PERMIAN	Ochoa	Dewey Lake	Orange-red hard sandy shale with some medium coarse red sand.	1820-1870	(50)
		Rustler	White crystalline anhydrite and brown crystalline dolomite.	1870-1960	(90)
		Salado	Halite with thin stringers of polyhalite and anhydrite. Cowden anhydrite member, 20 feet thick, 200 feet above base. Fletcher anhydrite member, 70 feet thick, at base.	1960-2900	(940)
	Guadalupe	Tansill	Anhydrite with interbedded salt.	2900-3015	(115)
		Yates	Sand with frosted quartz grains, interbedded with red shale, salt, and anhydrite. Brown porous dolomite in lower part carries gas.	3015-3280	(265)
		Seven Rivers	Largely anhydrite, with thin beds of gray and tan dolomite and a few sand stringers.	3280-3900	(620)
		Queen	Anhydrite interbedded with dolomite and sandstone. "Artesia red sand," 30 feet thick, at top. Thin bed of bentonite near base.	3900–4360	(460)
		Grayburg	Dolomite with interbedded anhydrite and sandstone.	4360–4650	(290)
	Leonard	San Andres	White to blue-gray crystalline dolomite in upper part; tan to brown finely crystalline oolitic dolomite below. Porous; carries oil. Lovington sandstone member, 30 feet thick, 100 feet below top.	4650–5050+	(400+)

A sandstone in the upper part of the San Andres formation is here named the Lovington sandstone member. Although it is found in nearly all wells in the pool, the type section is designated as that penetrated in the Skelly No. 3-0 State, 660 feet from the south line and 2,310 feet from the east line of sec. 31, T. 16 S., R. 37 E., at depths of 4,705 to 4,735 feet. The following description of the upper San Andres section in this well was made from cuttings on file at the Skelly Oil Co. office in Midland, Texas.

Sample Description of Lovington Member of San. Andres Formation in Skelly Oil Co. No. 3-0 State, Sec. 31, T. 16 S., R. 37 E., Lea County, New Mexico

Depth in Feet	Percent	Description
		GRAYBURG FORMATION
4600-10	60	tan crystalline dolomite
	40	finely sandy dolomite
		trace of pink dolomite
		SAN ANDRES FORMATION
4610-15	100	tan to pink finely crystalline dolomite
4615-30	100	tan finely crystalline dolomite
4630-35	100	tan crystalline dolomite, fairly porous
4635-45	100	tan crystalline dolomite, slightly porous
4645-50	60	tan finely crystalline dolomite
	40	fairly porous, oolitic dolomite
4650-55	100	tan crystalline dolomite, slightly oolitic
4655-65	100	tan to gray finely crystalline dolomite
4665-70	100	tan crystalline dolomite
		trace of porosity
4670-75	100	gray crystalline dolomite
		trace of porosity
4675-80	100	tan crystalline dolomite
		trace of porosity
4680-85	100	gray finely crystalline dolomite
4685-90	100	tan to gray crystalline dolomite
		trace of porosity
4690-95	30	tan crystalline dolomite
	70	slightly porous oolitic dolomite
4695-4700	100	tan crystalline fairly porous dolomite
4700-05	100	brown crystalline dolomite
Lovington Member 4705-4735		
4705-10	60	brown crystalline dolomite
	20	brown sandy dolomite
	20	fine gray sandstone
		trace of black shale
4710-15	90	brown to gray crystalline dolomite
	5	gray shale
	5	fine gray sandstone
4715-20	100	tan gray crystalline to finely crystalline dolomite
		trace of gray sandstone

4720-25	90	tan to gray crystalline to finely crystalline dolomite
	5	tan sandy dolomite
	5	fine gray sandstone
4725-30	100	brown to tan finely crystalline dolomite
4730-35	80	tan finely crystalline dolomite
	10	gray sandy shale
	10	gray fine sandstone
4735-40	100	brown to gray finely crystalline dolomite
4740-45	100	brown crystalline dolomite
4745-50	100	brown to gray finely crystalline dolomite

The interval from the top of the San Andres to the top of the Lovington member in the South Lovington pool ranges from 90 feet along the northeast-southwest axis of the pool to 150 feet in wells on the north and south edges. The surface of the San Andres is irregular, and its roughness indicates erosion in post-San Andres, pre-Grayburg time.

The Lovington member can be traced throughout all of northern Lea County and recognized in Gaines, Andrews, and Yoakum Counties, Texas. In some places the extreme variations in the interval between the top of this member and the top of the San Andres indicate considerable erosion and possibly the development of karst topography before the deposition of the Grayburg.

STRUCTURE

The accompanying subsurface contour map, Fig. 21, shows the structural form of the pool to be a quaquaversal dome. It lies on the north side of a deep structural depression known as the San Simon syncline. (See map, Plate 13.) Undoubtedly the structure is the result of the intersection of two anticlinal axes. One axis trends northwest from the Hobbs field across the San Simon syncline, while the other follows northeast along the north side of the syncline from the Vacuum field to the Wasson field in Yoakum County, Texas.

RESERVOIR ROCKS

The reservoir rock is porous dolomite in the San Andres formation. The pores are very fine and are scattered throughout the upper 150 feet of the San Andres. Oil stain and saturation are common throughout this interval, even in beds which have no visible porosity. The two gas wells are producing from the Queen formation of the Whitehorse group.

OIL AND GAS

The oil from this pool is moderately sour crude with an intermediate base and an average gravity of 34° A. P. I. Production for 1941 was 523,675 barrels, and total production of the pool to the close of 1941 was 1,180,941 barrels. The small amount of gas produced with the oil has a fairly high sulfur

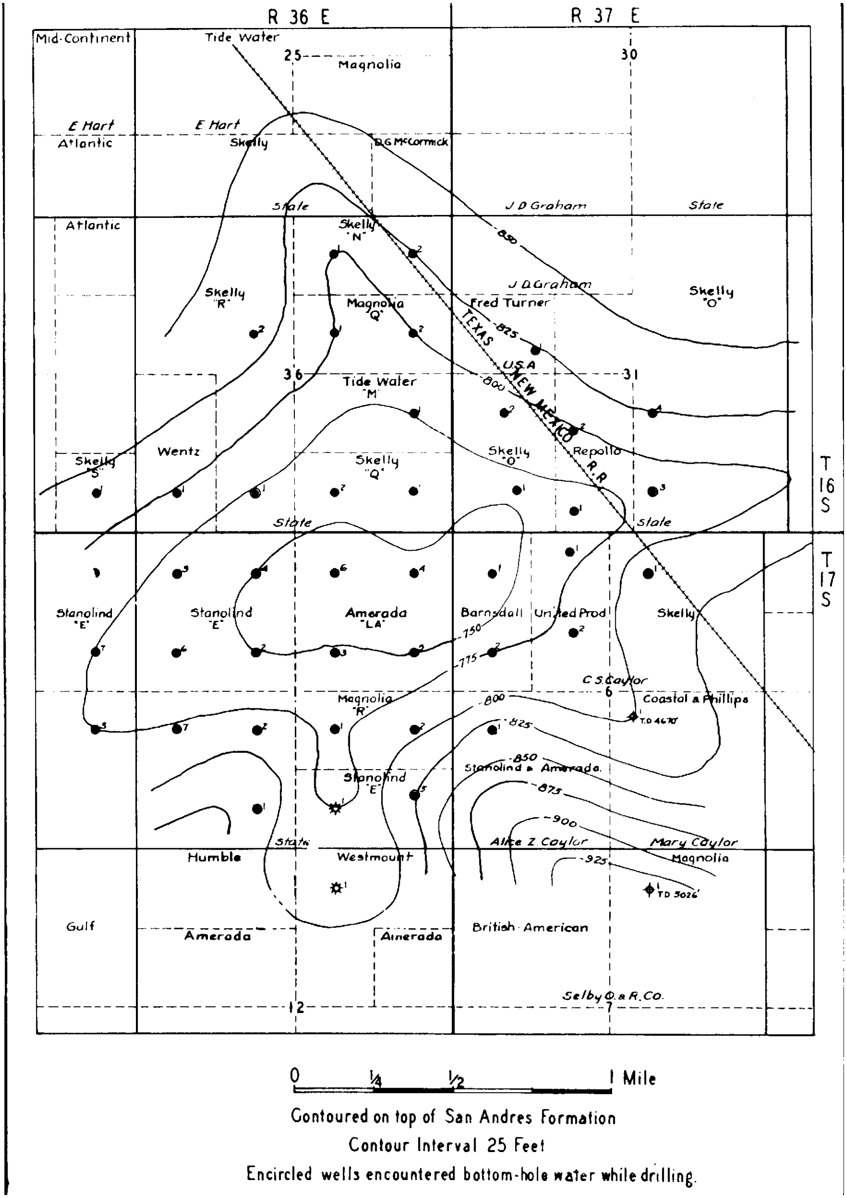


FIGURE 21.—Subsurface contour map of the South Lovington pool, Lea County.

content. The gas from the Queen sandstone is low in sulfur; all of it is used for fuel in drilling and for gas lift. The pool is served by a 5½-inch to 8-inch line of the Texas-New Mexico Pipe Line Co., which connects with the Monument station.

WATER

The four wells indicated by circles on the map found bottom-hole water during drilling, all at more than 1,130 feet below sea level. That some wells were drilled below this datum without encountering water is probably due to poor porosity below the water .level. On December 31, 1941, only five wells in the pool were reported to be making water, all in small amounts. The water is similar to that found in most of the dolomite pools of the Permian basin. Following is a typical analysis.

Water Analysis, South Lovington Pool

Substance	Parts per Million
Na	17,952
Ca	1,578
Mg	193
SO_4	3,829
Cl	27,570
HCO_3	1,122
H2S	Trace
Total solids	52,244

BOTTOM-HOLE PRESSURE

The first bottom-hole pressure survey of this pool, made between May and July, 1940, showed an average of 1,302 pounds per square inch at 800 feet below sea level. By December, 1941, this had declined to 1,191 pounds per square inch, a drop of 89 pounds per million barrels of oil produced.

DRILLING PRACTICE

Drilling is done entirely with rotary tools. A three-string casing program is generally followed. The surface pipe, of 10-inch to 13-inch outside diameter, is set and cemented at about 250 feet to protect the shallow fresh-water sands. The intermediate string of 7-inch to 10-inch casing is commonly cemented in an anhydrite bed in the Yates section at 3,000 to 3,100 feet, in order to protect the hole from the high-pressure gas in the Whitehorse. A few holes have intermediate strings set in the Rustler formation at 2,000 to 2,100 feet. The production string is cemented at or just above the top of the San Andres, from 4,500 to 4,600 feet. Although 7-inch casing for this string was used on the earlier wells in the pool, the tendency is now to use 5½-inch casing. All wells are produced through 2-inch tubing.

LAND OWNERSHIP

Most of the land in the pool is owned by the State of New Mexico. The 240-acre Caylor tract in sec. 6, T. 17 S., R. 37 E., is the only patented land in the pool. Principal operators are Amerada, Magnolia, Skelly, and Stanolind.

FUTURE POSSIBILITIES

The future possibilities of the pool are difficult to evaluate. As porosity in the dolomite dies out rapidly away from the San Simon syncline, very little extension to the north can be expected. To the south the structure falls off abruptly into the syncline. Therefore, any extensions to the pool can probably be expected either on the northeast or on the southwest. However, so far as depths now being exploited are concerned, limited porosity may confine the pool to essentially its present limits.

In view of the discovery of oil in the lower part of the Permian section in the Wasson field some 25 miles to the east, it is entirely possible that oil may be found in the deeper Permian beds at South Lovington. The pre-Permian possibilities are unknown, but cannot be ruled out entirely.

VACUUM POOL

J. C. WILLIAMSON[1]

Midland, Texas

LOCATION AND SURFACE FEATURES

The Vacuum pool is located in central Lea County on the broad plains known as the Llano Estacado. It covers the southeast part of T. 17 S., R. 34 E., the south half of T. 17 S., R. 35 E., the northeast part of T. 18 S., R. 34 E., and the northwest part of T. 18 S., R. 35 E. (See map, Plate 14). The surface of the field, like that of the Llano Estacado in general, is essentially flat; there is a regional eastward surface slope of from 15 to 20 feet per mile. No structure is indicated from surface topography.

GENERAL HISTORY

Exploration resulting from discoveries in Winkler County, Texas, in 1925, and in the Maljamar district in 1926, brought on the drilling of the Socony-Vacuum No. 1 State in sec. 13, T. 17 S., R. 34 E., in 1928. The well was drilled to 4,900 feet with cable tools, and was completed in 1929 for 120 barrels of oil per day pumping. Due to the disappointing potential, the lack of an outlet by either rail or pipe line, and also the condition of the oil business in the years that followed, eight years elapsed before another well was drilled.

