NEW MEXICO SCHOOL OF MINES

STATE BUREAU OF MINES AND
MINERAL RESOURCES

E. H. WELLS
President and Director

BULLETIN NO. 9

The Oil and Gas Resources of New Mexico

By

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SOCORRO, N. M.
1933

CONTENTS

Page

The State Bureau of Mines and Mineral Resources 11
Board of Regents 11
Publications 11
Preface 12
Introduction 13
Purpose and scope of report 13
Well logs 13
Acknowledgments 13
Geography and general geology 15
The Rocks 17
General features 17
Pre-Cambrian rocks 17
Sedimentary rocks 18
General succession 18
Cambrian system 18
Bliss sandstone 18
Ordovician system 19
General features 19
El Paso limestone 19
Montoya limestone 22
Silurian system 22
Fusselman limestone 22
Devonian system 23
Percha shale 23
Carboniferous system 23
General features 23
Lake Valley limestone and other limestones of Mississippian age 24
Magdalena group (Pennsylvanian) 24
Hueco limestone 25
Abo sandstone (Permian) 25
Chupadera formation (Permian) 26
Gym limestone (Permian) 28
Castile gypsum and Rustler limestone 29
Triassic system 29
General relations 29
Moenkopi formation 30
Shinarump conglomerate 30
Poleo sandstone 30
Chinle formation 31
Dockum group 31
Lobo formation (Triassic ?) 32
Jurassic system 32
Wingate sandstone 32
Todilto formation 33
Navajo sandstone 34
Cretaceous system 34
General relations 34
Morrison formation (Cretaceous?) 34
Sarten sandstone and associated limestones (Comanche) 35
Purgatoire formation (Comanche) 35
Dakota sandstone 36
Colorado group 36
Mancos shale 37

The Rocks—Continued Page
Sedimentary rocks—Continued
Cretaceous system—Continued
Pierre shale ... 38
Trinidad sandstone ... 38
Vermejo formation ... 38
Mesaverde group ... 39
Lewis shale ... 40
Pictured Cliffs sandstone ... 41
Fruitland formation ... 41
Kirtland shale ... 41
McDermott formation (Cretaceous ?) ... 41
Tertiary system ... 42
General features ... 42
Ojo Alamo sandstone (Tertiary?) ... 42
Galisteo sandstone (Tertiary ?) ... 43
Raton formation (Eocene) ... 44
Puerco formation ... 44
Torrejon formation ... 45
Wasatch formation ... 45
Tohachi shale and Chuska sandstone ... 46
Unclassified early Tertiary deposits ... 46
Santa Fe formation (Miocene and Pliocene) ... 47
Ogallala formation (Miocene and Pliocene) ... 47
Quaternary system ... 48
Bolson deposits ... 48
Saline deposits ... 48
Dune sands ... 48
Glacial deposits ... 49
Gila conglomerate ... 49
Igneous rocks ... 49
Intrusive rocks ... 49
Volcanic rocks ... 51
General geology of oil and gas ... 55
General structural and stratigraphic features of oil and *gas* accumulations in New Mexico ... 56
Summary of oil and gas possibilities ... 57
General features of oil and gas development and production ... 59
Northwest Area ... 60
Geography and geology ... 60
Oil and gas ... 60
San Juan Basin ... 60
Geography and geology ... 60
Oil and gas ... 63
Barker dome and Southern Ute dome ... 65
Chimney Rock dome ... 66
Hogback field ... 66
Location ... 66
History ... 66
Geology ... 67
Structure ... 68
Production ... 69
Rattlesnake field ... 69
Location ... 69
History ... 69
Geology ... 71
Structure ... 74
Developments ... 75
Characteristics of the oil and gas ... 75

Northwest Area—Continued Page
San Juan Basin—Continued
Rattlesnake field—Continued
Production from the Pennsylvanian rocks 79
Production methods 80
Biltabito dome 81
Table Mesa field 81
Location 81
History 81
Geology 82
Structure 83
The oil 83
Tocito dome 84
Beautiful Mountain anticline 84
Stoney Buttes anticline 85
Seven Lakes area 85
Bonita (Cathedral Rocks) anticline 86
Hospah dome 87
Carica anticline 90
Walker (Ambrosia Lake) dome 91
San Mateo dome 92
Chavez (Miguel Creek) anticline 92
French Mesa anticline 92
Gallina Mountain anticline 95
El Vado anticline 95
Dulce and Monero domes 96
Bloomfield oil field 97
Aztec gas area 98
Blanco district 99
Kutz Canyon gas field 99
Miscellaneous structures 101
Zuni Basin 101
General geography and geology 101
Cedar Butte dome 103
Defiance (Torrivio) anticline 103
Gallup dome 103
Ojo Caliente anticline 103
Pinon Springs (Manuelito) anticline 104
Acoma Basin 105
Alamosa Creek and Rio Salado valleys 105
General features 105
Geology 106
Red Lake anticline 107
Cow Springs anticline 110
La Cruz anticline 110
Puertecito district 110
Topography 110
Geology 110
Structure 111
Payne anticlinal dome 111
Field anticlinal dome 112
Miller anticline 113
Lawson anticline 113
(Upper) Red Lake anticline 114
Miscellaneous anticlinal structures 114
Acoma anticline 114
J. Q. Meyers anticline 114
Mesa Lucero anticline 115
South Suwanee dome 115

Page

Northeast Area 116
General geography and geology 116
Oil and gas 116
Sierra Grande uplift and associated structures 117
General relations 117
Cimarron dome 117
Capulin anticline 117
Abbott, Chico, Jaritas, Lunsford and Rito del Plano structures 119
Canadian anticline 121
Wagon Mound anticline 121
Cherryvale dome 123
Conclusions regarding the Sierra Grande uplift 123
Vermejo Park dome 126
Turkey Mountain dome 126
Esterito dome 127
Eastern San Miguel County and adjacent areas 127
General features 127
Geology 128
Structures 130
Bald Hill dome 130
Bell Farm anticline 130
Canadian anticline 130
Carpenter Gap anticline 130
Divide anticline 130
Dripping Springs anticline 131
Hudson anticline 131
Johnson dome 131
Media anticline 131
Mesa Rica anticline 131
Monilla Creek anticline 131
Pino Mesa anticline 132
Rattlesnake anticline 132
Triangle dome 132
V. K. Jones dome 132
Structures in southern Quay County 132
General features 132
Benita anticline 133
Jordan Ridge anticline 134
Frio dome 137
Other anticlinal structures in the Northeast Area 137
Southeast Area 139
Geography and general geology 139
Oil and gas 145
Artesia field 146
History and production 147
Stratigraphy 148
Structure 150
Reservoir rocks 151
Oil and gas accumulation 151
The oil 152
The gas 152
Maljamar area 153
Hobbs field 154
Location and topography 154
History 154
Stratigraphy 155
Tertiary system 156
Triassic system (Dockum group) 156
Shale 156

Southeast Area—Continued Page
Hobbs field—Continued
Stratigraphy—Continued
Triassic system (Dockum group)—Continued
Santa Rosa sandstone 156
Permian system 156
Post-Rustler red beds 156
"Evaporite Series" 156
"White Lime" 157
Dark anhydritic limestone 157
Structure 159
Land ownership 159
Production 159
Restrictions of production 162
The oil 163
The gas 165
Water 166
Drilling and production methods 167
Future development 168
Getty pool 168
Lea pool 170
Eunice area 172
Cooper area 175
Jal area 177
Miscellaneous structures 180
Median Area 182
General geography and geology 182
Oil and gas 182
Upper Rio Grande valley 182
Rio Grande valley in central New Mexico 183
Noe dome 186
Lower Rio Grande valley 186
Estancia Valley 188
General geography and geology 188
Structure 190
Estancia anticline 190
Wilcox anticline 190
Buffalo anticline 191
Punta del Agua anticline 191
East side of the valley 191
Jornada del Muerto 193
Local structure 194
Chupadera anticline 194
Location and topography 194
Geology 194
Structure 196
Oil and gas possibilities 196
Prairie Springs anticline and dome 198
Tularosa Basin 198
General geography and geology 198
Structure and oil possibilities 200
Miscellaneous structures in the Median Area 201
Galisteo anticline 201
Tijeras anticline 201
Southwest Area 202
General geography and geology 202
Oil and gas 203
Refining and transportation 204
Oil refineries 204

Page

Refining and transportation—Continued
- Natural gasoline plants 205
- Oil pipe lines 206
- Natural gas pipe lines 206

Bituminous sandstone 208
- Deposits near Santa Rosa, Guadalupe County....208
- Deposits in McKinley County....209

Geophysics and its use 210
- General features 210
- Gravimetric methods 211
- Magnetic methods 212
- Self-potential electric methods 212
- Radioactivity methods 212
- Geothermal method 213
- Seismic methods 213
- Electrical methods (except self-potential) 214

Selected bibliography 216

Index 219

ILLUSTRATIONS

Page

Plate I. Relief map of New Mexico 15

II. Geologic map of New Mexico ....In pocket

III. A, Limestone of Magdalena group in canyon of Rio Salado; B, North end of Sheep Mountain, (Bliss, El Paso, Montoya, Percha, Lake Valley and Magdalena formations).... 24

IV. A, Limestone of Chupadera formation southeast of Cloudcroft; B, Capitan limestone and Delaware Mountain formation at Guadalupe Point Texas.... 26

V. A, Badlands of Dockum group 10 miles east of Tucumcari; B, Dakota sandstone at Bluewater Falls 32

VI. A, looking east across Baca anticline, Harding County; B, Wingate sandstone capped by gypsum member of Todilto near Gallina Post Office.... 34

VII. A, Surface of recent lava flow near Carrizozo; B, Cretaceous and Navajo sandstones northeast of Zuni; C, Northwest end of Zuni Mountain uplift . 36

VIII. A, Greenhorn limestone near East Las Vegas; B, Northern edge of Llano Estacado near Tucumcari; C, Typical plains with sinks, Chupadera formation, Lincoln County 38

IX. A, Upper Mesaverde formation near Crown Point; B, Point Lookout sandstone near Chimney Rock; C, Ship Rock 40

X. A, Looking south across Walker dome; B, Wingate sandstone near Laguna 43

.XI. A, Looking north along crest of French Mesa anticline; B, Canadian Canyon near Sabinoso (Wingate, Morrison an Dakota)....45

			Page
Plate	XII	A, Escarpment near Gallegos, Harding County; B, Bituminous sand quarry of the New Mexico Construction Co., near Santa Rosa; C, New Mexico Construction Co. treating plant,	48
	XIII.	Map of Permian Salt Basin in New Mexico and Texas	55
	XIV.	Map of New Mexico, showing divisions of the State and areas covered by detailed maps	58
	XV.	Section across San Juan Basin	60
	XVI.	Map of northwestern San Juan County, showing geologic structure	In pocket
	XVII.	Map of part of Rio Arriba County, showing geologic structure	In pocket
	XVIII.	Map of Bloomfield-Kutz Canyon area	98
	XIX.	Map showing structure in valleys of Rio Salado and Alamosa Creek	105
	XX.	Geologic map and section of the Puertecito district	112
	XXI.	Map of Vincent K. Jones and Pino Mesa domes	132
	XXII.	Map showing geologic structure of part of Quay County	134
	XXIII.	Oil and gas map of New Mexico	In pocket
	XXIV.	East-west section in Eddy and northern Lea counties, based on well logs	144
	XXV.	North-south section in eastern Lea County, based on well logs	146
	XXVI.	Map of Artesia field	In pocket
	XXVII.	Map of Maljamar area	154
	XXVIII.	Map of Getty pool	168
	XXIX.	Map of Eunice area	172
	XXX.	Map of Cooper area	176
	XXXI.	Map of Jal area	178
	XXXII.	A, Continental Oil Co.—Santa Fe Corp. refinery at Farmington; B, Continental Oil Co. refinery at Albuquerque; C, Crude oil stabilization plant at Rattlesnake lease	204
	XXXIII.	A, Continental-Shell gasoline plant, Hobbs field; B, Malco refinery at Artesia; C, Continental Oil Co. refinery at Artesia	206
Figure	1.	Map of Rattlesnake dome	70
	2.	Map of Hospah dome	88
	3.	Sections across the Zuni Basin	102
	4.	Map showing larger structural features in northwestern New Mexico	119
	5.	Section across Colfax and Union counties	120
	6.	Section through Turkey Mountain	127
	7.	Map of Esterito dome	128
	8.	Map showing anticlinal folding in southeast New Mexico	141
	9.	Map of Hobbs oil field	158
	10.	Map of Lea pool	171
	11.	Map of Chupadera anticline	195

THE STATE BUREAU OF MINES AND MINERAL RESOURCES

The State Bureau of Mines and Mineral Resources of New Mexico was established by the New Mexico Legislature of 1927. It was made a department of the New Mexico School of Mines, and its activities are directed by the board of regents of the school. Its chief object is to assist and encourage the development of the mineral resources of the State.

PUBLICATIONS

Bulletin No. 1. The Mineral Resources of New Mexico—Fayette A. Jones, 1915. (Out of print.)

Bulletin No. 2. Manganese in New Mexico. H. Wells, 1918. (Out of print.)

Bulletin No. 3. Oil and Gas Possibilities of the Puertecito District, Socorro and Valencia Counties, New Mexico—E. H. Wells, 1919. (Out of print.)