The Magnolia No. 1-G State, in sec. 24, T. 17 S. R. 34 E., was completed in May, 1937, for 90 barrels of oil per day pumping. This production was attained only after treatment with 14,000 gallons of acid and shooting with 580 quarts of nitroglycerin. The well encountered water at 4,900 feet. Meanwhile the Magnolia No. 2 State-Bridges was being drilled and in September came in for 1,224 barrels of oil per day natural.

[1] Geologist, Phillips Petroleum Company.

This was the beginning of a rather spectacular development that lasted into 1941. In 1938 the Skelly Oil Co. and The Texas Co. drilled semi-wildcats to the south of the Magnolia wells and opened up the main structure. The Phillips Petroleum Co., drilling on core-drill information, extended the pool three to four miles east and northeast with the Santa Fe No. 6 and Santa Fe No. 7 wells.

The Texas-New Mexico Pipe Line Co. completed a line into the pool in the spring of 1938. By June, 1941, 330 producing wells had been drilled and the limits of the pool fairly well defined. Almost all of the major companies operating in the southwest have taken part in the development. The three leading operators are the Magnolia Petroleum Co., The Texas Co., and the Phillips Petroleum Co.

STRATIGRAPHY

As the thickness, and to some extent the lithology, of the formations change from east to west in the Vacuum pool, only a generalized geologic section will be discussed.

POST-PERMIAN

The surface is covered by a thin layer of recent soil underlain directly by about 30 to 50 feet of caliche. Below the caliche is a buff yellow sand of Pliocene age known as the Ogallala. It contains fresh water and is about 200 feet thick. Beneath the Tertiary are 900 to 1,000 feet of Triassic sand and shale of the Chinle and Santa Rosa formations (Dockum group). The Santa Rosa bears fresh water and is about 200 feet thick.

PERMIAN

Dewey Lake.—The Dewey Lake, uppermost formation in the Whitehorse group, is composed of red sand and red sandy shale, 400 to 450 feet thick.

Rustler.—The first important marker in the field is the Rustler formation. It consists in the upper part of anhydrite with poorly developed dolomite stringers, while the lower 150 feet is largely salt and sand. Its thickness is 250 feet.

Salado.—Below the Rustler is the Salado formation, which consists largely of salt with persistent layers of anhydrite, potash, and sand; it is 850 to 900 feet thick, and extends down 20 to 25 feet below what is commonly called the base of the salt in this field.

Tansill.—The Tansill, immediately below the Salado, consists of 120 to 130 feet of salt, anhydrite, and poorly developed dolomite.

Yates.—The Yates, the second good marker in the field, underlies the Tansill and is made up of red sand, anhydrite, and dolomite 350 feet thick. Sand is dominant in the upper part of the formation and contains characteristic frosted quartz grains.

Some oil is found in the lower dolomites, but it is not of commercial value.

Seven Rivers.—The Seven Rivers, beneath the Yates, is 500 to 600 feet thick and is almost entirely anhydrite. It contains some sand, and, toward the base, thin dolomite beds.

Queen.—The top of the Queen formation is characterized by 40 feet of red sand with frosted quartz grains, known as the "Artesia red sand." It is an excellent marker. The whole formation is 370 feet thick and is made up of sand, anhydrite, and dolomite.

Grayburg.—The Grayburg, below the Queen, consists of dolomite and gray sand 360 feet thick. Its top is the "top of the solid lime" in this field except on the north flank, where the upper 100 feet of the formation is mostly anhydrite. The dolomite is white to brown. The elastics in the formation distinguish it from the underlying San Andres dolomite. There are some oil shows, best developed on the south flank, whose value is yet to be determined.

San Andres.—The base of the sandy phase of the dolomite section is the base of the Whitehorse group and top of the San Andres. However, the Vacuum field must be considered a special case, as it is in the zone of transition between the San Andres dolomite and the Delaware sand. In the south part of the field, the San Andres dolomite has an abundance of sand and many frosted quartz grains. Pores in the dolomite contain the oil from which this field is getting production. The deepest producing wells penetrate about 350 feet of the San Andres. Three general zones of porosity are recognizable; the upper, about 50 feet from the top, is the best developed.

STRUCTURE

During late San Andres time, the Vacuum field was undoubtedly a high area, trending east-west, along which there was probably abundant animal life and deposition of almost pure dolomite. Evidence of erosion of the top of the San Andres is shown by its rough, channeled surface on which the Grayburg rests. Furthermore, a red shale and sand body lies at the base of the Grayburg, toward the landward side and off the structure, which laps up against the north and west flanks. Folding began in Whitehorse time with pressure from the east and south. Probably the most disturbance occurred during deposition of the Seven Rivers, as this formation shows approximately 100 feet of thinning over the structure. (See cross section, Plate 35.) Post-Permian movements, as shown by the Rustler, caused considerable uplift and gave the field its present shape. (See map, Plate 34.) Uplift to the west produced a regional dip of approximately 50 feet to the mile, but this uplift had very little to do with the shaping of the field.

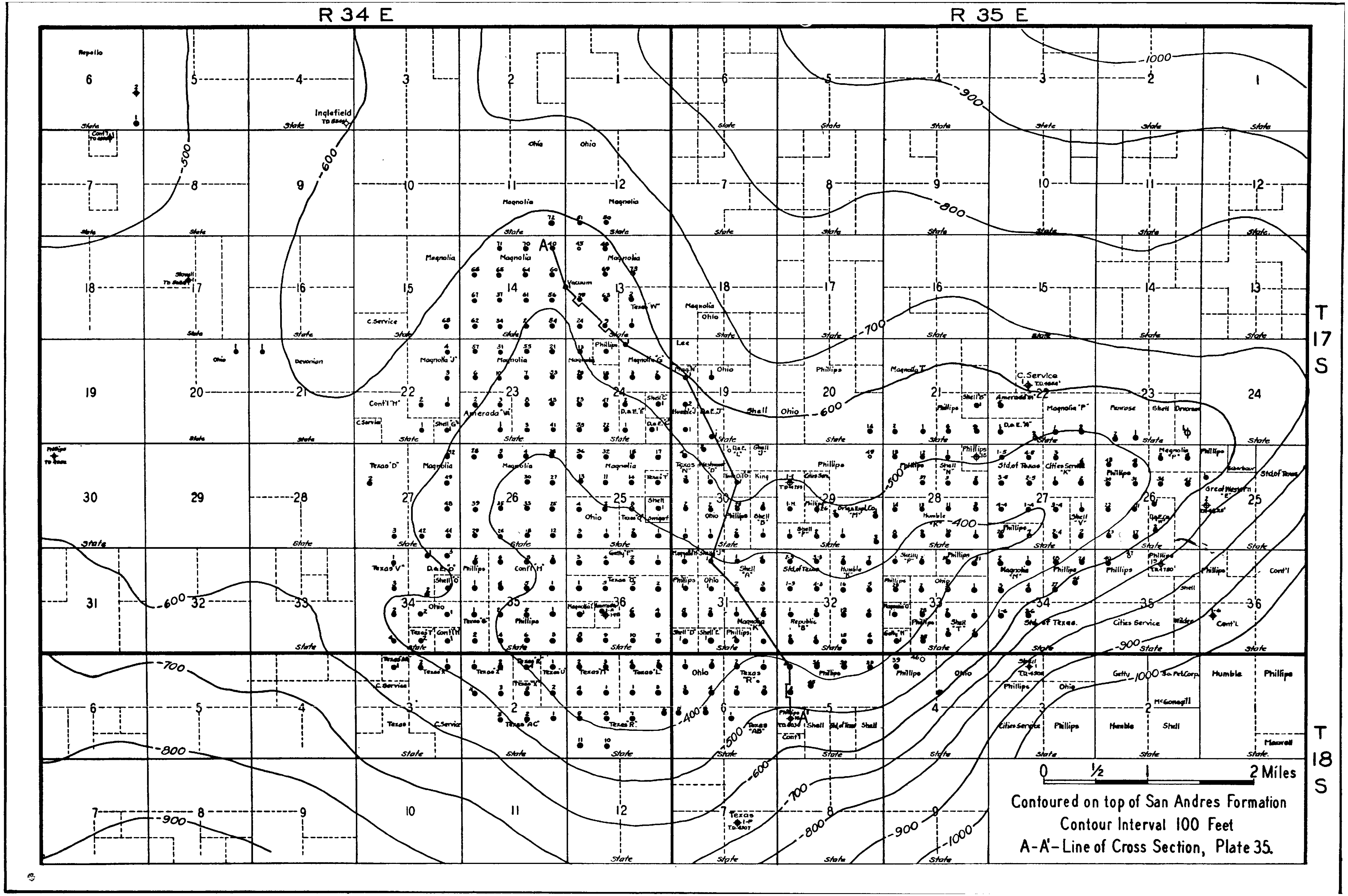
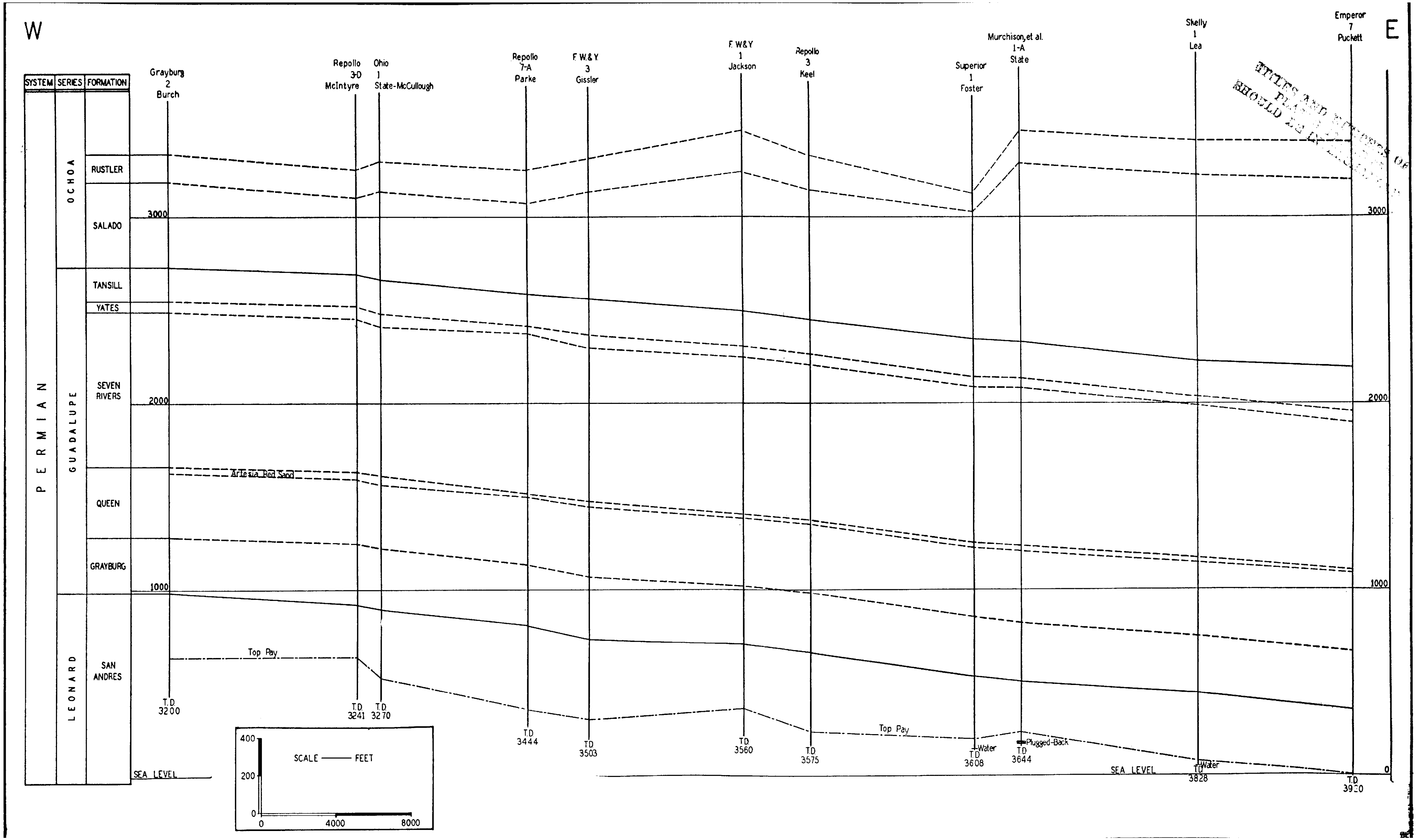


PLATE 34--Subsurface contour map of the Vacuum pool Lea County



North-south cross section of the Vacuum pool, Lea County. Along line A-A', Plate 34

OIL

Oil from the Vacuum field is brownish green in color and has a paraffin base. A general description follows.

General Crude Test of Oil from the Vacuum Pool

Gravity	38.7° A. P. I.
Basic sediment and water	Trace
Sulfur	0.77 percent
Pour point	15° F.
Saybolt Universal viscosity at 70° F.	40 sec.
at 100° F.	36.2 sec.
Conradson carbon residue test of still residue	8.3 percent
Initial boiling point of crude	82° F.

GAS

The approximate average gas-oil ratio for the Vacuum pool in June, 1941, was 550/1. This is only slightly above the solution ratio. No gas cap exists in this pool, and lack of gas is likely to become a problem. Many wells scattered over the field and especially along the edges are already on the pump. Though there are a few small gas shows in the Grayburg sands and dolomites, they are not important; the source of the gas, like that of the oil, is the San Andres dolomite. An analysis of the gas is as follows:

Analysis of Gas from the Vacuum Poole

Component	Mol Percent
CO_2	2.46
N_2	13.16
C_1	34.48
C_2	19.18
C_3	17.29
C_4	8.08
C_5	3.96
C_6	.93
C_7	.44
Total	99.98

WATER

A survey on June 1, 1941, revealed that 36 wells of the Vacuum pool were producing water ranging as high as 50 percent. The average percentage, however, was less than one percent. Many wells have been drilled into the water zone and plugged back, but as yet water is not a major production problem in this field.

The oil string, set somewhere in the Grayburg, cuts off all water except that in the San Andres. The depths of the water surface below sea level range considerably; the average is 675 to 725 feet. Porosity and permeability of the lime near the bottom of the hole determine whether a given well will make water or not. For example, the Magnolia No. 1-G State, second well to be

[2]Temperature 55° F.; pressure 13 lb. barometric.

drilled in the pool, did not reach water until a depth of 880 feet below sea level was reached. The dolomite for 200 feet above this horizon is too dense to contain water. In some cases on offset wells the shallower of the two wells will produce water while the deeper is water-free.

The field is thought to be under a water drive from the east and southeast. Not much evidence of encroachment from other directions is indicated. The water is spoken of as sulfur water. The following is an average analysis of water from five wells:[3]

Average of Five Water Analyses, Vacuum Pool

Substance	Parts per Million
Na and K	38,486
Ca	3,433
Mg	930
Cl	65,669
HCO_3	507
SO_4	3,025
Total solids	112,050

DRILLING AND PRODUCTION METHODS

The first three wells of the pool were drilled with cable tools but all others have been drilled with rotary equipment. The general procedure is to drill through the red shale and sand and set first pipe in the Rustler; the hard anhydrite furnishes a good casing seat. The only other string is generally located 30 to 40 feet below the top of the solid dolomite of the Grayburg. Seven-inch casing is in common use for this production string. In some wells the string is not cemented until the oil zone has been tapped and operators are sure of production. Water or light mud is used as a drilling fluid except when drilling-in, at which time oil or a heavy mud is used.

Most of the wells begin flowing soon after the hole is swabbed, and are completed for natural flow. A few wells which penetrated "tight" sections have been treated with acid, and some have been shot. Such wells are generally located on the back or north flank of the fold. Usually only 200 to 300 gallons of quick-acting acid are used. The results are varied. In some cases both acid and shot have failed, leaving dry or nearly dry holes surrounded by good production.

Potentials over the field are extremely varied, ranging from 2,170 barrels of oil per day made by the Magnolia No. 1-I State, sec. 36, T. 17 S., R. 34 E., to practically dry holes. The average well, however, has an initial daily production of about 450 barrels. This figure is usually determined by using a 6- to 8-hour test as a base.

LAND OWNERSHIP

The Vacuum pool is located entirely on land owned by the State of New Mexico. Various permits are owned by individuals,

[3] Phillips Nos. 17, 19, and 28 Santa. Fe, and Shell Nos. 2-F and 1-U State.

however, and these have in most cases been released to major operators in the field.

PRODUCTION

Before January, 1938, only 14,433 barrels of oil had been taken from the pool. By June 1, 1941, after 330 producing wells had been completed, 10,387,000 barrels had been recovered. The monthly production at this time was over 400,000 barrels. Production for 1941 was 4,800,608 barrels. Only a comparatively few wells were added to the field during this year. Over 14,000 acres are estimated to be productive. This gives an average recovery of approximately 948 barrels per acre on December 31, 1941.

Original bottom-hole pressure of the field is estimated at 1,660 lbs. In June, 1941, the average pressure was 1,245 lbs., showing a decline of 415 lbs. These figures give a drop in bottom-hole pressure of 40 lbs. per million barrels of oil recovered. Considering the undersaturated condition of the oil, this is not an exceptional drop; in fact, it is not as much as was expected. A water drive from the south and southeast is believed to be a major factor in keeping up the pressure.

Estimates of ultimate recovery per acre for the Vacuum pool are varied and represent a wide range of figures. The extreme differences of porosity and oil zone thickness over the field make figures on one section extremely different from those on another. Most of the oil wells will have to be pumped unless arrangements for repressuring can be made.

WEST EUNICE POOL

ROBERT L. BATES

LOCATION

The West Eunice pool lies approximately midway between the Lynch and Eunice fields. All the wells so far drilled are in the east half of T. 21 S., R. 34 E., and in the west half of T. 21 S., R. 35 E. The west half of T. 20 S., R. 36 E., although it contains no wells, is included in the West Eunice pool by the Oil Conservation Commission. (See map, Plate 14.)

HISTORY

The first productive well in the pool was drilled by the Empire Gas and Fuel Co. (now Cities Service Oil Co.) in 1928. This well, the No. 1-B State, was located in the NW1/$_4$ sec. 8, T. 21 S., R. 35 E. Initial production was 100 barrels of oil per day, with some water, from a total depth of 3,835 feet. After producing an estimated 60,000 barrels of oil, the well was plugged and abandoned in June, 1934.

In the ten years following discovery, a number of unsuccessful attempts were made to secure oil. It was not until late in 1938 that commercial production was found in the Wilson Oil Co. No. 1

State, in the NE¼ sec. 7, T. 21 S., R. 35 E. This well was completed for an initial production of 492 barrels of oil daily from a total depth of 3,813 feet. Seventeen more producers were drilled, mostly during 1940 and 1941, as well as some five dry holes. Drilling was still going on in 1942. All development has been by the Wilson Oil Co.

STRATIGRAPHY AND STRUCTURE

The section penetrated in the West Eunice pool is very similar to that of the Lynch pool (see pages 238 to 241).

Structurally the West Eunice pool is a northeast-trending series of low highs. (See map, Fig. 22.) These highs are situated on the Capitan Reef and probably represent depositional "bumps" rather than true anticlines. Structural similarity to the Lynch, Salt Lake, Halfway, and Getty-Barber areas is suggested.

RESERVOIR ROCKS AND FLUIDS

Oil at West Eunice occurs in porous sandy limestones of the upper Seven Rivers formation. Considerable gas is found in the overlying Yates formation, but no commercial quantities of oil.

The oil is sour, but its sulfur content averages lower than

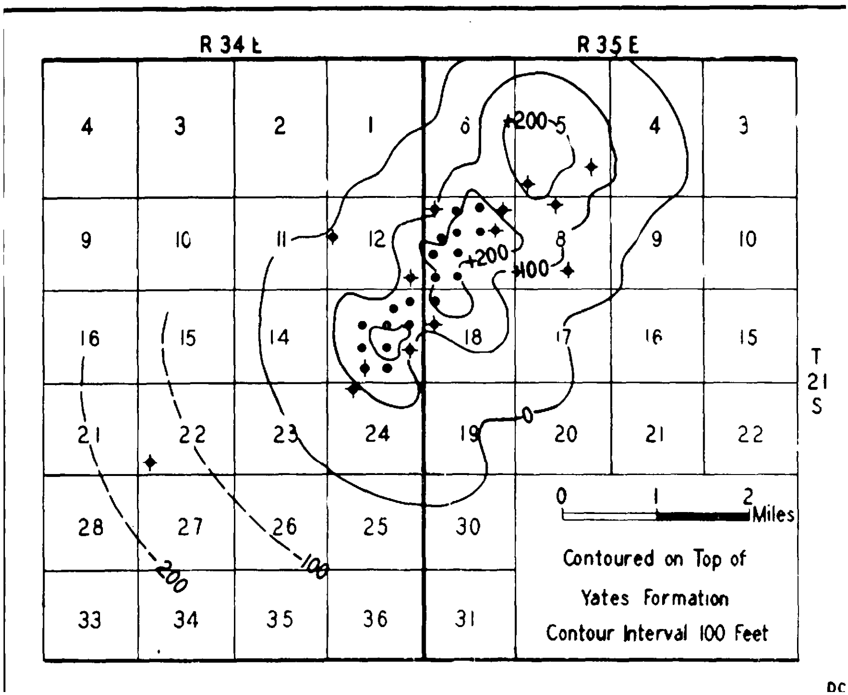


FIGURE 22.—Subsurface contour map of the West Eunice pool, Lea County.

that of the oil at Eunice and Monument. The average gravity is about 31° A. P. I. An analysis of oil from the West Eunice pool follows.

Analysis of Oil from Wilson No. 1 State, NE¼ Sec. 7, T. 21 S., R. 35 E., West Eunice Pool

Gravity	34.7° A. P. I.
Sulfur content	1.61 percent
Specific gravity	0.851

Distillation

Percent	Degrees Centigrade
0 to 10	51 to 108
10 to 20	108 to 151
20 to 30	151 to 198
30 to 40	198 to 245
40 to 50	245 to 295
50 to 60	295 to 338
60 to 70	338 to 368

30 percent residue

Fraction	Percent
Gasoline	36.6
Furnace oil	18.5
Gas oil	2.0
Residual	42.9
Total	100.0

A water drive, apparently from the north and east, has affected five producing wells in sec. 7 of the eastern township. In all other wells the recovery agency is gas; gas pressure at the casing-head runs as high as 1,300 pounds per square inch.

DRILLING AND PRODUCTION METHODS

Three of the early wells were drilled on contract, with rotary equipment. Early in 1939 the Wilson Oil Co. put in a cable-tool outfit with which the remainder of the wells have been drilled. A surface string of 16-inch casing is cemented at an average of 110 feet, and an oil string of 7-inch casing at an average of 3,500 feet. It has been found that treatment with acid is not effective. Ten of the wells have been shot with nitroglycerin. Production is through 2-inch and 2½-inch tubing. Drilling costs, including everything except surface equipment, have run about $4.00 per foot.

PRODUCTION

Initial productions have ranged from a few hundred barrels per day to 5,000. There are 18 producing wells, of which eight flow and ten are on the pump. Some water is produced in the pumping wells; about 3.6 barrels of water were produced in 1941 per barrel of oil. Oil production for 1941 was 165,287 barrels; cumulative production to the end of 1941 was 377,377 barrels. Yield per acre is about 468 barrels.

Miscellaneous Structures in the Southeast Area

Name	Location T.-S.	Location R.-E.	Surface Formation	Remarks
CHAVES COUNTY				
Black Hills anticline	17	20	San Andres	Untested.
Bluewater anticline	17	16	San Andres	Untested.
Dunken dome	17	18	San Andres	The Texas Co. No. 1 State-Wilson; T. D. 4,900 feet; dry. Formation bottoms: San Andres, 710; Glorieta, 780; Yeso, 2,775; Abo-Hueco to T. D. Gas show reported in top Abo.
Elkins anticline	8	27	Quaternary	Colorado Gas & Fuel Co. No. 1 Campbell Hill; T. D., 5,040 feet; dry. Shows of oil and gas reported.
Manning anticline	14, 15	17	San Andres	Arkansas Fuel Co. No. 1 Manning; T. D. 3,380 feet; dry.
Twin Mounds anticline	6	27	Quaternary	Shallow well; T. D. 665 feet.
Y-O Overthrust anticline	16-18	18-20	San Andres	Untested.
DE BACA COUNTY				
Buffalo Creek anticline	1	27	Triassic	Navajo Oil Co. No. 1 McAdoo; T. D. 5,860 feet ; dry.
EDDY COUNTY				
Big Eddy anticline	22	29	Rustler	Stanolind No. 1 Duncan; T. D. 3,658 feet; dry. Penetrated 200 feet of Delaware Mountain group.
Carlsbad domes	21, 22	6	Capitan	Small depositional structures. Ohio No. 1 Tracy; T. D. 5,805 feet; dry. Penetrated Delaware Mountain group and 875 feet of Bone Spring limestone.
Jones anticlines	21, 22	25	Carlsbad	Small depositional structures. Untested.
McKittrick domes	22, 23	25	Carlsbad	Small depositional structures. Untested.
Texas Hill anticline	22	21	San Andres	Estimated 200 feet of closure. Untested.
LINCOLN COUNTY				
McKnight anticline	12, 13	18	San Andres	Estimated 300 feet of closure. Untested.
Picacho anticline	11	18	San Andres	National Exploration Co. No. 1 Picacho; T. D. 2,191 feet; dry. Granite or arkose at bottom.
OTERO COUNTY				
Dog Canyon anticlines	24-26	19-20	Goat Seep	Untested.
ROOSEVELT COUNTY				
Pomeroy anticline	1	30	Ogallala	Steinberger et al. No. 1 State; T. D. 4,510 feet; dry.

ACKNOWLEDGMENT

The information on which this report is based has been furnished by Mr. Francis C. Wilson, president of the Wilson Oil Co., to whom the writer hereby expresses his appreciation.