Bulletin No. 4. Fluorspar in New Mexico—W. D. Johnston, Jr., 1928. (Price 60 cents.)

Bulletin No. 5. Geologic Literature of New Mexico—T. P. Wootton, 1930. (Price 25 cents.)

Bulletin No. 6. Mining and Mineral Laws of New Mexico—C. H. Fowler, 1930. (Price 25 cents.)

Bulletin No. 7. The Metal Resources of New Mexico and their Economic Features—S. G. Lasky and T. P. Wootton. (In preparation.)

Bulletin No. 8. The Ore Deposits of Socorro County, New Mexico—S. G. Lasky, 1932. (Price 60 cents.)

Bulletin No. 9. The Oil and Gas Resources of New Mexico—Dean E. Winchester, 1933. (Price $1.50.)

NOTE.—Bulletins 1, 2 and 3 were issued by the Mineral Resources Survey of the New Mexico School of Mines.

PREFACE

By E. H. WELLS

New Mexico has been an important producer of minerals for more than a century. The mining of copper ores at Santa Rita, Grant County, began in 1801, and these deposits have been worked almost continuously since that time. The Old Placers near Santa Fe, discovered in 1828, supplied the first placer gold mined west of the Mississippi River. Coal deposits of the State have yielded large amounts of coal annually since 1881.

Oil and gas in New Mexico have attained importance only in the last few years. The first important discovery of oil occurred near Dayton, Eddy County, at the Brown Well, which was drilled in 1909. Oil was obtained in small quantities from this well and from wells drilled in the Seven Lakes area, McKinley County, in 1911 and 1912, but important commercial production was not assured until the discovery of the Hogback field, San Juan County, in 1922. In 1923 the discovery well of the Artesia field, Eddy County, was drilled. The proving of these fields aroused a lively interest in the oil and gas possibilities of the State, and many geologists began to study and map areas considered promising for development. Wells were drilled in practically every county in which sedimentary rocks are present, and a number of additional fields of small or moderate size were found. In places considerable gas accompanied the oil, and in the Jal field in Lea County, discovered in 1927, exceedingly large quantities of gas were encountered.

The Hobbs field in Lea County was discovered in 1928. During the two years following, approximately 130 wells were drilled in the field, their total rated potential production being over 1,000,000 barrels of oil per day. Largely as the result of the yield from Hobbs, New Mexico increased its production of oil from 1,830,000 barrels in 1929 to 10,377,000 barrels in 1930.

The developments at the Hobbs field in 1929 and 1930 greatly increased the interest of oil operators and others in oil and gas in New Mexico, and a flood of requests for information regarding the geology and oil and gas possibilities of the State was received by State officials. The published information on the subject is relatively meagre and scattered, and most of the details, particularly of structure, have never been published. In the fall of 1930, the State Bureau of Mines and Mineral Resources of the New Mexico School of Mines decided to assemble the available information relating to oil and gas in the State and make the information available to the public in the form of a bulletin. This project was assigned to Mr. Dean E. Winchester, consulting oil geologist of Denver, Colo., formerly geologist of the United States Geological Survey, and work on the report began in November, 1930. Mr. Winchester's bulletin should be of distinct value to those who are engaged in developing the oil and gas resources of New Mexico.

The Oil and Gas Resources of New Mexico

By

Dean E. Winchester

INTRODUCTION

PURPOSE AND SCOPE OF REPORT

The purpose of this report is to present information dealing with the oil and gas resources and possibilities of New Mexico. In its preparation the writer has attempted to assemble all the available reports, maps, well logs, and other pertinent data. Out of this mass of information, the material considered most salient has been selected and has been incorporated in the report. 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 sections of the report dealing with the geology of the State are necessarily hardly more than a summary, and some of the areas which, on the basis of the available data, are highly interesting are only briefly considered. Innumerable problems of geology, structure, etc., have arisen, and some of these are mentioned primarily to arouse interest, in the hope that others may find the solution.

WELL LOGS

One very important by-product of the studies leading up to the final writing of this report is the record of drilling operations and the file of well logs. Prior to January 1, 1932, some 1,400 wells having a combined footage of more than 3,000,000 feet had been drilled for oil within the State. The drilling of these wells represents an expenditure of probably not less than $100,000,000. More than one-third of this footage has been drilled in Lea County since January 1, 1928. The State Bureau of Mines and Mineral Resources now has at Socorro a fairly complete well-log file, where it can be consulted by those interested. Copies of well logs may be obtained at a nominal cost.

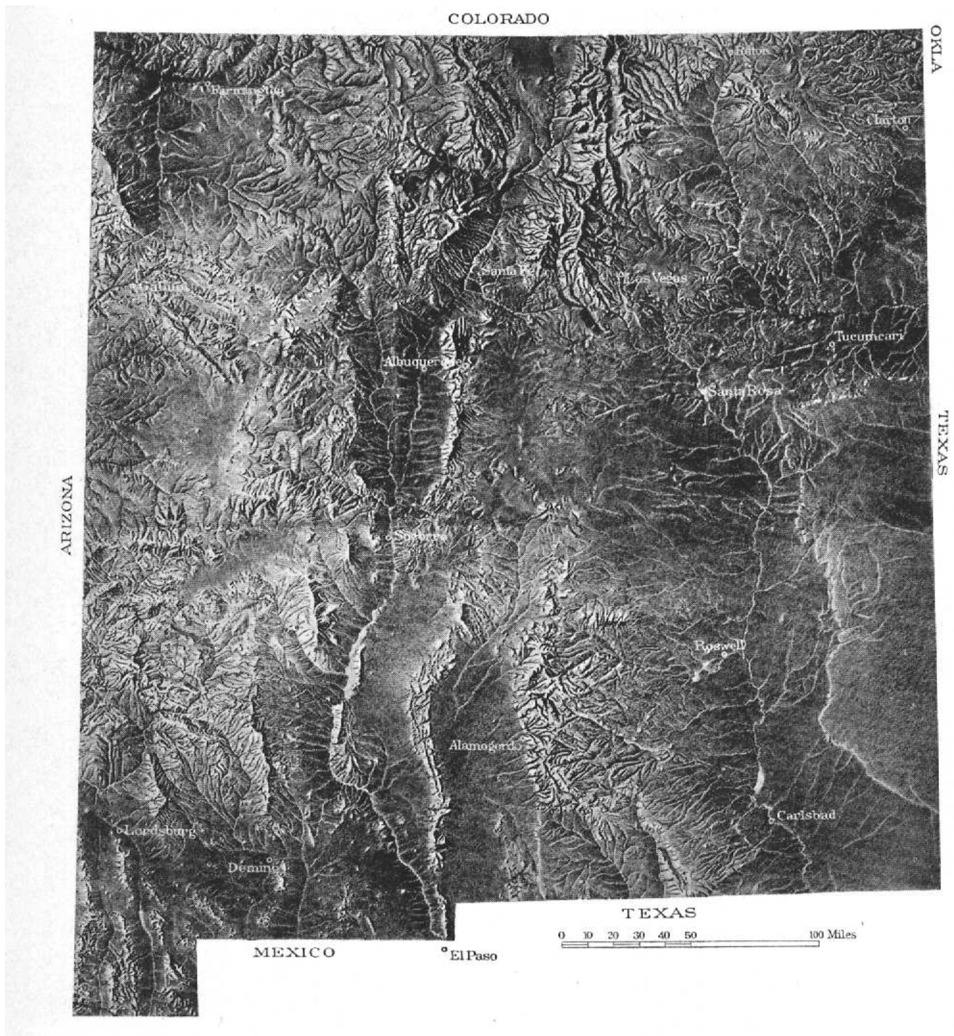
ACKNOWLEDGMENTS

In the assembling of material, maps, logs, historical and production information, etc., the companies and geologists who at one time or another have been concerned with the search for oil and gas in the State, its development, production, transportation, refining or marketing, have given their most hearty cooperation, and to all of these the writer wishes to express his thanks and appreciation. The United States Bureau of Mines and the United States Geological Survey furnished chemical analyses, drilling data and other information, and the Survey supplied many of the illustrations presented. The writer has quoted freely from publications of the United States Geological Survey, particularly those by N. H. Darton on the geology and structure of the State.

The writer wishes in particular to express his appreciation to the officials of the following companies, whose cooperation made the report possible: The California Co., Continental Oil Co., Cranfill-Reynolds Co., Empire Gas & Fuel Co., Geo. F. Getty, Inc., Gypsy Oil Co., Humble Oil & Refining Co., Midwest Refining Co., Ohio Oil Co., Phillips Petroleum Co., Shell Petroleum Corp., and The Texas Co.

The following geologists and individuals have also assisted most generously, not only with maps, logs, reports, etc., but with ideas and criticisms: Harry A. Aurand, Denver, Colo.; R. Clare Coffin, Denver, Colo.; C. E. Dobbin, Denver, Colo.; F. S. Donnell, Santa Fe, N. Mex.; John A. Frost, Farmington, N. Mex.; R. L. Heaton, Denver, Colo.; Tolbert R. Ingram, Denver, Colo.; C. D. Johnson, Denver, Colo.; E. Floyd Miller, Tulsa, Okla.; Emerson M. Parks, Denver, Colo.; E. P. Rushmore, Denver, Colo.; C. E. Shoenfelt, Denver, Colo.; C. G. Staley. Hobbs, N. Mex.; E. U. von Buelow, Denver, Colo.; and John H. Wilson, Golden, Colo.

The work of assembling information and the preparation of the bulletin has been under the supervision of E. H. Wells, director of the State Bureau of Mines and Mineral Resources and State Geologist, whose con-stant interest in the project has been most helpful. The writer has been ably assisted in the office preparation of maps, logs, etc., by Ralph W. Phillips and Myrtle Haldeman.



Relief map of New Mexico. (Courtesy of U. S. Geological Survey.)

GEOGRAPHY AND GENERAL GEOLOGY

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. (See Plate I.) Its population in 1930 was 423,317.

The Rio Grande, whose source is in southern Colorado, flows in a general southward direction completely across the State to El Paso, Tex., 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 and the Pacific Ocean, 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 Mountin 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 bed-rock 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, Tex.

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 Liana Estacado or Staked Plains which are covered with a mantle of sand 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 eastward 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 rims. 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 tq 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 & 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, Tex., and a branch from Clovis southwest to Roswell. Artesia and Carlsbad, N. Mex., and Pecos, Tex., in the Pecos Valley. The Southern Pacific railway crosses the southwestern part of the State to El Paso, Tex., 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, Tex. 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, Colo., 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

The rocks occurring in New Mexico have been described by Darton,[1] and the following quoted general and detailed descriptions of them are from his report. The general geologic map, Plate II, which accompanies this report, is taken largely from the "Geologic Map of New Mexico" by N. H. Darton published by the United States Geological Survey in 1928.

GENERAL FEATURES

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. [2] 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

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.

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,[3] 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, supplementing the earlier statements by Stevenson [4] and Keyes. [5]

Near Picuris, southwest of Taos, and on the Rio Grande near Glen-woody is granite or granite gneiss with basic intrusive rocks and a series of metamorphosed conglomerate, quartzite, and schist with many secondary

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

[2] Since Darton's report was written several wells have been drilled more than 5,000 feet deep without reaching basement rocks.

[3] Lindgren. Waldemar. Graton, L. C.. and Gordon. C. H.. The ore deposits of New Mexico: 1J. S. Geol. Survey Prof. Paper 68, 1910.

[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., 1881.

[5] Keyes, C, R., The fundamental complex beyond the southern end of the Rocky Mountains: Am. Geologist, vol. 36, pp. 112-122, 1905.

minerals. The pre-Cambrian rocks of the mountains east of Taos have been described by Gruner. [1] In the Hopewell and Bromide districts in the pre-Cambrian area in the eastern part of Rio Arriba County, Graton[2] observed gneissic granite cutting dark dioritic gneiss and cut in turn by porphyry of several kinds. Many ridges and knobs of quartzite also occur, and in the eastern part of the district there is some biotite-chlorite schist.

According to Schrader [3] the principal pre-Cambrian rock of the Nacimiento and Zuni Mountains is massive red granite, but schist also occurs. The pre-Cambrian rocks in the Silver City region have been described by Paige, [4] who found that granite occupies a considerable area in the Burro Mountains and the western flanks of the Little Burro Mountains. Small outcrops of granite appear in other uplifts in the region and minor masses of schistose and quartzitic rocks are included in places. The pre-Cambrian rocks of Luna County [5] consist mostly of coarse red to gray granite, and the largest exposure is in the Florida Mountains. Some small dikes of diorite amphibolite also occur. Gneiss is exposed in the Klondike Hills, and schist occurs in a breccia in Fluorite Ridge, north of Deming. Granite is exposed in the Hatchet Mountains, [6] in the northern part of Cooks Range and in places along the east foot of the Mimbres Mountains. The Hills of Pedernal and Cerrito del Lobo, in Torrance County, consist of white quartzite, but the southern extension of this old range is gneiss, except Chameleon Hill, which is granite. Much quartzite appears in the Sandia Mountains.

SEDIMENTARY ROCKS

GENERAL SUCCESSION

The unmetamorphosed sedimentary rocks in New Mexico range in age from Cambrian to Recent, but portions of several geologic periods are not represented by strata and the formations vary greatly in distribution.

The formations in the different parts of the State are correlated in the table, pages 20 and 21.

CAMBRIAN SYSTEM

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

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[1] Gruner, J. W., Geologic reconnaissance of the southern part of the Taos Range, New Mexico: Tour. Geology, vol. 28, pp. 731-742. 1920.

[2] Graton. L. C., op. cit. (U. S. G. S. Prof. Paper 68), pp. 124-128.

[3] Schrader, F. C.. op. cit. (U. S. G. S. Prof. Paper 68), pp. 141-146.

[4] Paige, Sidney, U. S. Geol. Survey Geol. Atlas, Silver City folio (No. 199), p. 3, 1916.

[5] Darton, N. H., Geology and underground water of Luna County, N. Mex.: U. S. Geol. Survey Bull. 618, pp. 19-23, 1916; U. S. Geol. Survey Geol. Atlas, Deming folio (No. 207), pp. 3-4, 1917.

[5] Dayton, N. H., Geologic structure of parts of New Mexico: U. S. Geol. Survey Bull. 726, p. 274, 1922.

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 6 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.

ORDOVICIAN SYSTEM

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, Tex., 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 Victorio 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. * * *

CORRELATION OF GEOLOGIC FORMATIONS IN NEW MEXICO

Based largely on data supplied by the United States Geological Survey

AGE	NORTHWESTERN	CENT. NORTHERN	NORTHEASTERN	SOUTHWESTERN	CENT. SOUTHERN	SOUTHEASTERN
Pleistocene				Palomas gravel 450-2000	Mescalero sands	Mescalero sands
Pleiocene		Santa Fe fm. 100-1200	Santa Fe fm. 0-150 + / Ogallala fm.	Datil fm. 0-2000± (late Tert.) / Gila cgl. 1000±		Ogallala fm.
Miocene						
Oligocene						
Eocene	Wasatch fm. 250-2000 (Lower Eocene) Torrejon fm. 300± Puerco fm. 0-500±		Raton fm. 600-1600			
Eocene (?)	Ojo Alamo ss. 0-400 / Animas fm. 0-2670	Galisteo ss. 700-3500				*** 600-800
Upper Cretaceous (?)	McDermott fm. 0-400					
Upper Cretaceous	Kirtland sh. 700-1180 / Farmington ss. memb. 0-480		Montana group: Vermejo fm. 425 / Rail Canyon ss. memb. 0-50			
	Fruitland fm. 190-530					
	Pictured Cliffs ss. 50-275		Montana group: Trinidad ss. 0-150			
	Lewis shale 76-2290	Lewis sh. 0-2000				
	Mesaverde group: Cliff House ss. 0-1076 Menefee fm. 272-1200 Point Lookout ss. 60-300	Mesaverde fm.	Montana group: Pierre sh. 3000±	Chamiso fm. 0-1850 (Probably=Mesaverde) (?)	Montana group 685±	
	Mancos sh. 750-2000: Tocito ss. lentil 0-35 735±	Mancos sh. 900-2200: Punto de la Mesa ss. memb. Tres Hermanos ss. memb. 0-155	Colorado group: Apishapa sh. 500, Timpas ls. 50 / Niobrara fm. Carlile sh. 150-250, Greenhorn ls. 50-80, Graneros sh. 150-160 / Benton sh.	Miguel fm. 0-2080 (Colorado age): Bell Mt. ss. memb. 75± Gallego ss. memb. 50-90 *** 800-1000	Colorado group 895±	
	Dakota ss. 50-250	Dakota ss. 50-250	Dakota ss. 100±	Dakota ss. 0-40	Dakota ss. 200±	
Lower Cretaceous (Comanche)		Purgatoire fm. 150-200	Purgatoire fm. 0-140	Sarten ss. 0-300 / Beartooth quartzite 90-125 (Upper Cret.) Ls. of Comanche age 0-400	Comanche 0-?	
Cretaceous (?)	McElmo fm. 0-200	Morrison fm. 0-310	Morrison fm. 150-300 (?)			
Jurassic	Navajo ss. 100-650 Todilto fm. 0-100± Wingate ss. 0-400 Puertecito	Navajo ss. 250-600 Todilto fm. 15-100± Wingate ss. 80-400	Navajo ss. thin Todilto fm. thin Wingate ss. 0-80	(?)		

Upper Triassic	Chinle fm. 850-900; fm. 1150-1250	Chinle fm. 250-950	*** 800-1500; Dockum group 800±	Lobo fm 0-350 (Triassic?)	Triassic red beds 340±	Red beds of Pecos Valley; Dockum group 800±; ***
Upper (?) Triassic	Shinarump cgl. 10-120	Shinarump cgl. 50-80; Poleo ss. 50-150	Santa Rosa ss. 50-100			Santa Rosa (?) ss.
Middle Triassic						
Lower Triassic	Moenkopi fm. 400-900					Rustler ls.
Permian	Manzano group: Chupadera fm 175-1200; Abo ss. 600-800	Chupadera fm. 100-1200; San Andres ls. 500±; Yeso fm 1200±; #; Abo ss. 600-900	Manzano group: Chupadera fm. 600-1200; #; Abo ss. 600-1000	Gym ls. 0-1200	San Andres ls. 500±; Yeso fm. 1260±; #; Abo ss. 0-1000	Castile gypsum 0-2800; Chupadera fm. 1500*; Guadalupe group: Carlsbad ls, Seven Rivers Gyp., Queen ss., Capitan ls. 0-2500*, Delaware Mt. fm. 0-2000*; Abo ss 600-700
Pennsylvanian	Magdalena fm. 0-1200±	Magdalena group: Madera ls. 0-500; Sandia fm 400±	Magdalena fm. 600-1800±	Fierro ls. 0-1200; Magdalena fm. 0-800	Madera ls. 300-500; Sandia fm. 500-700	Hueco ls. 2000±
Mississippian	**	Lake Valley ls. 0-210	**	Lake Valley ls. 0-500	Lake Valley ls. 125±; Kelly ls. 125	**
Devonian				Percha sh (Upper Devonian)	Percha sh. (Upper Devonian)	
Silurian				Fusselman ls 0-300	Fusselman ls.	
Upper Ordovician				Montoya ls. 250-300	Montoya ls. 0-400 (?)	
Middle Ordovician						
Lower Ordovician				El Paso ls. 500-900 (?)	El Paso ls. 0-1000 (?)	
Cambrian				Bliss ss. 30-200 (Upper Cambrian)	Bliss ss. 0-300 (Upper Cambrian)	
Pre-Cambrian	Granite and schist	Slate, quartzite, granite, etc	Granite, slate, quartzite and schist	Granite, etc.	Granite, schist quartzite, etc.	Granite, etc.

Dashed lines indicate unconformities
* Correlations in dispute.
# Glorieta ss. memb. 0-200

** Mississippian and older Paleozoic strata may be present but proof is lacking.
*** indicates intervening beds.

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 6-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 6 to 8 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 6 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

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

PERCHA SHALE

The Devonian system is represented in southern New Mexico by a widespread deposit of black shale named the Percha shale, from Percha Creek, near Kingston. It represents a portion of later Devonian time, and although accordant in attitude with overlying and underlying formations it is separated from them by breaks of sedimentation. It is absent in the Franklin Mountains and apparently also in the Permian overlap in the Florida and Victorio Mountains. It attains a thickness of nearly 500 feet in part of the Silver City region but is less than half as thick in the Cooks Range, the Sierra Caballo, and the Mimbres and Hatchet Mountains, 160 feet at Lake Valley, and about 100 feet in the San Andres and Sacramento Mountains. It thins out in the northern part of the San Andres Mountains but probably is represented by some red shale overlying Montoya strata in the southern part of the Oscura Mountains. It is absent in the Magdalena Mountains and other ranges in central and northern New Mexico. In most places the lower beds are fissile shales and the upper beds of gray shale contain layers of slabby and nodular limetone.

Many fossils occur in the Percha shale especially in the limy beds of its upper member. * * *

CARBONIFEROUS SYSTEM

GENERAL FEATURES

Rocks of the Carboniferous system occupy all parts of New Mexico except the higher portions of some of the uplifts, where they have been removed by erosion. Representatives of the lower Mississippian occupy most of the southwestern part of the State and probably are present under some of the southeastern part, but they appear to be absent in the Franklin, Florida, and Victorio Mountains. The Pennsylvanian series, represented by the Magdalena group, is widespread, but it is absent about Pedernal Mountain, in the east central area, in the Zuni Mountain region, and in part of Luna County. The Permian series, represented by the Abo sandstone, Chupadera formation, and Gym limestone, is still more widespread and becomes very thick under the eastern third of the State, especially to the southeast, where the Chupadera formation merges into the Guadalupe group.[1] In the Pedernal and Zuni Mountain regions the lower beds of the Permian series abut against slopes of a pre-Permian land surface, which, however, may have been entirely buried by later Carboniferous deposits. It is not unlikely also that originally the Permian strata may have extended over the southwest corner of the State, where the Lower Cretaceous and Pennsylvanian are now in contact.

LAKE VALLEY LIMESTONE AND OTHER LIMESTONES OF MISSISSIPPIAN AGE

The Lake Valley limestone is conspicuous in the Sacramento, San Andres, Robledo, Caballo, Cooks, and Mimbres Mountains, where it generally consists of 100 to 200 feet of massive to slabby, mostly coarse-grained light-colored limestone. In the Cooks Range locally its thickness reaches 500 feet. In the Magdalena Mountains it is apparently 243 feet thick. This horizon is represented by the lower part of the Fierro limestone in the Silver City region and by limestone which has not yet been classified in the Hatchet Mountains and Ladron Peak and probably in the Peloncillo Mountains., In the Magdalena Mountains and Sierra Ladrones this limestone lies on pre-Cambrian granite, but elsewhere it overlies the Percha shale without discordance in attitude. It is overlain by limestones of Pennsylvanian age (Magdalena group) without notable difference in attitude but separated by a break representing a long interval of late Mississippian time.

At the type locality near Lake Valley, where the top of the formation is eroded and in part overlain by Tertiary igneous rocks, the thickness is about 210 feet, including a lower member 50 feet thick of compact massive gray limestone with nodular chert which may possibly be Devonian. The other members of the Lake Valley limestone at this place consist of an upper light-colored, highly fossiliferous subcrystalline limestone 60 feet thick; blue shale with thin layers of bluish limestone, 25 feet; grayish-blue limestone, more or less siliceous, called "blue limestone" in the mines, 20 feet; and at the base coarse crystalline yellowish-white limestone, 5 feet. There are many exposures in the cliffs near Cooks Peak and in canyons north of Kingston, near Hermosa and along the steep escarpments of the Sacramento and San Andres Mountains, and slopes northwest of Silver City and east of Hanover. In the northern part of the east front of the San Andres Mountains the Lake Valley is a massive bed of limestone 100 feet thick to the south, but thinning to 25 feet near the north end of the range. In the mountain slope southeast of Alamogordo it consists of 150 feet of limestone, mostly coarse grained and light colored, and limy shale, both containing numerous crinoid stems and other fossils.

The Kelly limestone [2], the ore-bearing formation in the silver-lead mines in the Magdalena Mountains, * * * has yielded crinoids and other fossils which indicate its early Mississippian age. The thickness given by Gordon is 193 feet, not including 50 feet of a nonfossiliferous shale which extends to a pebbly quartzite 60 feet thick supposed to be the base of the Magdalena group. The northernmost exposure of limestone of Mississippian age is on the southwest slope of the Sierra Ladrones, where the formation thins out to the north. * * *

MAGDALENA GROUP (PENNSYLVANIAN)

The thick limestone succession of the Magdalena group is a prominent feature in the Sacramento, San Andres, Oscura, Franklin, Caballo, Los Pinos, Sandia, and Manzano Mountains, and it constitutes a large part of

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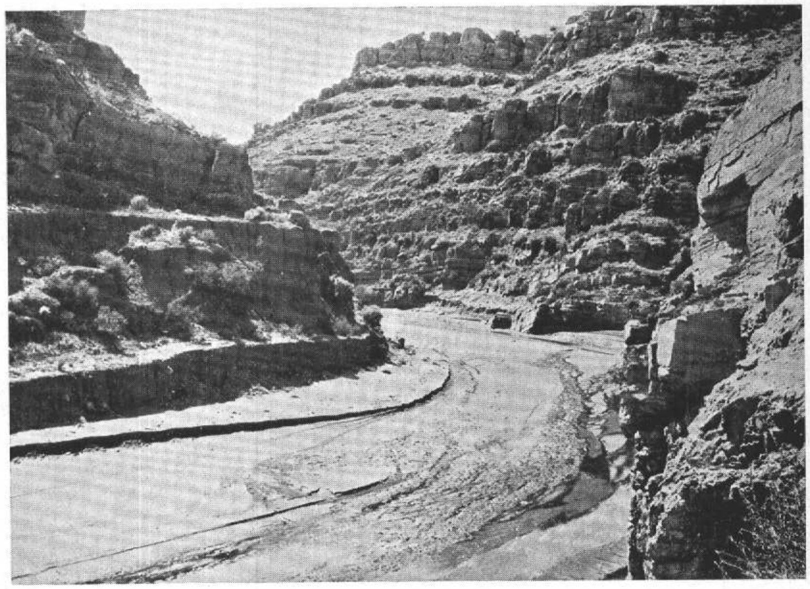
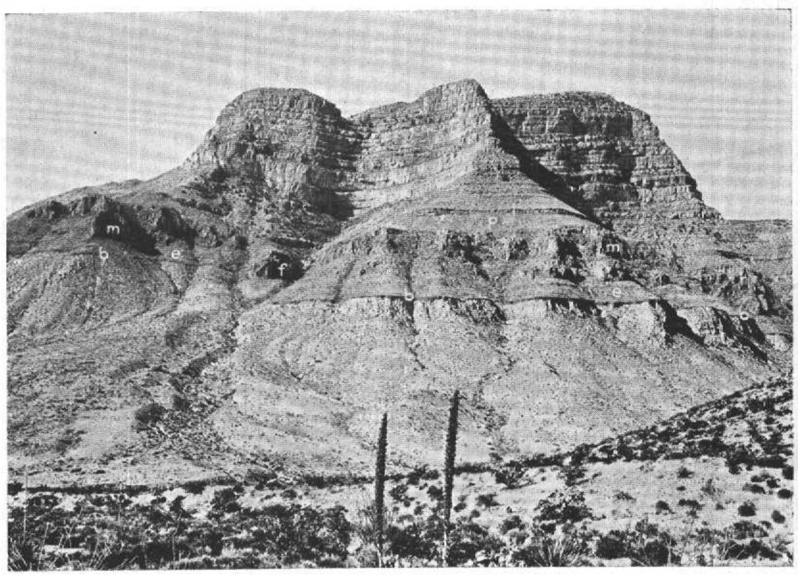
[1]Darton, N. H., and Reeside, J. B., jr., Guadalupe group: Geol. Soc. America Bull., vol. 37, pp. 413-428, pls. 12-16, 1927. Darton, N. H., The Permian of Arizona and New Mexico: Am. Assoc. Petroleum Geologists Bull. vol. 10, pp. 819-852, 1926.