OTHER PRODUCTIVE AREAS IN LEA COUNTY

Brief descriptions of several small productive areas in Chaves, Eddy, and Lea Counties are given on the chart, Plate 20. Areas in Lea County include Caprock, North Maljamar, Skaggs, and South Maljamar.

MISCELLANEOUS STRUCTURES IN THE SOUTHEAST AREA

A number of anticlinal folds have been found in the area of bedrock exposures west of the Pecos River. (See map, Plate 4.) Some of these structures have been drilled, but no commercial amounts of oil or gas have been found. The table on page 282 gives the available information on a number of these structures. A few anticlines east of the Pecos are also listed.

MEDIAN AREA[1]

ROBERT L. BATES

GENERAL GEOGRAPHY AND GEOLOGY

The Median Area includes that part of the State occupied by the main Rocky Mountain uplift with its numerous detached mountain ranges and intervening valleys. The area extends completely across the State from north to south (see map, Plate 5) and has an average width of about 75 miles. In the northern part of the area the Sangre de Cristo Mountains form the southern extension of the Rocky Mountains. To the south of Glorieta on the Atchison, Topeka & Santa Fe railway the uplift is faulted and broken into several more or less parallel ridges with broad intervening valleys. The more important are the Rio Grande Valley, Estancia Valley, Tularosa Basin and Jornada del Muerto. Albuquerque, the largest city in the State, and Santa Fe, the capital, are located in the Median Area.

Pre-Cambrian granite, schist, and quartzite are exposed in each of the following mountains, ranges, and hills within or bordering the Median Area: Sangre de Cristo Mountains, Truchas Range, Nacimiento Mountains, Sandia Mountains, Manzano Mountains, Ladron Mountains, Socorro Mountain, Magdalena Mountains, Oscura Mountains, Black Range, San Andres Mountains, Franklin Mountains (mostly in Texas) , Los Piños Mountains, Fra Cristobal Range, Caballos Mountains and Pedernal Hills. Above the pre-Cambrian are sedimentary formations ranging in age from upper Cambrian to Recent. The older sedi-

[1] Based in considerable part on Winchester, D. E., The oil and gas resources of New Mexico: N. Mex. Bur. Mines Bull. 9, pp. 182-201, 1933.

ments, including the Cretaceous, are profoundly and intricately faulted and folded and in large areas completely obscured by deposits of sand and gravel which fill the wide valleys. Along the margins of certain of the valleys, older sediments are exposed in limited areas and it has been possible to determine the structure in these areas. Much greater areas have not been worked because of the great thickness of recent deposits present.

OIL AND GAS

Considerable drilling has been done in the Median Area, as will be noted by reference to the Oil and Gas Map, Plate 4. To date this testing has given negative results except in the Estancia Valley where carbon dioxide gas has been developed on the Wilcox dome. As a whole the Median Area is not attractive as prospecting ground for oil or gas, because of the fact that in most places where Cretaceous or older sediments are exposed the beds are steeply folded and faulted. Elsewhere the formations which might be expected to contain oil and gas are buried beneath unknown thicknesses of recent sand and gravel, and geologic structure in them thereby completely obscured.

UPPER RIO GRANDE VALLEY

Darton[2] has given the following description of the Upper Rio Grande Valley:

> The valley of the Rio Grande in Taos, Rio Arriba, and Santa Fe Counties is occupied by thick deposits of the sands, loams and gravels of the Santa Fe formation (Miocene and Pliocene), overlain in part by lavas that have flowed down the valley in relatively recent geologic time. The underlying rocks are probably very largely pre-Cambrian granites and schists similar to those which constitute the adjoining Rocky Mountains on the east and appear in the scattered outcrops in the high ridges on the east side of Rio Arriba County. These rocks do not offer any prospects whatever for oil or gas. It is probable that some portions of the bottom of the basin are underlain by limestones and sandstones of the Magdalena group, which appear so extensively in the Rocky Mountains to the east. From Santa Fe to Truchas these rocks dip under the valley, but how far they extend in that direction can not be determined without test borings. Pre-Cambrian schists appear in the bottom of the valley at Glenwoody, and along the west side of the valley granite or schist extends down to the great lava flow at Tres Piedras, Petaca, and Ojo Caliente.

In 1931 a dry hole was completed at a total depth of 1,685 feet in sec. 26, T. 21 N., R. 9 E. Sandy brown shale, with thin beds of sandstone and limestone, was penetrated to below 1,600 feet. The well ended in hard gray lime. It is located on a reported anticlinal fold, the Santa Cruz anticline, whose axis trends in a general northeast direction. No detailed information is available regarding the structure.

[2] Darton, N. H., Geologic structure of parts of New Mexico: U. S. Geol. Survey Bull. 726, p. 217, 1922.

MIDDLE RIO GRANDE VALLEY

South of White Rock Canyon in eastern Sandoval County the valley of the Rio Grande widens so that for some 60 miles southward from Bernalillo it is approximately 30 miles wide. From La Joya south to San Marcial, at the upper end of the Elephant Butte Reservoir, the valley is only 10 to 15 miles in width. On the east the valley is bounded by the Sandia, Manzano and Los Pinos Mountains and a series of low ridges and hills southward through Carthage. On the west, Socorro Mountain and the Ladron Mountains form the western limit near Socorro. Between the Ladron Mountains and the main line of the Santa Fe railway to the north, the valley is bounded by a series of high mesas. North of the railroad Cretaceous formations are present.

The valley is floored by thick deposits of sand, soft sandstone, and conglomerate of the Santa Fe formation (Miocene and Pliocene), in places covered by more recent alluvium, sand, gravel, and detritus from adjacent mountain areas. In each of the mountain areas pre-Cambrian granite is exposed, with the valley deposits lying against the granite. In the area east of the valley between La Joya and Carthage sedimentary formations from Cretaceous to Pennsylvanian are intricately folded and faulted. Recent lavas, tuffs, and intrusive porphyries are present, particularly along the western margin of the valley.

Within the Rio Grande Valley area very little evidence of geologic structure is available. Only a few wells have been drilled to sufficient depth to furnish information even on the depth of the valley fill, and the correlation of formations described in the logs of the deeper wells is impossible. Darton[3] has described the general structural conditions as follows:

> The entire west front of the Sandia and Manzano Mountains and the Sierro de los Pinos consists of granite, schist, and other pre-Cambrian rocks, with a few small showings of westward-dipping limestones of the Magdalena group at the foot of the range. Near La Joya and on the east slope of the Sierra Ladrones granite appears, which may indicate that this rock underlies a considerable portion of the valley. Along the west side of the valley are areas of the Magdalena group and some of the immediately overlying sandstones and limestones, but they are cut off by a fault, so that the relations to the east are not indicated. Along the valley of Rio Puerco in most of Bernalillo County the Mancos and overlying higher Montana rocks are exposed, but they also are cut off to the east by a fault. It seems probable that although the west side of the Sandia-Manzano-Pinos uplift is marked by a fault of considerable amount, the dropped westward-dipping limb of the anticline lies west of this fault, and that there is a continuous series of westward-dipping sedimentary formations extending along the east side of the valley in Valencia, Bernalillo, and Sandoval counties. The valley is therefore probably a basin underlain by a regular succession of sedimentary strata from the Magdalena group to beds high in the Cretaceous, some of which come to the surface in the Puerco Valley west of Albuquerque. It is of course possible that a syncline of this character might be interrupted by domes or anticlines or other structural features favorable for the accumulation of oil or gas. Owing,

[3] Op. cit., pp. 220-221.

however, to the heavy covering of the young formations in the valley it is not possible to advance any definite opinion in this regard. In places the sandstones of the Santa Fe formation dip in various directions, but this structure should not be expected to continue downward into the Cretaceous and underlying rocks, to which the Santa Fe formation is entirely unconformable.

Several wells have been drilled in the valley, as will be seen by reference to the Oil and Gas Map, Plate 4. The deepest were six drilled on the Harlan ranch near Los Lunas, all in sec. 5, T. 6 N., R. 2 E. The total depths of these holes as shown by logs are given below.

Wells Drilled on the Harlan Ranch near Los Lunas

Company	Well	Depth, feet
Valencia Petroleum Co.	Harlan No. 1	2,093
Harlan et al.	Harlan No. 1	4,223
do.	Harlan No. 2	4,021
do.	Harlan No. 3	6,474
do.	Harlan No. 4	3,820
do.	Harlan No. 5	4,007

A driller's log of the Harlan No. 3 well, of doubtful stratigraphic value, indicates that valley fill was penetrated to a depth of at least 2,000 feet, and that the underlying strata consist chiefly of sandy shale and hard sandstone. A few limy zones were reported, in one of which, from 5,171 to 5,211 feet, a show of oil and gas was encountered. The last 25 to 30 feet of hole was reported to be in dark igneous rock, presumably volcanic.

Each of the Harlan wells, except Nos. 2 and 3 which were drilled only 24 feet apart, reported coal at several horizons associated with grayish green sandy shale. Slight shows of oil and gas were also reported. Careful study of the logs of these wells by D. E. Winchester led him to suggest that after passing through the valley fill the wells penetrated only Cretaceous formations, probably never reaching the Dakota sandstone. On the basis of the scanty information available, this conclusion seems warranted.

A number of other tests, from 2,600 to 5,000 feet deep, have been drilled in the valley area in Bernalillo and Socorro Counties. The absence of oil and gas in these wells, and the thick cover of valley-fill deposits masking bedrock structure, indicate that the Middle Rio Grande Valley is not a promising area for petroleum exploration.

NOE DOME

So far as known, only a single closed structure has been mapped in the Middle Rio Grande Valley in central New Mexico on the basis of beds exposed at the surface. The Noe dome, located east of the Rio Grande near the south line of the La Joya grant, in T. 1 S., R. 1 E., is a very small dome nearly round in form and having a total area of less than a section of land. Soft sandstones and dark shales of Cretaceous age are exposed at the surface. A well located near the crest of the dome was drilled to a depth reported as 860 feet without finding anything of interest.

LOWER RIO GRANDE VALLEY

The following data on the Lower Rio Grande Valley are from Darton.[4]

> The Jornada del Muerto extends to the lower Rio Grande valley between Rincon and Las Cruces. From Las Cruces southward the valley of the Rio Grande consists of a long down slope from the mountains on the east, a trench occupied by the river, and a higher plain or mesa which extends far to the west across Dona Ana and Luna counties. This plain, the valley trench, and the slope on the east are all underlain by a thick deposit of sand and gravel which completely hides the underlying rocks over wide areas, so that their character and structure cannot be determined. Ridges and knobs consisting of igneous rocks or limestone rise above the plain in places, and portions of the plain south of Afton and Aden are covered by lava flows…

Several holes, mostly less than 1,500 feet deep, have been drilled in the Lower Rio Grande Valley area. The nature of the records preserved makes interpretation and correlation impossible. Logs of shallow tests along the Southern Pacific railroad at Strauss, Noria, Mount Riley, Lenark, and Kenzin, in southern Dona Ana County, all indicate that down to about 1,000 feet the strata consist chiefly of sand and clay. A few beds of gravel and conglomerate have been logged.

ESTANCIA VALLEY

GENERAL GEOGRAPHY AND GEOLOGY

The Estancia Valley is a broad flat-bottomed topographic basin without outlet, occupying the central part of Torrance County and most of southern Santa Fe County. Altitudes in the valley area range from 6,100 to 6,400 feet, whereas the higher portions of the Manzano Mountains to the west are more than 9,000 feet above sea level. The valley is bounded on the east by the low Pedernal Hills, with their core of pre-Cambrian rocks, and on the west by the Manzano Mountains where Permian and Pennsylvanian formations are upturned and rest on schist and granite. To the south is the high Mesa Jumanes at the north end of Chupadera Mesa. Northward from the center of the basin the surface rises gradually and terminates in a northward-facing rim composed of Cretaceous sandstones and shales. The center of the basin is occupied by recent soil, sand, and clay having a maximum thickness of about 300 feet. Beneath these recent beds and outcropping in the slopes of the mountains to the west of the valley are limestones, arkose beds, sands, and organic shales belonging to the Abo formation and underlying

[4] Op. cit., pp. 232-234.

Pennsylvanian limestone series. The beds are well exposed in Abo Canyon to the southwest.

According to Winchester,[5]

> A small sample of black shale from the upper part of the Magdalena formation "near Scholle" . . . was subjected to distillation and found to yield oil at the rate of 41 gallons per ton. This is exceptionally rich for shales of Pennsylvanian age. Several of the black shale beds of the section [near Scholle] were tested by the writer and found capable of yielding oil on distillation. Coal found by the writer in the Magdalena formation on the west side of the Estancia Valley showed by analysis that it had not been greatly metamorphosed and devolatilized. It is evident, therefore, that the Magdalena formation on the west side of the Estancia Valley and in Abo Canyon west of Scholle includes organic material in considerable amount and that the formation has not been subjected to heat or pressure sufficient to devolatilize and drive off all the oil-forming substance. It appears, therefore, that where structural conditions are favorable the Magdalena formation in central New Mexico is worth testing for oil and gas.