[2]Gordon, C. H., Mississippian formations in the Rio Grande Valley, N. Mex.: Am. Jour. Sci., 4th ser. vol. 24, pp. 62-63, 1906; U. S. Geol. Survey Prof. Paper 68, pp. 229-231, 244-245, 1910.



A. Limestone of Magdalena group in canyon of Rio Salado at the south end of Ladrones Mountains. Looking west. (Courtesy of U. S. Geological Survey.)



B. North end of Sheep Mountain at Lava Gap near the north end of the San Andres Mountains. Looking south. b, Bliss sandstone on granite; e, El Paso limestone; m, Montoya limestone; p, Percha shale; 1, Lake Valley limestone overlain by limestone of Magdalena group; f, fault. (Courtesy of U. S. Geological Survey.)

the Sangre de Cristo Mountains. It also appears in the Magdalena, Ladron, Robledo, Lemitar, Lone, Hatchet, Cooks, Peloncillo, and Mimbres Mountains and the ridges east and west of Socorro, south and west of Hatchet, and west and north of Silver City, and in the uplift of Santa Rita and Hanover. * * * It underlies a part of the eastern third of the State, where, however, its limits are not known, as it has not yet been definitely recognized in the deep borings. It is absent in the Zuni Mountains, in parts of Grant County, in the Pedernal region, and in most of northeastern New Mexico, where deep borings find granite below probable Chupadera or Abo beds.

Limestone is the predominant rock in the Magdalena group, but interbedded sandstone and shale occur in all sections, and along the east side of the Sangre de Cristo Mountains, in the northern part of the State, gray and red sandstone preponderates.

The group ranges in thickness from 900 to nearly 2,500 feet and attains the maximum in parts of the Rocky Mountains. Gardner measured 1,237 feet near Pecos. In the San Andres Mountains the thickness is near 2,000 feet. In the Sandia and Manzano Mountains it is from 900 to 950 feet, and there is local thickening to 1,200 feet in the Los Pinos Mountains. In the Magdalena Mountains Gordon[1] measured about 1,100 feet. In the Sacramento Mountains the thickness is fully 1,500 feet. In part of the Nacimiento Mountains the maximum thickness is 500 feet, and in places the group thins out. It is thin where present locally in Grant County.

In the ridges near the Rio Grande, especially in the Sandia Mountains, the Magdalena group has been divided into the Sandia formation below and the Madera limestone above, but the plane of division appears not to be constant. The stratigraphic position of the sandstone beds and the transitions from one member to the other differ in different localities. Locally the group can be divided into several formations, some of them separated by apparent unconformities, but no notable faunal distinctions have yet been found in these formations.

Fossils occur abundantly in most parts of the Magdalena group at nearly all localities. * * *

HUECO LIMESTONE

The limestone of Carboniferous age in the Franklin and Hueco Mountains in Texas, which extend into the southern part of New Mexico, has been classed as Hueco limestone. In the northern extension of the Franklin Mountains the limestone has so far yielded only a Magdalena fauna, but the limestones constituting the northern extension of the Hueco Mountains apparently comprise not only the southern extension of the Magdalena group but also the Chupadera formation, both containing characteristic fossils. The Abo sandstone, which intervenes in the Sacramento Mountains, thins out at a point southeast of Oro Grande.

ABO SANDSTONE (PERMIAN)

The red strata of the Abo sandstone, the basal formation of the Manzano group, appear in many uplifts in central New Mexico, notably in the Sandia, Manzano, Sacramento, San Andres, Oscura, Nacimiento, Zuni, and Lucero Mountains, the south end and east side of the Sangre de Cristo Mountains, and the ridges east of Socorro, and there are small outcrops in the Magdalena and Mimbres Mountains and the ridge east of Fairview. The Abo thins out in the southern part of the southward continuation of the Sacramento cuesta, in the south-central part of Otero County, so that the Chupadera and Magdalena formations join to form the greater part of the limestone succession in the Hueco Mountains. The Abo is absent in the southwest corner of the State and in part of the Pedernal region, where its

[1] Gordon, C. H., op. cit. (U. S. G. S. Prof. Paper 68), p. 246.

edge lies against the old ridge of pre-Cambrian rock. * * * In most places the Abo formation appears to lie unconformably on the Magdalena group, but the nature, duration, and extent of the hiatus are not known. * * *

The thickness of the Abo sandstone ranges from 600 to 1,000 feet, and the formation thins rapidly near its southern termination southeast of Oro Grande. Although most of the rock is a slabby sandstone of strong red-brown color, with one notable massive member in the Zuni Mountains * * *, considerable sandy red shale is included, and in the western part of the State one or more thin limestone members occur near the base. * *

CHUPADERA FORMATION (PERMIAN)

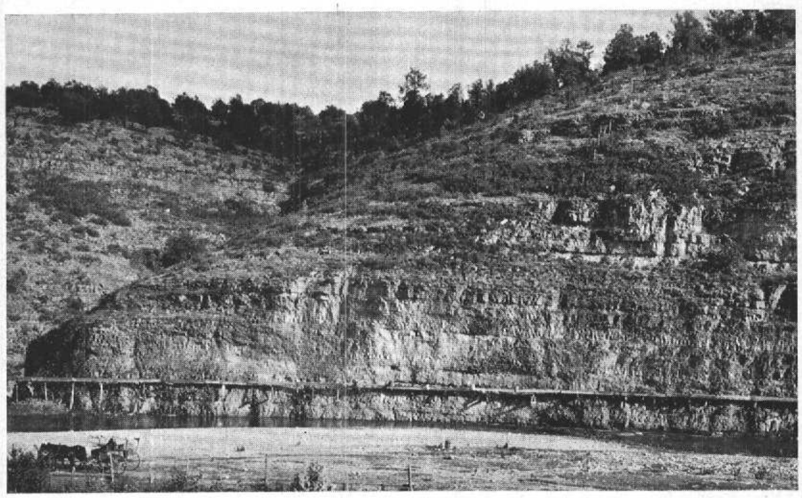
The Chupadera, the upper formation of the Manzano group, named from Chupadera Mesa [1], in eastern Socorro County, comprises the San Andres limestone above and the Yeso formation below. These divisions are not separable in all localities, however, or at least not at the same plane, and moreover the upper division consists not only of limestone but includes gray sandstone and to the south deposits of gypsum, anhydrite, and salt, which become very thick in the south-central and southeastern parts of the State. The lower division (Yeso) consists mainly of soft red sandstone with gypsum beds. To the north, where the Chupadera formation thins greatly, the anhydrite and salt disappear and gray sandstone predominates. A hard sandstone member prominent in Glorieta Mesa is the principal feature of the formation north of latitude 35°, where it is at or near the base, but it is not certainly represented in the Nacimiento uplift, and it apparently thins out north of latitude 36° in the Sangre de Cristo Mountains. In the Zuni Mountains both the gray sandstone and the massive limestone are present capping the Abo sandstone, and locally some gypsum is included in the lower red sandy members. The upper limestone member with Manzano fossils, is exposed in the uplift of Ojo Caliente, southwest of Zuni. In Valencia County the formation comprises a thick succession of sandstone, limestone, and gypsum. In the southwestern part of the State the formation is represented in whole or in part by the Gym limestone, which is prominent in the Florida and Victorio Mountains, Cooks Range, and Tres Hermanas. * * *

The limestone beds with thick interbedded deposits of gypsum and anhydrite attain a thickness of 2,500 feet in the east slope of the cuesta of the Sacramento Mountains and the thickness is still greater to the south, where the limestone develops into the Delaware Mountain formation and Capitan limestone. * * *

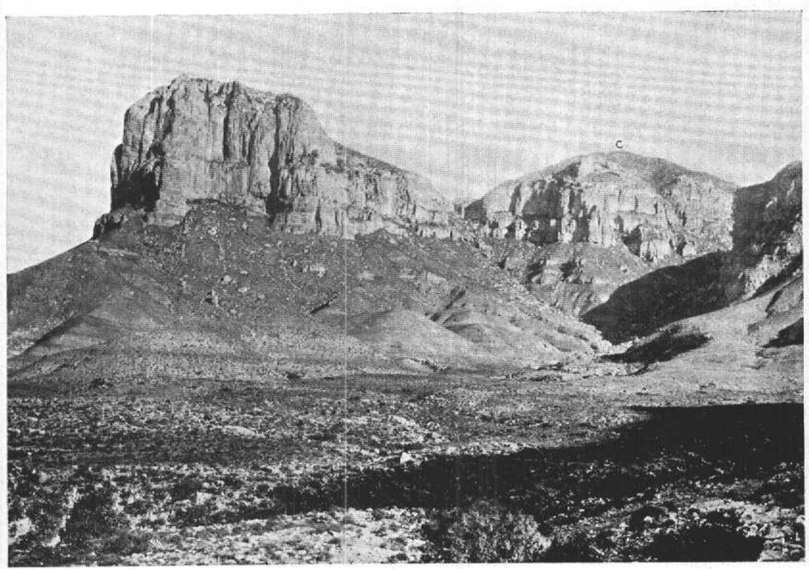
Recent studies by Lloyd[2] and others have shown that the Capitan limestone of southeastern New Mexico is in part an immense fossil coral reef. The reef itself can be followed from Capitan Mountain at the south end of the Guadalupe Mountains almost continuously to the vicinity of Carlsbad, where it dips under the plains. Reef materials have been identified in a number of wells in southeastern New Mexico east of the last visible reef outcrop, so that its subsurface trend is fairly well known and extends completely across the area east of the Pecos river to the southeast corner of the State and into west Texas. (See Fig. 8, page 141.) The reef formed a barrier separating an open sea with normal marine conditions on the south from a restricted and in later stages a super-saline sea on the north. Equivalent formations on opposite sides of the reef are markedly dissimilar in lithologic features.

[1]Darton, N. H., Geologic structure of parts of New Mexico: U. S. Geol. Survey Bull. 726, p. 181, 1922.

[2]Lloyd, E. R., Capitan limestone and associated formations of New Mexico and Texas: Am. Assoc. Petroleum Geologists Bull. vol. 13, No. 6, pp. 645-658, 1929.



A. Limestone of the Chupadera. formation on south side of Penasco Creek 18 miles southeast of Cloudcroft. Looking south. (Courtesy of U. S. Geological Survey.)



B. Capitan limestone and Delaware Mountain formation (Guadalupe group) at Guadalupe Point, Culbertson County, Texas. c, El Capitan Peak, highest point in Texas. (Courtesy of U. S. Geological Survey.)

The thick deposits of gypsum and associated red beds which overlie the Capitan limestone in the Pecos Valley south of Carlsbad in southern New Mexico are the northern extension of the Castile gypsum and Rustler limestone. They also are believed to be of Permian age, but they are not included in the Chupadera formation, as they were not included in the Manzano group as defined by Lee. The Chupadera formation thickens underground in eastern New Mexico, where thick beds of salt and anhydrite develop, as shown by records of numerous drill holes. One of these holes, [drilled by the Toltec Oil Co.] 3,120 feet deep, 13 miles northeast of Roswell * * *, appears to have been in Chupadera beds to 3,025 feet, where probably it entered the Abo sandstone. A boring [of the Ohio Oil Co.] 5,800 feet deep at Carlsbad in 1925 revealed 2,925 feet of limestone (Chupadera) and 2,000 feet of sandstone believed to be the northeastern extension of the sandstone of the Delaware Mountain formation with more limestone below. * * *

The sandstone member of the Chupadera formation, which is so prominent in Glorieta Mesa, is bared by the erosion of anticlines west of Santa Rosa, notably in Esterito Butte, and near San Ignacio, and it is extensively exposed along Pecos River in the canyon above Anton Chico. In all these places it is overlain by limestone containing distinctive fossils, which extends north over most of Glorieta Mesa. The thinning of the limestone toward the northwest is visible near Tejon and San Antonito, and this member is absent in the steeply dipping succession west of Las Vegas. The sandstone was not traced far north of Las Vegas and is absent in the region north of Mora. It appears to extend far to the south in central New Mexico, where, however, other similar sandstones are included at various horizons in the formations. The Chupadera formation is well developed along the west slope of the San Andres Mountains, * * * in the Lucero anticline 40 miles southwest of Albuquerque, the ridges east of Socorro, the eastern foothills of the Sierra Caballo, the Fra Cristobal Range, the ridge east of Fairview, Jarilla Hills, and several knobs in Tularosa Valley. * * The following sections show the typical succession of Chupadera strata in the San Andres Mountains and the region west of the Rio Grande.