STRUCTURE

The Estancia Valley is essentially a structural basin, with structural details on all except the west side effectually concealed by recent deposits of sand and soil. On the west where the older sedimentary formations are not covered several minor anticlinal folds are found superimposed on the general eastward-dipping monocline of the Manzano Mountains. Three of these structures — Buffalo Draw, Estancia, and Wilcox anticlines—were studied in detail by Winchester, and a fourth, the Punta del Agua anticline, is reported farther to the south. On each of these structures limestones, shales, and arkose beds of the Abo are exposed at the surface. Limited exposures near the above-named folds suggest that additional structures may be present.

BUFFALO DRAW ANTICLINE

The Buffalo Draw anticline, located to the north of the Wilcox structure, is less completely exposed than either the Wilcox or the Estancia anticlines. From the available evidence, however, it appears that the Buffalo Draw anticline may have a larger area within the lowest closing contour, although perhaps less closure. The crest of the Buffalo Draw anticline is located in the SW¼ sec. 32, T. 9 N., R. 8 E. In 1935-36 a 2,160-foot test, The 48 Petroleum Co. No. 1 Greenfield, was drilled in the SW¼ sec. 17, T. 9 S., R. 8 E. No shows of oil or gas were reported and the hole was plugged and abandoned.

ESTANCIA ANTICLINE

The Estancia anticline has a proved closure of over 100 feet and an area of about 5,400 acres within the lowest closing contour. The axis of the fold runs northeast and the crest of the structure is in sec. 5, T. 6 N., R. 7 E. In 1925-26, the Estancia Co. drilled a test well in the NE cor. SW¼ sec. 5, to a total depth

[5] Winchester, D. E., The oil and gas resources of New Mexico: N. Mex. Bur. Mines Bull. 9, p. 190, 1933.

of 1,346 feet without finding commercial oil or gas. In a five-foot sand at 1,027 to 1,032 feet, a small amount of carbon dioxide gas was found. The log of the well shows it to have been bottomed in green micaceous schist containing numerous quartz veins.

PUNTA DEL AGUA ANTICLINE

South of the Estancia anticline and in the vicinity of the village of Punta del Agua, the Navajo Oil Co. in 1928 drilled a test well to a total depth of 1,983 feet without finding oil or gas. The well was located in the SW¼SW¼ sec. 36, T. 5 N., R. 6 E.

WILCOX ANTICLINE

The Wilcox anticline, located northeast of the Estancia anticline, is a dome-like structure with a closure of 60 to 80 feet. Formations exposed at the surface are of the same series as on the Estancia anticline. The surface beds are faulted along the axis of the fold, the maximum displacement occurring southwest of the crest. The high point of the anticline is located in the SE¼SW¼ sec. 12, T. 7 N., R. 7 E.

The discovery and development of carbon dioxide gas on the Wilcox anticline are discussed on pages 304-305.

EAST SIDE OF THE VALLEY

To the east of Estancia, two wells have been drilled by the San Juan Coal & Oil Co. They are not situated on a known structure. The deeper well, drilled in 1927-28, reached a total depth of 5,321 feet. An interpretation of the log follows.

Log of San Juan Coal & Oil Co. No. 2 Randall
SW¼ Sec. 20, T. 6 N., R. 10 E.,
Torrance County

	Feet
Valley fill:	
Caliche, gypsum, and gravel	0- 95
Yeso formation:	
Pink sand, red shale, gray limestone	95- 595
Abo formation:	
Red sandy shale	595-1040
Pennsylvanian system:	
Chiefly black, gray, and brown limestone in upper part; sand and shale predominate in lower 1,000 feet	1040-5321 T. D.

Pre-Cambrian granite and schist are at the surface in the Pedernal Hills only 10 miles southeast of this well. The presence of a sedimentary series more than 5,300 feet thick so near the pre-Cambrian outcrop demonstrates the deep basinal character of the Estancia Valley. Shows of oil and gas from Pennsylvanian rocks in the San Juan deep well indicate that commercial quantities might be encountered if some of the structures in the Estancia Valley were subjected to deep drilling.

JORNADA DEL MUERTO

The name Jornada del Muerto (Spanish, journey of the dead) is applied to the long, wide desert valley extending through the eastern part of Socorro County and southward across the eastern part of Sierra County into Dona Ana County, a distance of 125 miles. It is bounded on the east by the San Andres Mountains, Sierra Oscura, and Chupadera Mesa, and on the west by the Sierra Caballos and Fra Cristobal Range. South of Rincon it merges with the Rio Grande Valley. The remarkably smooth and nearly level floor consists mostly of sand or loam which in an area southeast of San Marcial is covered by a large sheet of recent lava. In most places the deposit of sand, loam, and gravel is so thick that details of geologic structure are completely obscured. However, the general structure of the Jornada is indicated by the relations of the formations exposed in the adjoining ridges, and some additional data are afforded by the records of a few widely scattered wells. In general the Jornada is a long, moderately narrow syncline, probably not very deep, for dips appear relatively gentle in most places.

LOCAL STRUCTURE

Darton[6] has made the following summary of the information available concerning local structure in the Jornada del Muerto.

> Local anticlines or domes may occur in this valley, but except for those on the margin no evidence can be obtained as to their existence until numerous borings are made. It appears unlikely that many such features are present. The anticline at Carthage and Prairie Springs and the prominent plunging anticline at the north end of the Oscura uplift, in Tps. 2, 3, 4, and 5 S., R. 6 E., are outside of the main basin... The higher part of the west face of the Sierra Oscura, in which granite and other old crystalline rocks rise 1,500 feet or more above the Jornada, is doubtless due to a fault, but it is probable that westward-dipping rocks occur not far west of the foot of these mountains. This structure is indicated by outcrops of Cretaceous sandstone (Mesaverde?) in the southeast corner of T. 8 S., R. 4 E., and by outcrops of westward-dipping Dakota (?) sandstone in the northern part of T. 11 S., R. 3 E., and the southeastern part of T. 11 S., R. 2 E. . . . In Tps. 9 and 10 S. limestone of the Chupadera [San Andres] formation dips gently to the west on the west slope of the San Andres Mountains and rises again on the east dip on the east slopes of the Fra Cristobal and Caballo Mountains, thus forming a synclinal basin...

CHUPADERA ANTICLINE

Location and Topography.—The Chupadera anticline (Oscura anticline of Darton[7]) is located in eastern Socorro County at the north end of the Jornada del Muerto about 35 miles east of Socorro. The accompanying map of the structure is taken from a private report by E. H. Wells, and the following notes are based on Wells' report.

[6] Darton, N. H., Geologic structure of parts of New Mexico: U. S. Geol. Survey Bull. 726, p. 231, 1921.

[7] Op. cit., p. 239.

The Chupadera anticline extends in a general northward direction from the southern part of T. 4 S., R. 6 E., to the northeastern part of T. 2 S., R. 6 E. The crest of the fold is in a basin-like area, which is bounded on the east by the high escarpments of Chupadera Mesa and on the west by low cuestas formed by resistant sandstone which separate it from the Jornada del Muerto to the west. The topography is quite irregular, with altitudes ranging from 5,800 to 6,300 feet. Chupadera Mesa has altitudes of 6,500 to 7,000 feet.

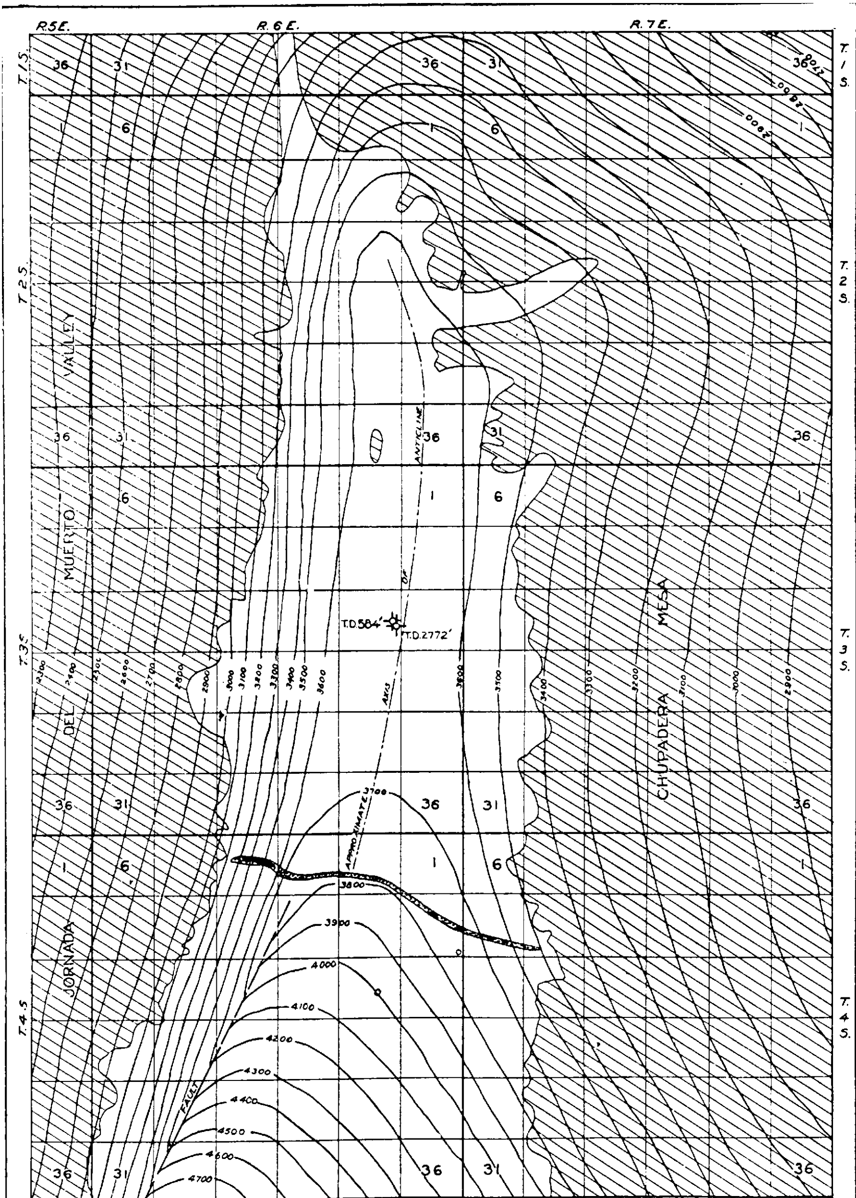
Geology.—The surface rocks along the axis of the anticline consist of gypsum, limestone, and gypsiferous shale of the Yeso formation of Permian age. The massive Glorieta sandstone, which occurs at the top of the series, forms the bluffs on the east and the cuestas on the west side of the structure. The total thickness of the Yeso formation is approximately 2,100 feet. The overlying San Andres limestone is the surface rock of most of Chupadera Mesa and outcrops in a narrow area west of the cuestas.

The Abo sandstone which underlies the Yeso formation is approximately 1,100 feet thick and is composed of interbedded red sandstone and red shale. Beds of Pennsylvanian age, below the Abo, are well exposed in Abo Canyon near Scholle, 25 miles to the north, where they are composed of fossiliferous limestone, organic shale, arkose, and sandstone. The total thickness of the Pennsylvanian strata is approximately 1,100 feet in Abo Canyon. They rest on pre-Cambrian quartzite, granite, and schist.

Dikes, plugs, and sills occur at a number of places on the Chupadera anticline. The principal intrusion is a dike of latite and monzonite porphyry which is traceable almost continuously across the structure through the northern part of T. 4 S. (See map, Fig. 23.) This dike is essentially vertical, and in places is as much as 400 feet wide. Adjacent sedimentary rocks in the vicinity of the dike are slightly upturned. The dike appears not to have penetrated the thick Glorieta sandstone, but it seems probable that this igneous wall reaches to great depths.

There is a small igneous plug in secs. 25 and 36, T. 2 S., R. 6 E. Sills up to 60 feet thick occur just below the massive Glorieta sandstone at the top of the Yeso on the east side of the anticline, but these sills can be traced for only short distances.

Structure.—The Chupadera anticline is a long anticlinal fold whose axis trends in a north-south direction. The crest of the fold is essentially level from sec. 14, T. 2 S., R. 6 E., to sec. 35, T. 3 S., R. 6 E., a distance of about nine miles. It rises rather abruptly farther south, and plunges to the north in the northern part of the anticline. The contours of the map, Fig. 23, are based on elevations of the top sandstone member of the Yeso formation



EXPLANATION

DRY AND ABANDONED HOLE
WATER WELL
DIKE
UPPER CHUPADERA FORMATION
LOWER CHUPADERA FORMATION
ABO SANDSTONE
3200 STRUCTURE CONTOURS, INTERVAL 100 FEET
CONTOURS ON TOP OF MAGDALENA FORMATION

MAP OF

CHUPADERA ANTICLINE

SOCORRO COUNTY, NEW MEXICO

BY

E.H. WELLS

JUNE 20, 1931

SCALE

but are drawn to represent the structure on the top of the Pennsylvanian strata.

Structural closure on the east, west, and north is well defined. To the south it is weak or absent, but is augmented and probably made effective by the dike which crosses the structure from east to west through the north tier of sections of T. 4 S. This dike probably is continuous and cuts all of the sedimentary formations, and should form an adequate seal against the migration of oil and gas up the dip to the south. Along the terraced part of the axis of the structure there may be slight undulations, although the beds continue essentially level for long distances.

Oil and Gas Possibilities.—The Pennsylvanian section, as exposed in Abo Canyon to the north, contains good organic deposits, both shale and limestone, which might well be source beds for both oil and gas. Sands are present which might serve as reservoir rocks.

The well drilled in 1929-1930 by the Rio Grande Oil Co. on the axis of the anticline in sec. 14, T. 3 S., R. 6 E., started in the upper part of the Yeso, reached the Abo at about 1,610 feet, and the Pennsylvanian at about 2,700 feet. The hole was lost and abandoned at a depth of 2,772 feet, after penetrating only a short distance into the Pennsylvanian rocks, and hence it was not an adequate test of the structure. A well less than 4,000 feet deep should reach the pre-Cambrian rocks and completely test the oil and gas possibilities of the anticline. A number of features are in favor of such a test.

PRAIRIE SPRINGS ANTICLINE AND DOME

These structural features, located about 18 miles east of Socorro at the north end of the Jornada del Muerto, are described by Darton[8] as follows.

> Rising from the Jornada del Muerto near Prairie Springs is an anticline which is expressed in the wide area of ridges of limestone and other rocks of the Chupadera formation extending to the mesas east of Rayo and beyond. In the center of this area, or near the middle of T. 2 S., R. 4 E., the red Abo sandstone is exposed for about a square mile along the axis of the anticline. The line of ridges east of the old auto road in that vicinity consists of limestone of the Chupadera formation dipping eastward into the basin of Arroyo Chupadero. The Sierra del Venado consists of the same limestones dipping west on the west side of the axis. Between these limestone ridges is a wide area of lower beds of the Chupadera formation.
>
> Just west of Prairie Springs is a small local anticline or elongated dome on the west slope of the main anticline. It is shown by limestone of the Chupadera formation dipping on all sides below red shale of Triassic age. The spring is on the southwest end of this minor uplift.

According to Andreas,[9] small areas of pre-Cambrian granite are exposed along the axis of the Prairie Springs anticline near Rayo. The structure is therefore apparently a partly denuded

[8] Op. cit., p. 238.
[9] Andreas, A., Personal communication, July 1942

high on the pre-Cambrian surface. Any testing for oil and gas would have to be some distance down the flank of the structure, where stratigraphic traps might possibly be found.

TULAROSA BASIN

GENERAL GEOGRAPHY AND GEOLOGY

The Tularosa Basin consists of a wide valley area lying between the Sacramento Mountains and Sierra Blanca on the east and the Oscura and San Andres Mountains on the west and extending from the south line of the State northward to near Carrizozo. Most of the surface of the valley is covered by sand, lava, and wash, but scattered local exposures along the edges of the bordering mountains and in the area east of the Oscura Mountains and Chupadera Mesa at the north, furnish data on the general geology as well as structure of the area. In the northern part around Carrizozo and White Oaks shales and sandstones with coal beds belonging to the Dakota and overlying Upper Cretaceous formations encircle the basin. Older sediments, representing all the geologic systems from Triassic to Cambrian, are exposed around the basin in the mountainous areas. Recent lava flows occupy considerable areas west and north of Carrizozo. Granular gypsum sands (White Sands) occupy an area of approximately 270 square miles on the west side of the basin west of Tularosa and Alamogordo.

STRUCTURE AND OIL POSSIBILITIES

Although over much of the area geologic structure is obscured by recent deposits, it appears that the basin is in general synclinal in form with considerable minor folding and much faulting indicated in scattered exposures of older sedimentary formations. According to Darton,[10] "An anticlinal arch crosses the basin diagonally southwest of Carrizozo and west of Oscuro, passes under the eastern part of Alamogordo, rises in the west face of the Sacramento Mountains and continues southward into the Hueco Mountains." Numerous isolated exposures indicate local highs along this line of folding. Darton[11] gives the following details.

> The anticline of the Sacramento Mountain front is first manifested in an anticline or dome west of "the Malpais" (recent lava flow) 15 miles northwest of Carrizozo. Its axis crosses the basin west of Oscuro, where it is marked by a dome of limestone of the Chupadera formation in T. 9 S., R. 8 E., and appears in the Phillips Hills, which present a complete arch of the Chupadera formation along their western slope. Limestone at the top of the Magdalena group rises on this axis a short distance southeast of Tularosa, and the uplift is well exposed from La Luz to High Rolls, where there are two arches and an intervening basin containing the Abo sandstone... The anticline is well defined east of Alamogordo and in

[10] Darton, N. H., Geologic structure of parts of New Mexico: U. S. Geol. Survey Bull. 726, p. 223, 1921.

[11] Op. cit., p. 226.

Alamo Canyon. South of the latter place the beds on the axis rise rapidly, and near the center of T. 19 S., R. 11 E., the basement of granite is brought up at the foot of the west front of the mountain. Doubtless in this region for some distance the west limb of the uplift is faulted, with the dropped block on the west side. A diagonal fault passing into the Sacramento Mountain front is well exposed five miles south-southeast of Alamogordo. South of Escondida the anticline pitches down again to the south, and its wide, low arch is well exhibited southeast of Turquoise…

Additional minor folding is described by Darton[12] as follows:

> A small dome of similar character exists in the northeastern part of T. 9 S., R. 8 E., and another has its apex in the center of T. 5 S., R. 12 E., about five miles southwest of Ancho. In these uplifts the gray sandstones of the Chupadera formation are at no great depth and may yield oil, but in the 800 to 1,000 feet of red sandstones of the Abo formation next below the prospects are less promising. In the still lower Magdalena group there are several beds of sandstone, especially near its base. The thickness of this group is somewhat more than 2,000 feet…

North of the Hueco Mountains and east of Orogrande the limestones of Pennsylvanian age are arched into a low anticlinal fold known as the Hueco anticline. In 1925 the Kinney Oil & Gas Co. drilled a well in sec. 14, T. 25 S., R. 10 E., on this structure. The log of this well shows alternating limestone and shale to the bottom at 2,168 feet. No details are available regarding the structure.

At the north end of the basin several small anticlinal folds are indicated on maps but no details concerning them are available.

Geologic conditions prevailing in the central part of the basin are suggested by the record of a well drilled in sec. 34, T. 13 S., R. 8 E., 12 miles northwest of Tularosa. The log of this well shows 370 feet of valley fill deposits below which are redbeds and gypsum to 1,302 feet. Darton[13] suggests that "the 110 feet of red strata from 1,750 to 1,860 feet may be part of the Abo sandstone." The lower beds are probably Pennsylvanian. The total depth of the hole was 3,965 feet.

On the west side of the basin the recent sands and gravels lap up on the granite which forms the core of the San Andres Mountains.

In 1930-31 a test was drilled by R. H. Ernest to 1,328 feet in sec. 20, T. 25 S., R. 7 E., in the southern part of the Tularosa Basin. In 1939-42 this well was deepened to 3,941 feet, at which depth it was plugged and abandoned. An incomplete log of the well indicates that valley fill was penetrated to about 2,100 feet. This material consists chiefly of buff fine to medium coarse sand, with flakes of mica and scattered pieces of basic igneous rock in the lower 900 feet. At 2,100 feet the bit entered Pennsylvanian limestone which is varicolored and cherty and contains

[12] Op. cit., p. 227.

[13] Darton, N. H., "Red Beds" etc. : U. S. Geol. Survey Bull. 794, p. 219, 1928.

numerous fossil fragments. It is not known what thickness of this limestone was penetrated. Slight shows of oil and gas were logged at intervals between 2,090 and 2,450 feet, and also from 3,100 to 3,180 feet and from 3,858 to 3,868 feet.

MISCELLANEOUS STRUCTURES IN THE MEDIAN AREA

Several anticlines occur in the Median Area outside the divisions described on the preceding pages. Among these are the Galisteo anticline, the Pecos structure, and the Tijeras anticline.

GALISTEO ANTICLINE

Southeast of Galisteo, in southeastern Santa Fe County, Triassic, Jurassic, and Cretaceous sediments are steeply upturned and arched into what is shown on the Oil and Gas Map, Plate 4, as the Galisteo anticline. The axis of this fold is shown extending in a general northeast direction for some 15 miles. No information is available on the character of the fold nor the amount of its closure. Several wells have been drilled along its axis. No. 2 well of the Toltec Oil Co. on the Pankey ranch in sec. 33, T. 14 N. R. 11 E., evidently started below the Dakota sandstone and reached a total depth of 2,898 feet. No shows of either oil or gas were reported and the hole stopped in sand. Arkose is reported at 2,015-30 and 2,450-2,650 feet. Well No. 1 of the same company in sec. 2, T. 13 N., R. 10 E., was reported bottomed in schist and quartzite at 2,165 feet, having found nothing of interest. Several shows of oil and gas were reported from a 3,240-foot test drilled in 1921 in sec. 7, T. 12 N., R. 10 E.

PECOS STRUCTURE

Northeast of the Galisteo anticline is a small uplift known as the Pecos structure. It lies in Tps. 15 and 16 N., R. 12 E., San Miguel County. Descriptive details are not available; it is thought that the structure may be complicated by faulting. Rocks at the surface include the Abo formation and limestones of Pennsylvanian age, exposed between Glorieta Mesa on the south and the pre-Cambrian mass of the Truchas Range on the north.

Proximity of the pre-Cambrian outcrops indicates slight chance for oil accumulation. Nevertheless, two holes have been put down. The Austin No. 1 Fee, in sec. 16, T. 15 N., R. 12 E., was abandoned in 1930 at a total depth of 1,855 feet after having drilled about 1,700 feet into Pennsylvanian rocks. Several shows of oil and gas were reported. According to the log, the well was still in sedimentary rocks when abandoned. The Keith No. 1 McCune, in sec. 32, T. 16 N., R. 12 E., was drilled to 1,822 feet in 1939-40. The Abo formation, containing considerable amounts of red and white granite wash, was penetrated from the surface to 691 feet, at which depth white limestone and gray shale of the Pennsylvanian was entered. It is not known whether granite was encountered in this well.

TIJERAS ANTICLINE

The Tijeras anticline is located in the Sandia Mountains in eastern Bernalillo County about 20 miles east of Albuquerque. Cretaceous coal-bearing rocks occupy the center of an irregular syncline about five miles long by two miles wide, lying between faults on either side. Within the Cretaceous area the beds are steeply folded and considerably faulted. Near the center of this block-fault area is the Tijeras anticline, a small upfold having a closure of perhaps 75 feet. Mancos shale, surrounded by beds of Mesaverde age, is exposed at the surface. The crest of the structure is located in the SW¼ sec. 1, T. 10 N., R. 5 E., and the area within the lowest closing contour includes less than a section of land. Because of the smallness of the structure itself and the fact that it occupies the central portion of a down-faulted block with little possible gathering ground for oil or gas, the Tijeras anticline is considered as holding but slight promise for extensive commercial development.

SOUTHWEST AREA[1]

GENERAL GEOGRAPHY AND GEOLOGY

The Southwest Area includes that part of the State west of the Rio Grande Valley and south of the north boundary of the Datil Mountains—all or part of Catron, Socorro, Sierra, Luna, Grant, and Hidalgo Counties. (See map, Plate 5.) The northern half of the area belongs to the Colorado Plateau province and includes the Datil, San Mateo, San Francisco, Tularosa, and Mogollon Mountains. Altitudes range from 6,000 to 10,000 feet. The surface of the mountainous area is rough and rugged, but valleys or basins such as the Plains of San Agustin occupy large areas. Rock formations in the northern half of the Southwest Area consist largely of thick flows of Tertiary igneous rocks, great thicknesses of relatively recent sediments composed largely of material of igneous origin, and deposits of sand, gravel, and conglomerate filling the basins.

The southern part of the area belongs to the Basin and Range province. It is characterized by wide desert plains out of which rise abruptly many hills and narrow rough mountain masses. The plains are normally arid and covered with sparse desert vegetation, although considerable areas have been converted into farm land by the development of irrigation from shallow wells. Drainage is largely intermittent, and some of the closed basins contain playa lakes.

[1] Slightly modified from Winchester, D. E., The oil and gas resources of New Mexico: N. Mex. Bur. Mines Bull. 9, pp. 202-203, 1933.

The plains and valleys are floored by sand, gravel, and recent bolson deposits derived from nearby upland areas. The Gila conglomerate is present in some of the valleys. Little is known concerning the depth of these valley deposits or the configuration of the bedrock surface below. Only a few wells have been drilled to depths sufficient to reach the bedrock floor, and logs of these are lacking or inaccurate. The valley deposits are at least several hundred feet in thickness.