Section of Chupadera Formation near Rhodes Canyon, *in the Central Part of the San Andres Mountains*

	Feet.
Limestone, gray, hard	200
Gypsum	18
Sandstone, buff or red	45
Gypsum with some red sandstone and thin limestones	200
Limestone	20
Gypsum	100
Limestone, gypsum, and red sandstone	45
Gypsum	35
Limestone	18
Red shale and gypsum	70
Buff sandy shale on Abo sandstone	50
	801

Section of Chupadera Formation near Santa Rita (Riley Post Office)	Feet.
Limestone under red shale (Triassic)	25
Gypsum	30
Limestone and gypsum	35
Gypsum	80
Limestone	25
Gypsum	25
Limestone and gypsum	25
Gypsum with thin limestone layers	100
Limestone	60+
Gypsum	30
Sandstone, gray	35+
Gypsum with limestone	20
Sandstone, gray	125+
Sandy shale and sandstone, red, with some gypsum and limestone layers	140+
Red-brown sandstone and shale (Abo sandstone).	

In the northern part of the Nacimiento uplift and the Chama Basin the Chupadera formation is absent unless some of the massive Poleo sandstone capping the red beds of the Abo formation represents a portion of it. A supposed northern extension of the Poleo sandstone, however, is believed from evidence of fossil plants and animals to be of Triassic age, possibly in places lying on a representative of the Moenkopi formation (Lower Triassic). Bones of Permian animals occur in Abo beds a short distance below the Poleo sandstone near Coyote, and remains of Triassic animals have been collected not far above the Poleo sandstone in the same vicinity.

Throughout central and southern New Mexico the limestones of the Chupadera formation carry many fossils of the well-known Manzano fauna described by Girty,[1] originally regarded as late Pennsylvanian, but now classed as Permian. [2] This formation overlies the Abo sandstone, which, as shown above, is of Permian age, and I have traced it continuously southward into the Capitan and Delaware Mountain formations of the Guadalupe Mountains of Texas * * * which are unquestionably Permian.

GYM LIMESTONE (PERMIAN)

The Chupadera formation is represented in southwestern New Mexico by the Gym limestone, a light-gray massive limestone, which crops out extensively in the Florida Mountains, the type locality, in the Victorio Mountains, and in the Tres Hermanas and some small buttes in the southern part of Luna County. In the Florida Mountains it lies unconformably on formations from the El Paso to the Fusselman, for the Percha shale, Lake Valley limestone, and limestones of the Magdalena group are absent. In the Cooks Range about 50 feet of Gym limestone lies in part on Lake Valley limestone and in part on shale of Magdalena age. In the Tres Hermanas the formation is uplifted and much altered by porphyry and includes 50 to 60 feet of gray to reddish quartzite. In the Florida Mountains the Gym limestone is about 1,000 feet thick, but * * * it is greatly faulted and the uppermost beds have been removed by erosion. In the Silver City-Hanover district and in Grant County the Permian strata are absent and strata of Lower Cretaceous age lie directly on Pennsylvanian limestone. It is not unlikely that the Gym limestone was deposited in that region and

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[1] Lee, W. T., and Girty, G. H., The Manzano group of the Rio Grande Valley, N. Mex.: U. S. Geol. Survey Bull. 389, 1909.

[2] Lee, W. T., General stratigraphic break between Pennsylvanian and Permian in western America: Geol. Soc. America Bull., vol. 28, pp. 169-170, 1917; Notes on Manzano group: Am. Jour. Sci., 5th ser. vol. 4. p. 325, 1920, in which he refers to "a definite decision of the United States Geological Survey approving N. H. Darton's reference of the Manzano group to the Permian in a report on the Red Beds now in preparation."

was removed by erosion in Triassic or Jurassic time. It appears to be represented in the upper part of the Naco limestone of southeastern Arizona.

CASTILE GYPSUM AND RUSTLER LIMESTONE

The two formations defined by Richardson[1] as the Castile gypsum and Rustler limestone extend northward from the type locality in Texas into Eddy County, N. Mex., and pass under the overlap of the Dockum group toward the east. The gypsum is extensively exposed in places, notably along the valley of Black River, along Pecos River * * * and near Carlsbad, and the deep boring * * * 8 miles east of Carlsbad revealed alternations of anhydrite and salt [2] which began under red shale at a depth of 300 feet and continued considerably below 2,380 feet, showing a thickness of more than 2,100 feet, presumably all Castile.

Limestone and red shale that extend into Eddy County near Red Bluff and cap the gypsum there and at intervals to the north and northeast are an extension of the Rustler limestone. * * *

TRIASSIC SYSTEM

GENERAL RELATIONS

Triassic rocks occupy a large proportion of New Mexico, but they have been extensively removed by post-Cretaceous erosion in the central part of the State, notably in the wide cuestas and plateaus of the Chupadera formation. They are absent in the Southwestern part of the State, owing either to non-deposition or to removal by erosion in late Triassic or Jurassic time, but it is possible that a portion of the Triassic period is represented by the Lobo formation in Luna County. In most areas west of the Rio Grande in central New Mexico, especially in the Zuni Mountain uplift, three Triassic formations are recognized—the Moenkopi formation (Lower Triassic) at the base, the Shinarump conglomerate (Upper? Triassic) in the middle, and the Chinle formation (Upper Triassic) at the top—but the recognition of these divisions to the east has not been satisfactory so far. East of the Rio Grande the Chinle formation (Upper Triassic) is represented in the Dockum group, which occupies most of the eastern third of the State. Near or at its base is a conspicuous sandstone which I have named the Santa Rosa sandstone [3] and which crops out across the eastern part of the state and may possibly be an eastern extension of the Shinarump conglomerate. In the Nacimiento uplift and Chama Basin a local sandstone, the Poleo,[4] occupies approximately the same horizon as the Shinarump, but it appears to lie directly on the Abo sandstone. A portion of it, if not all, however, strongly suggests the sandstone of Glorieta Mesa, which is the basal member of the Chupadera formation in that region, but apparently it is the formation that contains Triassic plants at the old Cobre copper mine, near Abiquiu, and bones of Triassic animals have been collected just above it near Coyote. In some places the upper part of the Chupadera formation includes red beds that contain bones of Permian animals, but the great mass of overlying red beds is of Triassic age. The extent to which the Moenkopi formation, or Lower Triassic, is represented east of the Rio Grande is not yet ascertained. Although the red rocks of the Pecos Valley in southern New Mexico are probably of Permian age, it is possible that strata of Lower Triassic age are also present. The overlap of the western edge of the Dockum group is now believed to be marked by the sandstone outcrop which extends along the foot of the western slope of the escarp-

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[1] Richardson, G. B., Report of a reconnaissance in trans-Pecos Texas north of the Texas & Pacific Railway: Texas Univ. Min. Survey Bull. 9, pp. 43-45, 1904.

[2] Darton, N. H., Permian salt deposits of the south-central United States: U. S. Geol. Survey Bull. 715, p. 221, 1921.

[3] Darton, N. H., op. cit. (U. S. G. S. Bull. 726), p. 183.

[4] Huene, F. von, Kurze Mitteilung uber Perm, Trias, and Jura in New Mexico: Neues Jahrb., Beilage-Band 32, p. 736, 1911.

ment of the Llano Estacado, crosses the Pecos Valley near latitude 34°, and extends northwestward to the western margin of Guadalupe County. The southern limit of the Triassic rocks in south-central New Mexico is not known; they have been traced southward nearly to Tularosa but are absent under the Cretaceous rocks in exposures 10 miles north of Organ. * * *

MOENKOPI FORMATION

The lowest formation of the Triassic system in the Colorado Plateau province extends eastward for some distance into western New Mexico, but its eastern limits and representatives have not been recognized. The formation is well exhibited in the Zuni uplift, where it crops out along the lower slopes on all sides of the Zuni Mountains, except to the east, where lava covers a wide area. On the south slope north of Ramah the formation extends far up the flanks of the southern limestone ridge. Here the thickness is about 1,000 feet, but along the north slope of the mountains it appears to be somewhat less. The formation is also exposed in the uplift at Ojo Caliente,[1] overlain by Shinarump conglomerate. The rocks consist mainly of shale of maroon, dark purplish-red, and chocolate-brown colors, alternating with dark ash-gray or lavender. At the base, especially to the east in the Bluewater region, is a thin mass of brown-red conglomeratic sandstone overlying the top limestone of the Chupadera formation. This is overlain by about 500 feet of soft shale of gray, buff, reddish, and purplish tints containing beds of sandstone from a few inches to several feet thick. This sandstone is mostly red in the lower beds, but higher beds are of lighter color and largely cross-bedded. A peculiar limestone conglomerate about 3 feet thick occurs in the shale about 50 feet above the base and is traceable from a point near Bluewater to a point beyond Fort Wingate. The strata vary in character from place to place, especially in the color of the shale and the thickness and character of the included sandstones. In many exposures to the west there is a basal shale of dark-red, maroon and purple colors. The exposures south of Guam have at the base from 30 to 40 feet of gray sandstone, followed by 50 to 70 feet of red shale, 30 feet of the peculiar conglomerate with limestone pebbles, and 120 feet of maroon to gray massive shale with three gray sandstone members in its upper half.

Red shale similar to that of the Moenkopi formation appears extensively in the uplift zone extending through Lucero Mesa and reaching the Rio Salado valley near Puertecito. As the Shinarump conglomerate does not show its characteristic features in this area and as no paleontologic evidence has been obtained, the classification and the limits of the Moenkopi strata are uncertain, but the formation may have a thickness of 400 feet or more.

SHINARUMP CONGLOMERATE

The Shinarump conglomerate crops out along the north and west sides of the Zuni uplift, where however, most of the rock is light-colored sandstone, from 30 to 100 feet thick, constituting the crest and upper slope of a hogback ridge of considerable prominence. It also appears in the uplift at Ojo Caliente, where much of the material is conglomeratic. Coarse sandstone in the middle of the "Red Beds" succession in the Lucero uplift strongly suggests the Shinarump conglomerate in character and position, but its equivalence is not positively determined. The Shinarump may also be present in some of the uplifts in the central part of the State and probably is represented by the Poleo sandstone in the Nacimiento uplift and Chama Basin and by the Santa Rosa sandstone in eastern New Mexico.

POLEO SANDSTONE

The bed of massive sandstone extending along the Nacimiento uplift and extensively exposed in the Chama Basin has been classed as Triassic

[1]A pueblo in the Zuni Indian Reservation.

by Huene [1] and Case.[2] It constitutes the Poleo Mesa, north of Coyote, and the west rim of the Cobre Basin, northwest of Abiquiu. At the latter place it appears to be the bed from which plant remains identified by Newberry and Knowlton [3] were obtained. At this place and throughout the northern part of the Nacimiento uplift, it lies on red slabby sandstone believed to be the Abo sandstone, the Moenkopi and Chupadera formations being absent. The formation strongly resembles the basal sandstone of the Chupadera formation constituting Glorieta Mesa and the Coconino sandstone of Arizona, but the paleontologic evidence appears to indicate Triassic age. It is probable, however, that both Poleo and Chupadera sandstones are present in the southern part of the Nacimiento uplift.

CHINLE FORMATION

The upper red shale of Triassic age in the Zuni uplift is undoubtedly an extension of the Chinle formation of eastern Arizona. The Atchison, Topeka and Santa Fe Railway follows a valley excavated in the shale of this formation from a point west of Bluewater to and beyond Wingate, and the outcrop extends just north of Ramah and makes the valley between Inscription Rock and Tinajas. It also appears extensively in the valley of Zuni River between Zuni and Ojo Caliente and southward from Ojo Caliente to Atarque. Its thickness averages about 850 feet, but precise measurements are difficult to make on account of the softness of the beds. The principal material is red shale, but a few thin beds of purplish-brown slabby sandstone are included, and in places at the top there is a member of purple to gray calcareous pebbly sandstone and sandy shale, with scattered bone fragments. Rocks of this same character appear extensively in the Lucero uplift, in which they reach the valley of the Rio Salado at Puertecito. They are also present, overlying the Poleo sandstone, along the west side of the Nacimiento uplift and throughout the Chama Basin from the mouth of the Rio Cebolla nearly to Abiquiu. Presumably the red shale overlying the Chupadera formation in the northern part of the Sandia uplift and in the ridges east of Socorro is an extension of the same formation. Farther east it is represented in the Dockum group, but the limits of its representatives in that group have not been ascertained.