The mountains of the southern part of the Southwest Area rise abruptly out of the plains and consist of pre-Cambrian rocks, Paleozoic and Cretaceous sediments, and Tertiary sediments and igneous rocks. Pre-Cambrian rocks predominate in the Big Burro and Florida Mountains; the Little Hatchet Mountains, Cooks Peak, and the mountains near Silver City and Hanover consist of Paleozoic and Cretaceous sediments and subordinate igneous stocks, dikes, and sills. These sedimentary rocks are intensely folded and greatly faulted. The Peloncillo, Pyramid, Cedar, and Alamo Hueco Mountains consist chiefly of igneous flows and subordinate intrusions of Tertiary age.

Much of New Mexico's metal production has come from mineralized parts of the mountains of the Southwest Area. The geology of several of the more important areas has been described in detail by Ferguson,[2] Page,[3] Lindgren, Graton, and Gordon,[4] Lasky,[5] and others, and Darton[6] has discussed the geology of Luna County.

OIL AND GAS

The sedimentary formations exposed in the mountains in the southern part of the Southwest Area are in most places so intensely folded, faulted, and mineralized that oil or gas, if ever present, would have been driven off and the porous beds left barren. In the northern part of the area there is little probability of either oil or gas being found in areas underlain by Tertiary volcanic formations. The more recent bolson deposits,

[2] Ferguson. H. G., Geology and ore deposits of the Mogollon mining district: U. S. Geol. Survey Bull. 787. 1927.

[3] Paige, Sidney, Description of the Silver City Quadrangle, U. S. Geol. Survey Geol. Atlas, Silver City Folio, (No. 199), 1916.

Copper deposits of the Tyrone district, N. Mex.: U. S. Geol. Survey Prof. Paper 122, 1922. The ore deposits near Piños Altos, N. Mex.: U. S. Geol. Survey Bull. 470, pp. 109-125. 1911.

Metalliferous ore deposits near the Burro Mountains, Grant County, N. Mex.: U. S. Geol. Survey Bull. 470, pp. 131-150, 1911.

Santa Rita and Tyrone, New Mexico: Copper resources of the world, 16th Int. Geol. Cong., pp. 327-335, 1935.

[4] Lindgren, Waldemar, Graton, L. C., and Gordon, C. H., The ore deposits of New Mexico: U. S. Geol. Survey Prof. Paper 68, 1910.

[5] Lasky, S. G., The Lordsburg district, New Mexico: Copper resources of the world. 16th Int. Geol. Cong., pp. 337-341, 1935.

Geology and ore deposits of the Bayard area, Central Mining District, N. Mex.: U. S. Geol. Survey Bull. 870, 1936.

Outlook for further ore discoveries in the Little Hatchet Mountains, New Mexico: Econ. Geology, Vol. 33, No. 4, pp. 365-389, June-July 1938.

Lasky, S. G., and Wootton, T. P., The metal resources of *New* Mexico and their economic features: N. Mex. Bur. Mines Bull. 7, 1933.

[6] Darton, N. H. The geology and underground water of Luna County, N. Mex.: U. S. Geol. Survey Bull. 618, 1916.

which occupy the valleys or plains, entirely obscure the formations below so that prospecting is extremely hazardous and chance of success very remote. In the desert plains area to the south there appear more chances of success, but even there the finding of oil or gas, if not accidental, will be attended by great expense. It is possible that careful geophysical studies over wide areas may indicate the presence of geologic structures in the bedrock below the recent deposits. Even then it would probably be impossible to determine in advance of drilling what sedimentary beds were involved in the structure. Several of the formations exposed in the mountain areas evidently originally contained organic material which under ordinary conditions would have been converted to oil or gas, and these fluids would have accumulated at the top of anticlinal folds of low dip. With folding, faulting, and intrusion by igneous rocks such as is present in the mountain area, the oil and gas have doubtless been dissipated. Cretaceous shales above the Dakota sandstone normally contain oil-forming substances. These shales outcrop in certain parts of the Southwest Area and may be present under parts of the desert plains. The Percha shales contain organic material and if not completely devolatilized by folding and faulting might be found to yield oil.

The Southwest Area is for these reasons not considered likely territory for oil or gas formation and accumulation.

REFINING AND TRANSPORTATION

ROBERT L. BATES

In the past 15 years New Mexico's oil and gas transportation system and refining capacity have greatly expanded. The bulk of the 39,000,000 barrels of crude oil produced in the State in 1941 was moved by pipe line, mainly to refineries in Texas the remainder was refined in New Mexico. In the case of natural gas, on the other hand, a large amount is processed in the State or used locally. The great field of refining and transportation, which is distinct from oil discovery and production, is not considered to fall fully within the scope of this bulletin. The following general notes outline only the more important aspects of the picture in New Mexico.

NORTHWEST AREA

As shown on the State oil and gas map, Plate 4, all the chief producing districts of northwest New Mexico are connected by pipe line with towns or refineries. Extent and diameter of the pipe lines are shown on the more detailed maps, Plates 8, 9, and 10. Brief discussion of refining and transportation facilities is given under Northwest Area, pages 83 to 140 and under individual pool discussions. Important activities in recent years include the replacing of nine miles of 6-inch pipe with 8-inch pipe at the southern end of the Southern Ute Dome-Kutz Canyon gas line, the laying of 32 miles of 4-inch pipe line from the Hospah field in McKinley County to the town of Prewitt, and the construction at Prewitt of a small refinery to treat Hospah crude.

NORTHEAST AREA

The 22-inch line of the Colorado Interstate Gas Co., connecting the Amarillo, Texas, gas field with Colorado Springs and Denver, Colorado, crosses the northeastern corner of the State. A line from the Amarillo field furnishes gas to Clovis, Portales, and Tucumcari. Carbon dioxide gas from the Bueyeros field in Harding County is converted into dry ice (see pp. 301 to 306).

SOUTHEAST AREA

Oil refineries in southeastern New Mexico include the Continental and Malco plants at Artesia and a small refinery at Roswell. There are natural gasoline plants in the Artesia area, the Hobbs field, and the Mattix field. Natural gas is burned in a large carbon-black plant located between Eunice and Jal.

Oil pipe lines connect all the major producing districts in the southeast part of the State, some of the lines leading to local refineries but the majority taking the crude to storage areas in Texas, from where it is eventually piped to the Gulf Coast.

Pipe lines connect some of the gas-producing areas with nearby municipalities. A major gas line is the El Paso Natural Gas Co.'s 16-inch welded line from the Jal area to El Paso, Texas.

MEDIAN AREA

Dismantling of the Continental Oil Co.'s refinery in Albuquerque left the Median Area without refining facilities. Nor do any oil pipe lines enter the area. Gas is brought to Albuquerque by a line from the Bloomfield-Kutz Canyon area, and branches of this line supply Santa Fe to the north and Belen to the south.

SOUTHWEST AREA

As shown on the State map, Plate 4, a 12¾-inch gas line of the El Paso Natural Gas Co. extends from El Paso across southwestern New Mexico. This line provides gas for towns and smelters in New Mexico and Arizona. Extensions have been built to Santa Rita, Silver City, and Lordsburg.

CARBON DIOXIDE IN NEW MEXICO

STERLING B. TALMAGE[1] AND A. ANDREAS[2]
SOCORRO, NEW MEXICO

GENERAL FEATURES

Carbon dioxide, at atmospheric temperatures and pressures, is an inert non-inflammable colorless gas, tasteless when dry and not capable of supporting combustion or life. It exists in the air in quantity approximating one-thirtieth of one percent at sea level. This gas is known to the coal miner as "black damp" it is not actively poisonous in a true physiological sense, but it tends to accumulate in low places on account of being somewhat heavier than air, and a man breathing carbon dioxide will suddenly lose consciousness without warning and will die quickly from lack of oxygen. Such fatalities are caused by smothering, not by poisoning.

The critical temperature for carbon dioxide is 31.1° C. (88° F.), at which temperature the gas can be liquified under a pressure of 73 atmospheres less than half of that pressure will liquefy carbon dioxide at the temperature of freezing water. Carbon dioxide freezes to a white solid at –56° C. (-69° F.) under a pressure of 5.1 atmospheres. Cold liquid carbon dioxide under pressure, expanding rapidly into the air, will precipitate directly as a solid resembling snow, having a temperature of –78.3° C. (-109° F.). Such carbon dioxide snow, compressed into blocks, is now manufactured and marketed under the commonly used term "dry ice."

ORIGIN AND OCCURRENCE

Carbon dioxide is abundant in many volcanic gases,[3] and appears to be the normal product accompanying the dying-out of volcanic activity, as in the Yellowstone Park region, at Soda Springs, Idaho, and elsewhere. In a region showing as much evidence of recent vulcanism as New Mexico, it seems probable that such a source would be more than adequate accumulations of carbon dioxide underground would, of course, be formed only where there were favorable structural traps.

It has been suggested that carbon dioxide deposits may have been formed by the action of igneous rocks at great depth coming in contact with limestones, and driving off the carbon dioxide as is done in a lime kiln. Many cases are known where limestone has been altered to metamorphic silicates with obvious loss of carbon dioxide, but there is no proof of such process in connection with known carbon dioxide accumulations. Still another suggestion, that carbon dioxide has been liberated by the action of acid waters on limestones, is entirely plausible and

[1] Professor of Geology and Mineralogy, New Mexico School of Mines.
[2] Geologist. New Mexico State Oil Conservation Commission.
[3] Clarke. F. W., Data of geochemistry, 5th ed., U. S. Geol. Survey Bull. 770, pp. 252-271, 1924.

chemically sound, but there is no geological evidence that such a process has occurred on a large scale.

Carbon dioxide accumulations in New Mexico, of commercial grade or promise, have been found only in porous sediments, where either structure or variation in porosity has provided a trap. Determination of the exact age of the formations carrying carbon dioxide has not been made, but the rocks are all of late Paleozoic or early Mesozoic ages. Except for the one occurrence in Estancia Valley, all carbon dioxide wells in the State are within a few miles of geologically recent igneous rocks.

PREPARATION AND USES

Recovery.—At all of the wells now producing, recovery of the gas is made by means of natural pressure. Gas from the wells is piped directly to the processing plants, through pipe lines ranging in length from a few rods to nearly 20 miles.

Purification.—All of the carbon dioxide now being used commercially in New Mexico is more than 99 percent pure. It carries a fraction of one percent of nitrogen, which is negligible. No purification of the gas is required; at some wells a little water seeps in, necessitating drying of the gas to avoid trouble with freezing in the pipes at a late stage of processing. Not all of the plants have driers installed at the same stage.

Compression.—The gas as it comes from the wells is compressed, with consequent heating. The compressed gas then passes through water-cooled coils, and is brought down to ordinary atmospheric temperature.

Refrigeration.—The compressed gas, after drying if necessary, is chilled in refrigerating coils to a liquid. Some plants use ammonia as a refrigerant; one plant uses carbon dioxide. Liquefaction completes the process at one plant.

Sublimation.—From an insulated storage supply tank, the chilled liquid carbon dioxide is blown into the snow chamber, which is 20 inches square and 30 inches high. Here about half of the carbon dioxide precipitates as a snow, filling the chamber loosely. The top of the chamber is the plunger of a hydraulic press, which is forced down under approximately 200 tons pressure, and compresses the carbon dioxide snow to a dense block of dry ice about 10 inches thick. The portion of the carbon dioxide that formed as gas instead of as snow is returned to the circuit, either mixing with incoming gas or passing through the refrigerating coils, depending on the plant process.

Packing and shipping.—Blocks from the press are sawed across twice; the sawed blocks, approximating cubes 10 inches square of nearly 60 pounds weight, are wrapped in specially designed double sacks of heavy paper. The wrapped blocks are placed in insulated storage bins, or loaded directly for shipment.

From the plants on the railroad, shipment is in standard refrigerator cars, with insulation reinforced on all sides by the addition of an extra layer of kapok 12 inches thick. By this means the loss in transit, from factory to warehouse, has been reduced to below one percent per day of travel. One plant ships by specially insulated trucks; by strewing a layer of loose dry ice on top of the blocks and under the kapok mattress, it is said that the losses may be confined to the loose material, bringing the pay-load loss down to about one percent per day. Liquid carbon dioxide is shipped in specially constructed tank trucks, in sizes carrying from 3½ to 8 tons of the liquid. The tanks are described as being made of 1¼-inch rifle steel, competent to withstand internal pressures exceeding 300 pounds per square inch, and covered throughout with kapok one foot thick.