DOCKUM GROUP

Most of northeastern New Mexico east of the Rocky Mountain front ridge and all of southeastern New Mexico east of Pecos River is underlain by a thick succession of red beds which are continuous with the Dockum group of western Texas and Oklahoma. The maximum thickness is about 1,000 feet. Although red shale and red sandstone predominate, some of the rocks are gray to brown. Near the base of the group in the northern part of the area is a prominent dark-gray sandstone, the Santa Rosa sandstone, about 100 feet thick, which has considerable prominence in the topography of that area. It is underlain by red shale, which lies on the top limestone member of the Chupadera formation and attains a thickness of 200 feet northwest of Santa Rosa. This shale thins toward the south and apparently disappears near latitude 34° 30', south of which the supposed southern extension of the Santa Rosa sandstone constitutes the base of the group. The rocks of the Dockum group are, however, mostly covered by sand in Chaves, Eddy, and Lea Counties, where outcrops are widely scattered. In the Santa Rosa region and northward the strata above the Santa Rosa sandstone consist of red shale and a succession of red, brown, and gray sand-

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[1] Huene, F. von. op. cit., p. 737.

[2] Williston, S. W., and Case. E. C., The Permo-Carboniferous of northern New Mexico: Jour. Geology, vol. 20. pp, 8-11, 1912; Permo•Carboniferous vertebrates from New Mexico: Carnegie Inst. Pub. 181, 81 pp., 1913.

[3] Fontaine. W. M., and Knowlton, F. H. Notes on Triassic plants from New Mexico: U. S. Nat. Mus. Proc., vol. 13, pp. 281-285, pls. 22-26, 1890.

stones having in all a thickness of about 500 feet. These rocks are extensively exposed along Concho and Canadian Rivers * * * north of which they are overlain by the Wingate sandstone. The stratigraphy has not been fully determined, and the beds change in character from place to place in the area. Farther south the upper strata are covered by the sand and gravel of the Llano Estacado.

Fossil bones obtained by Case [1] and others in the Dockum group at several localities in eastern New Mexico, mainly in the vicinity of the Canadian and Concho Valleys, and collected by Case [2] in red beds of Chinle character and position near Carthage are regarded by Case [3] as Upper Triassic. A few fresh-water shells have also been collected, notably at a locality a few miles north of Santa Rosa, and Lee [4] found similar remains on the Rio Concho at a point 30 miles southeast of Las Vegas.

LOBO FORMATION (TRIASSIC?)

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 the Gym limestone (Permian) and the Sarten sandstone (Lower Cretaceous). The formation occurs mostly in the Florida Mountains and southern spurs and outliers of the Cooks Range. The rocks are mainly reddish and gray shale and gray to pinkish impure limestone, but considerable conglomerate is present in the basal strata. In an exposure in the north end of the Florida Mountains 318 feet of beds lie across a fault, which * * * lifts granite into juxtaposition with the Montoya and El Paso limestones. At the type locality in Lobo Draw in the Florida Mountains, the formation consists largely of buff and red shale and massive very fine grained sandstone and limestone. * * * In the Cooks Range, where the greatest thickness is about 100 feet, the reddish-brown sandstone, shale. and conglomerate lie unconformably on the Gym limestone. At one place the top member is 50 feet of conglomerate with a limestone matrix. In the Vittorio Mountains the Gym limestone is overlain unconformably by about 700 feet of shale and sandstone, largely reddish, which resemble the Lobo formation but may be Cretaceous or Tertiary. The Tertiary assignment is suggested by the presence of andesite boulders in the basal conglomerate.

As no fossils were found in the Lobo formation, its age is not determined. In the central part of the Cooks Range, it lies unconformably on the Gym limestone, of Permian age, and is also separated from the overlying Sarten sandstone (Lower Cretaceous) by an unconformity; hence its age may be Permian, Triassic or even earliest Cretaceous. Because of its unconformable relations with the overlying and underlying formations, however, the Lobo is tentatively classified as Triassic (?).

JURASSIC SYSTEM

WINGATE SANDSTONE

The outcrop of the Wingate sandstone extends into the western margin of New Mexico in the Zuni region, and the formation is extensively exhibited in the Zuni uplift. It also is conspicuous in the Nacimiento uplift and the Chama Valley, in the Cobre uplift, in the Lucero anticline, on the east side and at the north end of the Sandia uplift, in the monoclinal ridge west of Cerrillos, in the east front of the Rocky Mountain uplift in the Las Vegas region, and thence continuously southward to and along the southern front of the Canadian Escarpment to the vicinity of longitude 103° 30' where it thins out. It is present in the outliers of the Canadian Escarpment south

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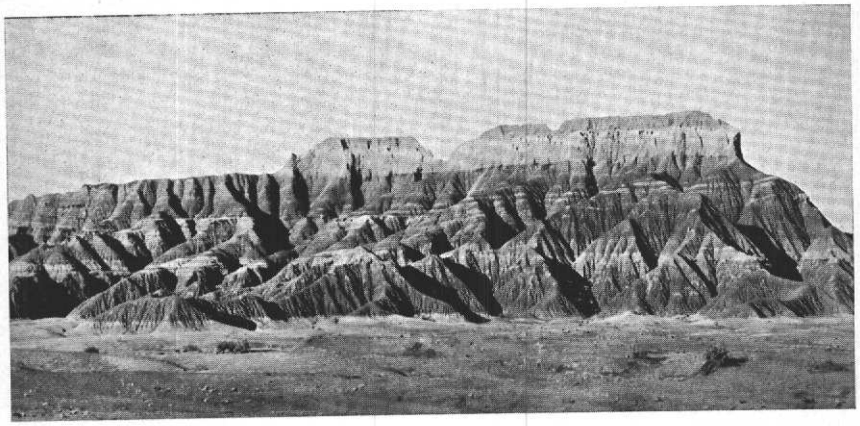
[1]Case, E. C., Jour. Geology, vol. 22, pp. 257-258, 1914.

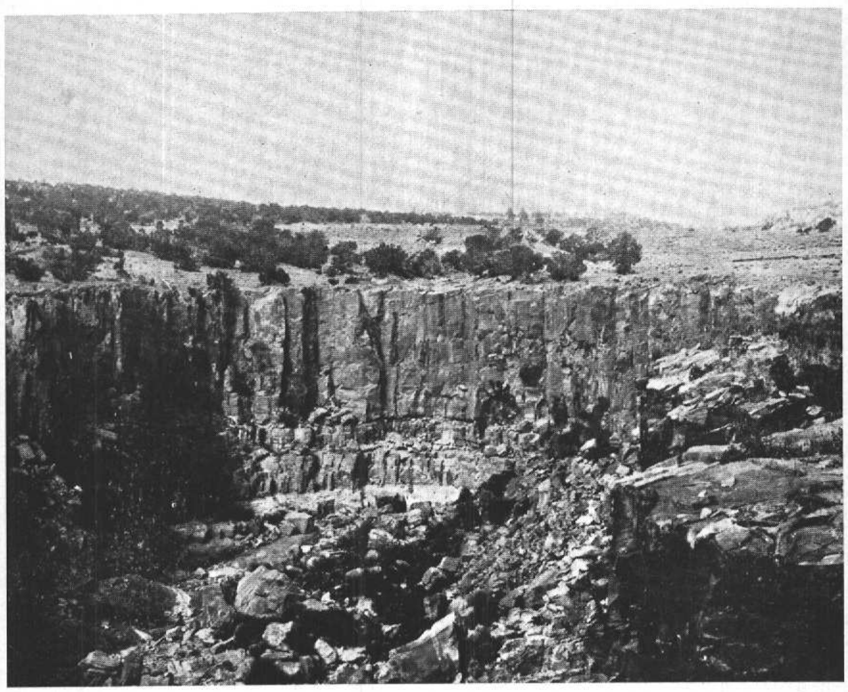
[2]Case, E. C., Science, new scr., vol. 44, pp. 708-709, 1916.

[3]Case, E. C., personal letter, June 23, 1927.

[4]Lee, W. T., Note on the red beds of the Rio Grande region in central New Mexico: Jour. Geology, vol. 15, pp. 55-56, 1907.



A. Badlands of Dockum group 10 miles east of Tucumcari. (Courtesy of U. S. Geological Survey.)



B. Badlands of Dockum group 10 miles east of Tucumcari.

(Courtesy of U. S. Geological Survey.)

and west of Tucumcari, including Cuervo Hill and Mesa Rica, but appears to be absent in the canyon of the Cimarron in Union County. In all the exposures it is a massive, compact, but only moderately hard pale-red to buff sandstone, generally giving rise to a prominent cliff in which the entire thickness of the formation is exhibited. * * * In a large part of the area the upper portion of the sandstone is white, buff, or yellowish. It is conformably capped by the Todilto limestone throughout nearly its entire area of outcrop. The lower contact, on the red shale of the Chinle formation or Dockum group, is very abrupt, owing mainly to difference in the character of the materials, but it shows very little evidence of channeling or coarse deposits, and there is no notable difference in attitude. In the northeastern part of the State the Wingate lies on a thick succession of Dockum strata. The thickness of the Wingate sandstone is about 300 feet at the maximum north of Thoreau, but 150 feet in most other portions of the Zuni uplift and in the Nacimiento and Lucero uplifts, 80 feet in the Canadian Escarpment, and still less in the vicinity of Tucumcari, and the sandstone thins out rather abruptly east of Ute Creek and in the northern edge of the Great Plains. It also thins out rapidly in the southern part of Valencia County near longitude 107° 30'. No fossils have been found in the Wingate sandstone, and it was regarded as Triassic by Newberry[1], Gilbert [2], Howell [3], Dutton [4] and Darton [5]. Later it was thought to be an extension of the lower part of the La Plata sandstone and was classed as Jurassic [6], but still later observations by Paige [7], Lee [8] and others appear to show that it is older than the La Plata of Cross.

TODILTO FORMATION

The thin-bedded limestone that caps the Wingate sandstone in most of northeastern Arizona has been traced southward from its type locality in Todilto Park [9], in western New Mexico, and found to be present in the north slopes of the Zuni and Lucero uplifts, near Suwanee and Acoma, throughout the Nacimiento uplift, the Chama Basin, and the northern part of the Sandia uplift, in the Cerrillos Basin, near Lamy, and in the Las Vegas region. and it extends along the southern front of the Canadian Escarpment eastward nearly to longitude 104°. not quite as far east as the underlying Wingate sandstone. The southern margin of the limestone is a few miles south of Acoma. Its northern limit has not been ascertained, but the formation is not present in Mora and Colfax Counties. It appears to thin out northwest of Tucumcari but is well exhibited in Cuervo Hill, 18 miles northeast of Santa Rosa. The maximum thickness ordinarily is not more than 10 feet, and the limestone is in thin layers. Locally it becomes sandy, and at a point 20 miles south of Grant it may be represented by white conglomerate at the base of the Navajo sandstone.

In the Nacimiento and Sandia uplifts, the northern part of the Lucero uplift, and the Cerrillos Basin the limestone is overlain by a bed of pure-white gypsum, which attains a thickness of 60 feet and which is regarded as a local upper member of the Todilto formation. This gypsum is conspicuous in cliffs along the Santa Fe Railway near El Rito, a few miles east of Laguna, * * * and also at a point half-way between Domingo and Cerrillos * * *, and throughout the Nacimiento uplift and Chama Basin * * * .

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[1] Newberry, J. S., Report upon the Colorado River of the West explored in 1858-59, by Lieut. J. C. Ives, pt. 3, p. 89, 1861.

[2] Gilbert, G. K., U. S. Geol. Survey W. 100th Mer. Rept., vol. 3, pp. 551-553, 1875.

[3] Howell, E. E., idem, p. 290.

[4] Dutton, C. E.. 'Mount Taylor and the Zuni Plateau: U. S. Geol. Survey Sixth Ann. Rept.. pp. 135 et seq., 1885.

[5] Darton, N. H., op. cit. (U. S. G. S. Bull. 435). pp. 45-53.

[6] Gregory, H. E., Geology of the Navajo country: U. S. Geol. Survey Prof. Paper 93, pp. 52-55. 1917.

[7] Paige, Sidney, communication to section E, Am. Assoc. Adv. Sci., December, 1924.

[8] Lee, W. T.. nersonal communication.

[9] Gregory, H. E., op. cit., p. 55.

No fossils have been found in the limestone or gypsum in New Mexico, but the formation is believed to be an eastern extension of Jurassic strata of southern Utah. Limestones in the same general succession in that State contain abundant Jurassic fauna, but apparently they are at a much higher horizon than that of the Todilto.