Uses.—The principal use of solid carbon dioxide, commonly known as dry ice, is as a refrigerant for long-distance shipments; for this purpose it is said to be from ten to fifteen times as effective, pound for pound, as water ice. It is also used for some purposes for which water ice would not serve, as in quick freezing of fresh fruits and vegetables, which requires temperatures far below "ice-cold." Liquid carbon dioxide has long been used in fire extinguishers, where it serves the double purpose of smothering the flame and lowering the temperature; for carbonated water and beverages; as a preservative for foods, preventing oxidation; and for a variety of minor purposes. Recently liquid carbon dioxide has replaced explosives for some purposes. In coal mining it is used extensively, expanding more slowly than dynamite and consequently breaking the coal more cleanly, and with a greatly decreased proportion of fines. Success is reported in some experiments utilizing liquid carbon dioxide in rifles. It is reported that experiments utilizing dry ice in a newly developed synthetic rubber process are distinctly promising. For some of the purposes for which liquid carbon dioxide has been used, solid carbon dioxide is proving more effective.

PROCESSING PLANTS

Four plants preparing carbon dioxide for market were operating in New Mexico in July, 1942, with a total productive capacity approximating 75 tons daily. Three plants are making solid carbon dioxide, and one is shipping carbon dioxide as a liquid. Summer demand, especially for dry ice, exceeds the total capacity of these plants, but winter demand is only from a third to a half of the summer maximum.

Carbonic Chemicals Corp.—This plant is the largest one in the State, and the only one using a high-pressure process. It draws its gas from the deeper stratum in the Bueyeros field. The plant is at the station of Dioxice, on the Southern Pacific railway about a mile southeast of the village of Solano. The gas is piped

CARBON DIOXIDE WELLS IN NEW MEXICO

Well	Location ¼ Sec., T.-N., R.-E.	Year Com- pleted	Depth to CO_2 Zone (Feet)	Per- cent CO_2	Reported Productive Rock	Reported Potential (Thousands Cu. Ft.)	Reported Pressure (Lbs. per Sq. In.)	Present Status
Bueyeros Field, Harding County								
Carbonic Chemicals Corp. No. 2 Mitchell	SW -20-19-30	1938	2086	99.8	Granite wash (Upper Pennsylvanian)	2300	568	Dry ice, Carbonic Chemicals Corp.
Carbonic Chemicals Corp. No. 3 Mitchell	SE -18-19-30	1939	2100	99.8	Granite wash (Upper Pennsylvanian)	4051	568	Dry ice, Carbonic Chemicals Corp.
Adams No. 1 State	SW -27-21-30	1937	960	99.61	Santa Rosa sandstone (Triassic)	889	38	Dry ice, Ute Car- bonic Co.
Neill No. 1 Gonzales	SW -28-21-30	1937	853	99.6	Santa Rosa sandstone (Triassic)	1447	36	Dry ice. Ute Car- bonic Co.
Neill No. 1 Gallagher	SW- 9-21-30	1937	814	99.6	Santa Rosa sandstone (Triassic)	1500	36	Dry ice, Ute Car- bonic Co.
Kummbaca Oil and Gas Co. No. 1 Kerlin	NW-34-21-30	1931	940	99.9	Santa Rosa sandstone (Triassic)	3000	38	Liquid CO_2, Timmons Carbonic Co.
American Prod. Corp. No. 1 Bueyeros	NW-32-20-31	1916	2000			25000		Plugged and aban- doned.[1]
Waddell and McFann No. 1 DeBaca	NW-19-20-31	1936	1706	99.4	Probably Permian	132	388	Plugged and aban- doned.
Colo-Mex Gas Co. No. 2 DeBaca	NE -31-20-31	1937	2041		"Sand 100 feet thick"	25000	578	Plugged and aban- doned.[2]
Carbonic Chemicals Corp. No. 1 Mitchell	NW- 9-18-30	1939	1576			"Poor"		Plugged and aban- doned.
Danube Oil Co. No. 1 Beller	SE - 1-20-30	1937	650		Santa Rosa sandstone (Triassic)	308	34	Shut in. Chemical Corp.

Estancia Field, Torrance County								
Witt Oil and Gas Co. No. 1 DeHart	NW-12- 7- 7		1245	99.0	"Lower Magdalena"	100	415	Dry ice, WittIce and Gas Co.
Witt Oil and Gas Co. No. 2 DeHart	SE-12-7-7	1934	1200	99.0	"Lower Magdalena"	2250	415	Dry ice, Witt Ice and Gas Co.
Orville Lee No. 1 Pace	SW-12-6-7	1937	1704			1000		Dry ice, WittIce and Gas Co.
Orville Lee No. 1-A Pace	12-6-7	1939	2017	99.0	Pennsylvanian	60		Dry ice, WittIce and Gas Co.
Orville Lee No. 1 Milburn	SW-36- 7- 7	1941	1860		Conglomerate	50		Dry ice, WittIce and Gas Co.
Estancia Valley Development Co. No. 1 Crawford	NE -32- 7- 7	1939						Plugged and abandoned.
Estancia Valley Development Co. No. 1 Roland	SE-12-7-7	1934	1359					Plugged and abandoned.
Estancia Valley Development Co. No. 1 Strong	SW-5-6-7	1926	1030		"Lower Magdalena"	"Small amounts"		Plugged and abandoned.
Wilson et al. No. 1 Pace	SW-12-6-7	1928	1760					Plugged and abandoned.
Drice Co. No. 1 Garland	NW-32-7-7	1940	1965		Sand			Plugged and abandoned.
Jaritas Dome, Colfax County								
California No. 1. Floersheim State	SW-15-23-24	1925	1509	67.0	Upper Permian	500		Plugged and abandoned.
Near Maxwell, Colfax County								
York Denton No. 1 State	NW-2-26-24	1940	1515	99.8	Porous sand	153	128	Shut in.[3]
Wagon Mound Anticline, Mora County								
Arkansas Fuel Co. No. 1 Kruse	NE -11-19-21	1926	1420-2225	90.0	"Permian arkose"	26000		Plugged and abandoned.[4]
Quaker State Oil Co. No. 1 Apodaca	NE -14-19-21	1935	1316			"Flowed"		Plugged and abandoned.
Sierra Grande Uplift, Union County								
Sierra Grande Oil Co. No. 1 Rogers	SW- 4-29-29	1935	2300	98.6	Permian	6000		Plugged and abandoned.[5]

[1] Discovery well. Blew wide open for one year, then bridged; later plugged.
[2] Described as offset to discovery well. Ice plant reported under construction in 1937, but never completed.
[3] Reported ready for plant construction (personal communication from Mr. York Denton, Maxwell, N. M., 1942).
[4] Well allowed to run wild for one month. Figure represents sum of flows reported from four horizons.
[5] Three horizons reported productive.

18 miles from the Bueyeros field to the Dioxice plant. In July, 1942, this plant was operating at full capacity, with three eight-hour shifts, and the newly pressed and wrapped dry ice blocks were being conveyed directly into special refrigerator cars for shipment, without intermediate storage.

The Dioxice plant was built in 1939. It ships its product directly to four distributors, the easternmost at Akron, Ohio, and the westernmost at Los Angeles, California.

Ute Carbonic Co.—This plant is situated about four miles northwesterly from the village of Bueyeros ; it is immediately adjacent to the Adams No. 1 State well, and draws gas also from the Gonzales well a mile to the southwest, and from the Gallagher well some three miles northerly.

The Ute Carbonic Co. manufactures dry ice by a low-pressure method, and takes its gas from a low-pressure zone much higher than the beds producing for the plant near Solano. Pressure in all the wells is adequate for forcing the gas through pipes to the plant. This plant was built in 1940, and it is reported that no diminution of pressure has resulted from operations.

Shipment from this plant is entirely by truck, with principal markets reported as Wichita, Kansas; Oklahoma City, Oklahoma; and El Paso, Texas. Operation during the summer is in three shifts, at full capacity.

Timmons Carbonic Co.—This plant is the only one in New Mexico now marketing liquid carbon dioxide; it draws its gas from the same zone as that feeding the Ute Carbonic Co. wells. The plant is situated at the Kerlin No. 1 well, nearly a mile southerly from the Ute Carbonic Co. plant, and some three miles northwesterly from Bueyeros. In July, 1942, this plant was operating on two shifts, with all of its gas coming from a single well. The plant has been in operation about two years, with pressure from the well reported as not yet diminished under operating conditions.

All of the liquid carbon dioxide produced by this plant is shipped to Denver, to the Cardox Corp. The major use of liquid carbon dioxide in Colorado is as an improvement over explosives, in coal mining.

Witt Ice and Gas Co.—This plant is the oldest carbon dioxide plant in the State, and is reported td be the first plant in the United States to manufacture dry ice by a low-pressure process. Its first unit was completed in 1934, and another unit was added later. It is situated at the station of Witt, five miles north of Estancia on the Atchison, Topeka and Santa Fe railway, and draws its gas from several wells in the Estancia Valley field. Gas is piped from the wells to the plant a maximum distance of six miles under its own pressure, but it is reported that the full flow of gas cannot be utilized at present, as water is encroaching on some of the old wells, and a considerable back pressure has to be maintained to minimize water flow. Much of the early drilling in this field was experimental, if not indeed haphazard, and some of the older wells are proving troublesome. Some new drilling is under way, which should constitute a considerable improvement. In July, 1942, this plant was operating at only part capacity, limited largely by water troubles then in process of adjustment.

The Witt Ice and Gas Co. ships to warehouses in 12 cities, one at Albuquerque, four in California, three in Texas, and the easternmost at St. Louis, Missouri, and Decatur, Illinois. Dry ice can be loaded directly on the cars, or kept in insulated storage bins ready for shipment.

In addition to manufacturing solid carbon dioxide, the Witt Ice and Gas Co. supplies compressed carbon dioxide gas, in steel bottles, to local markets that can be reached by truck. Bottled gas is used principally in the carbonation of beverages, and to a smaller extent in fire extinguishers.

Available data, some of it contradictory or not confirmed, on all of the carbon dioxide wells in New Mexico is presented in the accompanying table.

FUTURE PROSPECTS

All of the plants now operating in New Mexico can market all that they can produce during summer seasons. Present plans for expansion are in abeyance, inasmuch as priorities and national defense demands make it difficult to get new machinery, and even replacement and repair material.

Prospects seem favorable for further development by more drilling in the Estancia Valley, and deeper drilling in the Bueyeros field. The neglected area near Wagon Mound, the Sierra Grande uplift, and the demonstrated occurrence of carbon dioxide east of Maxwell seem to warrant further critical attention when conditions make it possible to consider the building of new plants.

BITUMINOUS SANDSTONE

DEPOSITS NEAR SANTA ROSA, GUADALUPE COUNTY

The following notes are based largely on Winchester's discussion.[1] Much of the information was obtained by Winchester from Mr. Vincent K. Jones of the New Mexico Construction Co.

The Santa Rosa sandstone (Triassic) in Guadalupe County near Santa Rosa is saturated with bituminous material over a considerable area. In order to determine the continuity, character, and extent of the saturation, the New Mexico Construction Co. has drilled approximately 100 core-drill holes covering some 3,000 acres on the Preston Beck, Jr., Grant about seven miles north of the town of Santa Rosa. These holes have proved a

[1] Winchester, D. E., The oil and gas resources of New Mexico: N. Mex. Bur. Mines Bull. 9, p. 208. 1933.

saturated zone from 10 to 60 feet thick. In only one hole was saturation absent.

The saturated sand is a well-consolidated cross-bedded rock composed of sharp quartz grains and containing from four to eight percent of bituminous substance, about one-fifth of which will evaporate at air temperature over a period of several weeks. Some parts of the sand are found to be completely saturated with asphaltic material, while other parts contain no asphaltum. The fresh rock when extracted yields a very ductile asphalt which has a penetration of approximately 230 at 77° F.

In some of the core holes a heavy black viscous oil which would flow at ordinary temperatures was found in pockets. In one hole a small flow of water was found trapped in such a way as to be under slight artesian pressure. Developments indicate that this deposit of bituminous sandstone contains approximately 2,000,000 tons having a residual asphaltic content of five percent. The overburden, which is composed of non-saturated sandstone, ranges in thickness from a few inches to forty feet.

For several years a quarry was operated at a place where there is little or no overburden and where the saturated sandstone is about 50 feet thick. More than 1,000 tons of the rock was extracted, most of which was used for pavement construction within the town of Santa Rosa. The rock was crushed in a small plant to minus $1/_4$-inch size, mixed with 1 to 1½ percent of asphalt and a small amount of gasoline or naphtha, and laid cold. Apparently one inch of this material laid on a substantial foundation is all that is required for heavy traffic pavement.

A visit in July, 1942, disclosed that the plant was not operating. However, it is under supervision of a caretaker and is ready to be re-opened at any time. Two Government departments are reported to have investigated the deposit and plant, with the possibility in mind of using the asphalt rock in construction of defense plants and airports.

DEPOSITS IN McKINLEY COUNTY

Approximately 20 miles northeast of Gallup on the north fork of the Rio Puerco, a sandstone reported to belong to the Dakota (Cretaceous) is saturated with a paraffin-base oil over a relatively wide area. According to information furnished to D. E. Winchester by J. M. McClave of Denver, Colorado, the saturated sandstone has a thickness of not over 40 feet. The sand is coarse-grained and hard. Analysis shows an oil content of as much as 24 percent. No economic use for this sand has been developed.

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