NAVAJO SANDSTONE

In the portion of New Mexico west of longitude 107° the Todilto formation is overlain by a thick bed of sandstone, in part white or gray and in part red, that is believed to be a southern extension of the basal part of the La Plata sandstone (Jurassic) of southwestern Colorado. It is extensively exposed in the vicinity of Zuni and in the Zuni uplift, and its outcrop extends eastward to the eastern slope of the Lucero anticline west of Rio Puerco station. To the south it thins out at a point about 15 miles south of Acoma. In parts of the Nacimiento uplift and Chama Basin it may possibly be represented by sandstone overlying the gypsum member of the Todilto formation, but this sandstone more probably is a sandy portion of the Morrison formation. The thickness of the Navajo sandstone is about 400 feet at the west but not more than half this amount at the east and south. The formation reaches the surface on the west side of the Zuni Basin, where it crops out in high cliffs that extend from a point near Manuelito past Zuni to Atarque, * * * where the formation is cut off by a fault and a wide lava flow. It appears extensively in the cliffs south of Grant and about Acoma and Laguna, where the thickness is 150 to 200 feet and the rock is a massive fine-grained gray sandstone of moderate hardness. At Rito siding there is a red lower member and a massive gray upper member. * * *

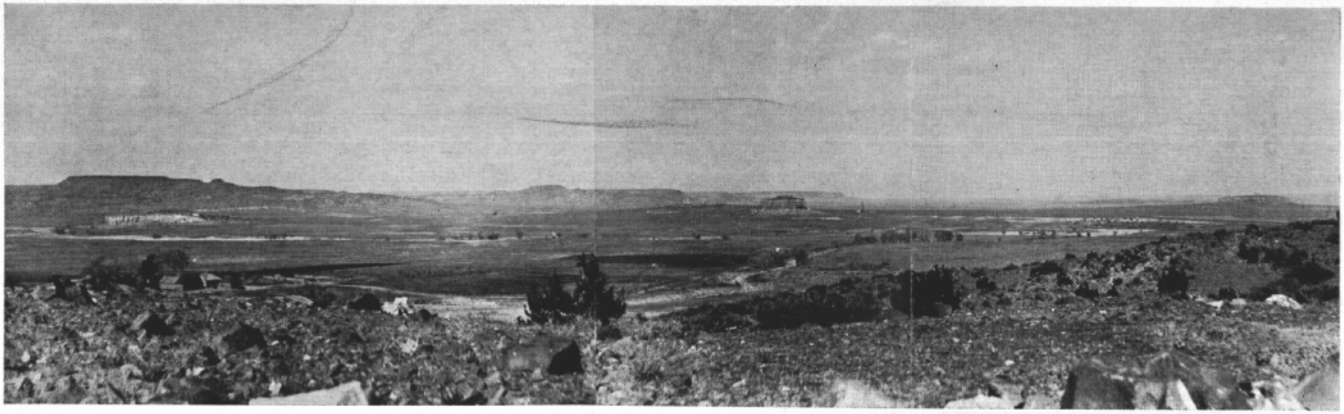
CRETACEOUS SYSTEM

GENERAL RELATIONS

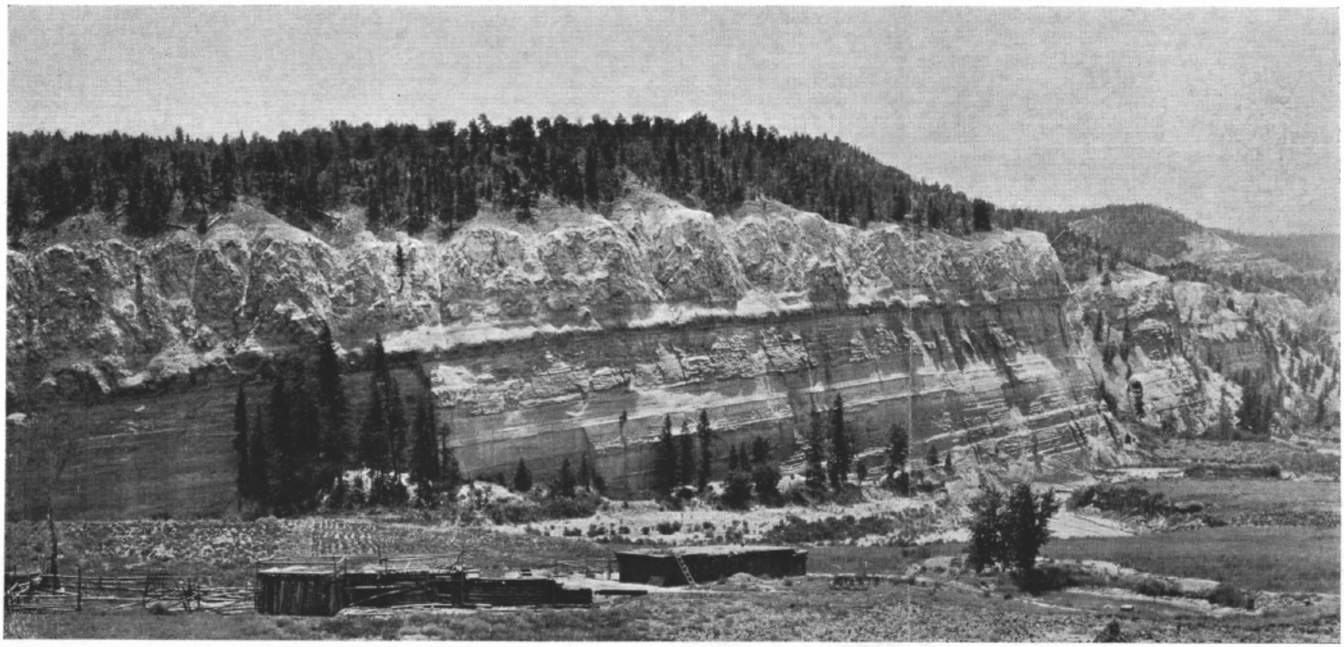
Rocks of Cretaceous age occur extensively in New Mexico, but in most places the succession is incomplete, and in the southern part of the State the areas of later Cretaceous strata are very widely separated, a condition possibly resulting from extensive removal by erosion in post-Cretaceous time. The earliest formation that may belong in the system is the Morrison, which is classed as Cretaceous (?) because of lack of evidence as to the precise age of the reptilian remains it carries. Next in age are the shale and sandstone of the Purgatoire formation in the northeastern part of the State and the Sarten and other sandstones and limestones of Comanche age in the southern part; these, however, represent only a small portion of Comanche time. The Upper Cretaceous consists of the Dakota sandstone and the shales and sandstones of the Colorado and Montana groups, which are divided into formations that bear different names and differ in range in the eastern and western parts of the State. It is probable that some of the volcanic rocks in southwestern New Mexico are of Cretaceous age, but evidence as to their equivalence is lacking.

MORRISON FORMATION (CRETACEOUS?)

The Morrison formation occurs throughout northern New Mexico and appears to be well represented in part of the structural basin about the Sierra Blanca, in the western part of Lincoln County. It consists chiefly of pale greenish-gray clay or massive shale, with maroon portions at most localities, and includes more or less light-colored sandstone; some of which is greenish. Thin beds of limestone, mostly concretionary, and some reddish chalcedony concretions also occur in the northeastern part of the State. The chalcedony concretions may possibly indicate the presence of the Sun-dance formation (Jurassic) at some localities. The average thickness of the formation is near 150 feet, but the amount varies considerably from



A. Looking east across Baca anticline, Harding County.



B. Wingate sandstone capped by gypsum member of Todilto formation on bank of Gallina River near Gallina Post Office, Rio Arriba County. The wooded slope is Morrison shale. Dakota sandstone is at top of plateau. (Courtesy of U. S. Geological Survey.)

place to place. The formation crops out extensively in the high plateaus of northeastern New Mexico, the Canadian Escarpment, the Cimarron and Ute Valleys (Union County), and the Las Vegas region, and apparently it is also present in the outlying buttes south and west of Tucumcari and in the basin of the Sierra Blanca. In the Sandia uplift and Cerrillos Basin it crops out at intervals from the vicinity of Tijeras to Rosario, and it appears near Lamy and farther south. It is exposed near Suwanee, Laguna, and Rito siding but thins out to the south in the ridges between Laguna and Acoma. Extensive exposures, * * * occur north of Laguna station. In the Zuni uplift the Morrison formation appears in the vicinity of Horace and Grant and high along the slopes extending north of Thoreau, Guam, and Wingate, but it is absent in the southern part of the uplift. North of Wingate the beds become very sandy and appear to merge laterally on the west into sandstone which has been classed as "McElmo formation" by Gregory,[1] although it is possible that at this place there is an overlap onto a remnant of an older sandstone. It thins out near the railroad 3 miles east of Gallup. This sandstone comes to the surface again at Manuelito, where, according to Gregory, it is in seven beds, in all 340 feet thick.

The only fossils so far reported from the Morrison beds in New Mexico are scattered bones of saurians of various kinds, which have not yet been studied. Remains of many of these animals have been collected from the formation in Colorado and Wyoming. Some paleontologists regard this fauna as early Cretaceous, but others regard it as late Jurassic or possibly as representing a transition from one period to the other.

SARTEN SANDSTONE AND ASSOCIATED LIMESTONES (COMANCHE)

In southern and southwestern New Mexico the Lower Cretaceous is represented by the Sarten sandstone, which I have separated in Luna County[2] and found to extend northward into the Silver City-Hanover region, where it has been called the "Beartooth quartzite"[3] and classed as Upper Cretaceous (?). * * * Farther south in New Mexico the Comanche strata are limestones, which are extensively developed about El Paso, Tex., where they are quarried for the manufacture of cement. They have yielded fossils of Fredericksburg and Washita age. Similar limestone constitutes the Cornudas Mountains, the Potrillo Mountains, the Sierra Rica, and parts of the Hatchet Mountain and adjoining ridges, in the southwestern part of the State. The limestones in the Hatchet Mountain region closely resemble the Mural limestone of the Bisbee and Douglas region, Arizona, to which doubtless they are equivalent. Fossils from this region determined by T. W. Stanton comprise forms characteristic of both Washita and Trinity groups of the Comanche series. * * *

PURGATOIRE FORMATION (COMANCHE)

The plateaus of northeastern New Mexico are underlain by shale and sandstone of Lower Cretaceous age which are extensively exposed in many canyons, in the southern face of the Canadian Escarpment, and in several outliers of that escarpment in the region south and west of Tucumcari. In most areas they are overlain by the Dakota sandstone, which constitutes the floor of the plateaus, and they lie on the clays of the Morrison formation. In many places there is a lower member of sandstone and an upper member of dark sandy shale, in all about 100 feet thick, but the local sections are variable. The sandstones are mostly gray and massive, similar to the overlying Dakota sandstone. The Purgatoire formation has not been observed west of the Rocky Mountains and in the central part of the State, where the Dakota sandstone lies on the Morrison or older formations. Possibly

[1] Gregory, H. E., op. cit., map.

[2] Darton, N. H., op. cit. (U. S. G. S. Bull. 618), PP. 43-44. See also U. S. Geol. Survey Geol. Atlas, Deming folio (No. 207), p. 6, 1917.

[3] Paige, Sidney, U. S. Geol. Survey Geol. Atlas, Silver City folio (No. 199), pp. 5-6, 1916.

there are also breaks in the continuity of the Purgatoire formation in the northeastern part of the State. Fossil shells that have been collected in the shale of the formation by T. W. Stanton and W. T. Lee in the valley of the Cimarron (Union County) and also in Colorado indicate its Comanche age, and abundant fossils of that age occur in buttes in the Tucumcari region * * *, including Cuervo Hill, to which, however, the name Purgatoire has not yet been applied. * * *

W. B. Lang recently found outcrops containing Comanche fossils 13 miles southeast of Portales, rising as an island in the Staked Plains.

DAKOTA SANDSTONE

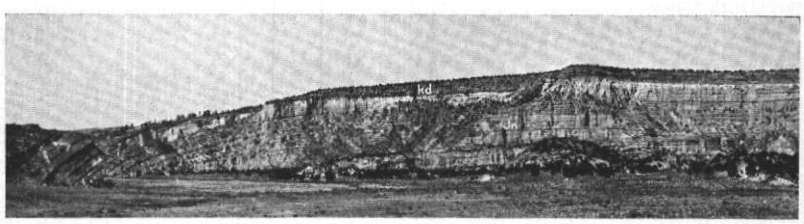
Throughout northeastern New Mexico the basal formation of the Upper Cretaceous succession is a hard gray massive sandstone supposed to be a southern extension of the Dakota sandstone. It constitutes much of the surface of the Canadian Plateau in Union and Mora Counties, which extends southward to the 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 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. There is also some doubt as to the identity of the formation in the Carthage region and the ridges east and northeast of Socorro.

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 Carlisle 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

A. Surface of recent lava flow or "malpais" at upper crossing, 12 miles southwest of Carrizozo. (Courtesy of U. S. Geological Survey.)

B. Cretaceous and Navajo sandstones on southwest side of Zuni uplift near Nutria, northeast of Zuni. Looking northwest. (Courtesy of U. S. Geological Survey.)



C. Northwest end of Zuni Mountain uplift four miles northeast of Gallup. kd, Dakota sandstone; Jn, Navajo sandstone. (Courtesy of U. S. Geological Survey.)

of Las Vegas,* * * . The overlying Carlisle 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 Hermanos sandstone member of Lee.

MANCOS SHALE

The Mancos shale comprises shale of the Colorado group as above des-scribed 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 [1] 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 Joya. 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 [2] 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 [3] as the Tres Hermanos member. An included sandstone in the northwestern part of the State has been called the Tocito sandstone lentil; [4] it attains a thickness of 35 feet near Tocito.

In the Gallup-Zuni basin Sears [5] 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

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[1] Lee, W. T., The Tijeras coal field, Bernalillo County, N. Mex.: U. S. Geol. Survey Bull. 471, p. 575, 1913.

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

[3] 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: Geol. Soc. America Bull., vol. 23, p. 631, 1912.

[4] 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.

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

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 [1] 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, [2] 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. * * *

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 [3] 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 [4] 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

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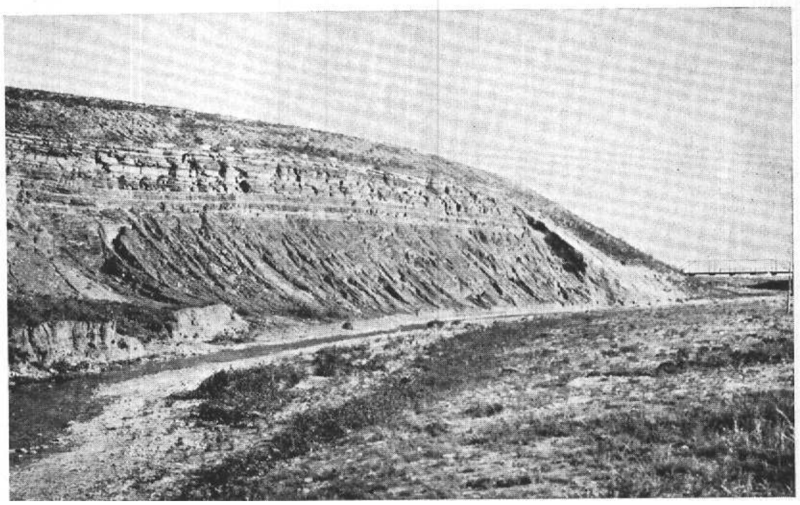
[1] Lee, W. T., The Engle coal field, N. Mex.: U. S. Geol. Survey Bull. 285, p. 240, 1906. See also U. S. G. S. Prof. Paper 95, p. 41; Prof. Paper 101, p. 33, 1917.

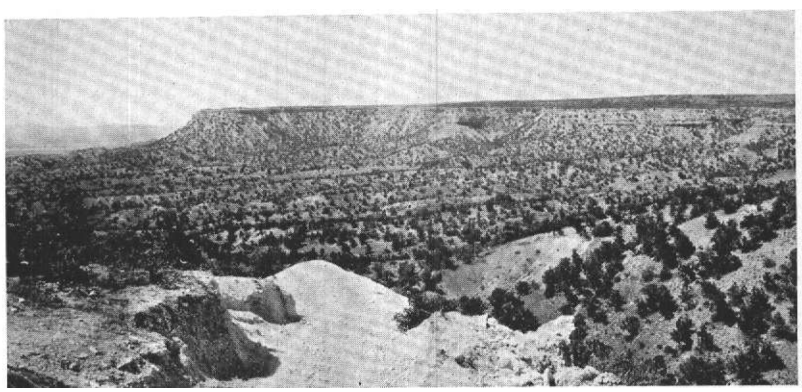
[2] Lee, W. T., op. cit. (U. S. G. S. Prof. Paper 101), p. 189.

[3] 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.

[4] Lee, W. T., op. cit. (U. S. G. S. Prof. Paper 101), pp. 51-56. See also Folio 214, pp. 6.7, 1922.



A. Greenhorn limestone on north bank of Gallina Creek at East Las Vegas. Looking southwest. (Courtesy of U. S. Geological Survey.)



B. North edge of Llano Estacado near Ragland, 25 miles south of Tucumcari. (Courtesy of U. S. Geological Survey.)

C. Typical plains with sinks, in limestones of the Chupadera formation in northeastern Lincoln County. (Courtesy of U. S. Geological Survey.)

places. Many fossil plants have been collected from the Vermejo and according to Knowlton [1] 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,[2] 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 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,[3] 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 [4] 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. [5] 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 [6] 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 [7] in 1906 and in greater detail by Sears [8] 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. There are three persistent massive beds of sandstone near the base and other sandstones higher up which vary greatly from place to place. The top of the formation is eroded, so that the section is not complete. The following members are recorded by Sears:

[1] 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.

[2] Reeside, J. B., jr., op. cit. pp. 13-16.

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

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

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

[6] Lee, W. T., op. cit. (U. S. G. S. Prof. Paper 101), pp. 192-195.

[7] 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, 380, 1907.

[8] Sears. J. D., op. cit. (U. S. G. S. Bull. 767), no. 15-18.

Strata of the Mesaverde Formation in the Gallup-Zuni Basin

	Feet.
Allison barren member: Light-colored sandstone and shale, with thin irregular coal beds of no commercial importance	800+
Gibson coal member: Light-colored sandstone and shale with coal beds	150-175
Bartlett barren member: Light-colored sandstone and shale with thin coal beds of no commercial importance	330-400
Dilco coal member: Light-colored sandstone and shale with valuable widespread coal beds	240-300
Gallup sandstone member: Three thick beds of hard gray to pink sandstone, the upper one locally very coarse and arkosic, separated by shale containing coal beds, of which those in the upper shale are of commercial importance in most places	180-250

The lowest sandstone is the hardest. Along the hogback ridge the upper and lower sandstones are pink and the middle bed light gray. The anticline at Gallup exposes the upper sandstone, and it is also exposed in the arch at Defiance switch, where, however, all the beds are light gray.

The formation extends southward to the Hagan or Una del Gato field, [Sandoval Co.] where Lee [1] 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 [2] 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.

According to Gardner [3] the uppermost member of the Cretaceous succession with coal measures at Carthage is regarded as Mesaverde. The coal measures of the Sierra Blanca Basin studied by Campbell [4] and Wege-mann [5] are regarded as Mesaverde.

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, Colo. Its outcrop zone extends around the San Juan Basin, varying in width from 1 to 5 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 [6] 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 [7] 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.

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

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

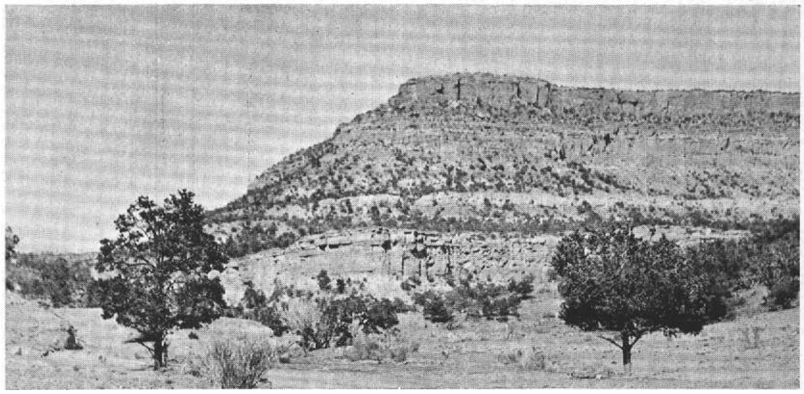
[3] Gardner, J. H., The Carthage coal field, N. Mex.: U. S. Geol. Survey Bull. 381, p. 453, 1910.

[4] Campbell, M. R., op. cit. (U. S. G. S. Bull. 316), pp. 431-434.

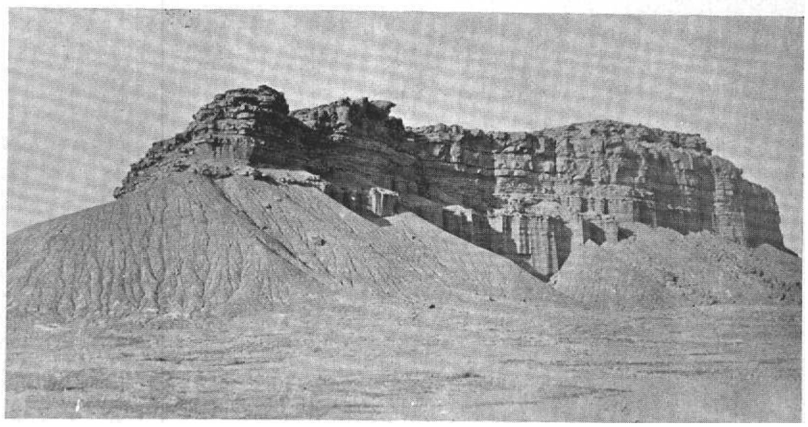
[5] Wegemann, C. H., Geology and coal resources of the Sierra Blanca coal field, Lincoln and Otero Counties, N. Mex.: U. S. Geol. Survey Bull. 541, pp. 419-452, 1914.

[6] Reeside. T. B.. jr.. op. cit.. o. 17.

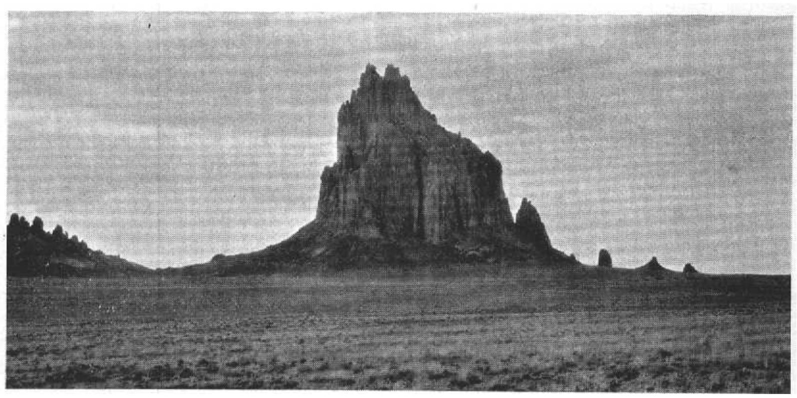
[7] Gardner, J. H., op. cit. (U. S. G. S. Bull. 341), p. 339.



A. Upper Mesaverde formation near Crown Point, McKinley County.



B. Point Lookout sandstone (basal Mesaverde formation) near Chimney Rock seven miles northeast of Shiprock, San Juan County.



C. Ship Rock, an igneous plug 12 miles southwest of Shiprock, San Juan County. (Courtesy of Denver & Rio Grande Railroad Co.)

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,[1] 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[2] 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 [3] 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, 425 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. * * *

This flora together with that of the Kirtland formation is regarded by Knowlton [4] as of Montana age.

Reeside [5] 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 [6] 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 by Gilmore [7], Stanton[8], and Knowlton [9] indicate a fluviatile origin. * * *

McDERMOTT FORMATION (CRETACEOUS?)

In the San Juan Basin the Kirtland shale is succeeded by the McDermott formation, which is provisionally regarded as Cretaceous, according to Reeside [10], because it seems to have much closer relations to the under-

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[1] Reeside, J. B., jr., op. cit., p. 18

[2] Lee, W. T.. op. cit. (U. S. G. S. Prof. Paper 101), p. 183.

[3] Reeside, J. B., jr., op. cit., pp. 20-21.

[4] Knowlton, F. H., Flora of the Fruitland and Kirtland formations: U. S. Geol. Survey Prof. Paper 98, pp. 330-331, 1917.

[5] Reeside, J. B., jr., op. cit., pp. 20-21.

[6] Idem, pp. 21-24.

[7] Gilmore, C. A., op. cit. (U. S. G. S. Prof. Paper 119), p. 8.

[8] Stanton, T. W., op. cit. (U. S. G. S. Prof. Paper 98), p. 310.

[9] Knowlton, F. H., op. cit. (U. S. G. S. Prof. Paper 98), p. 330.

[10] Reeside, J. B., jr., op. cit. pp. 27-28.

lying strata than to 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 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. The formation has yielded a few vertebrate remains, which have been regarded by Gilmore [1] as of Montana age. * * *

TERTIARY SYSTEM

GENERAL FEATURES

Several sedimentary formations of Tertiary age occupy different parts of New Mexico, and probably there are deposits of that age buried under the volcanic rocks and valley fill of some of the deserts in the southwestern part of the State. One of the most extensive outcrop areas is the wide, shallow basin in western Rio Arriba County and eastern San Juan County, where there is a well-known succession of lower Eocene strata, including the Wasatch, Torrejon, and Puerco formations, about 2,000 feet thick. The underlying Ojo Alamo sandstone and the Animas formation, at the base of this succession are probably of early Tertiary (Eocene) age, together with the Galisteo sandstone in the region near Cerrillos, the Raton formation of the Raton coal basin, and some other similar beds farther south. These all lie unconformably on Upper Cretaceous formations, generally with a basal conglomerate and more or less irregularity of overlap. The Tohachi shale and Chuska sandstone of the Chuska Mountains probably represent the Wasatch and possibly some underlying beds. Later Tertiary strata are represented by the Santa Fe formation and remnants of sand and gravel on high plateaus in both the western and eastern parts of the State. The sand mantle of the Llano Estacado and outliers of the same formation farther west are a southern extension of the Ogallala formation, which caps the High Plains of the Nebraska, Kansas, and Colorado region. Doubtless these later Tertiary formations underlie parts of some of the desert valleys of the south-central and southwestern parts of New Mexico and are also included in the succession of volcanic rocks in the west-central and southwestern parts. This great succession of volcanic products is mostly of Tertiary age and may represent a large part of that period. It comprises thick and widespread flows of lava of various kinds with interbedded volcanic tuff and ash, as well as gravel and sands, some of them separated by unconformities representing considerable erosion intervals.

OJO ALAMO SANDSTONE (TERTIARY?)

Outcropping along the western margin of the Tertiary deposits in the San Juan Basin is the Ojo Alamo sandstone, provisionally regarded as lower Tertiary (Eocene ?), though the precise age is still under discussion. According to Reeside [2], the sandstone includes considerable conglomerate, in which the pebbles are in part silica of various kinds but many are of rhyo-

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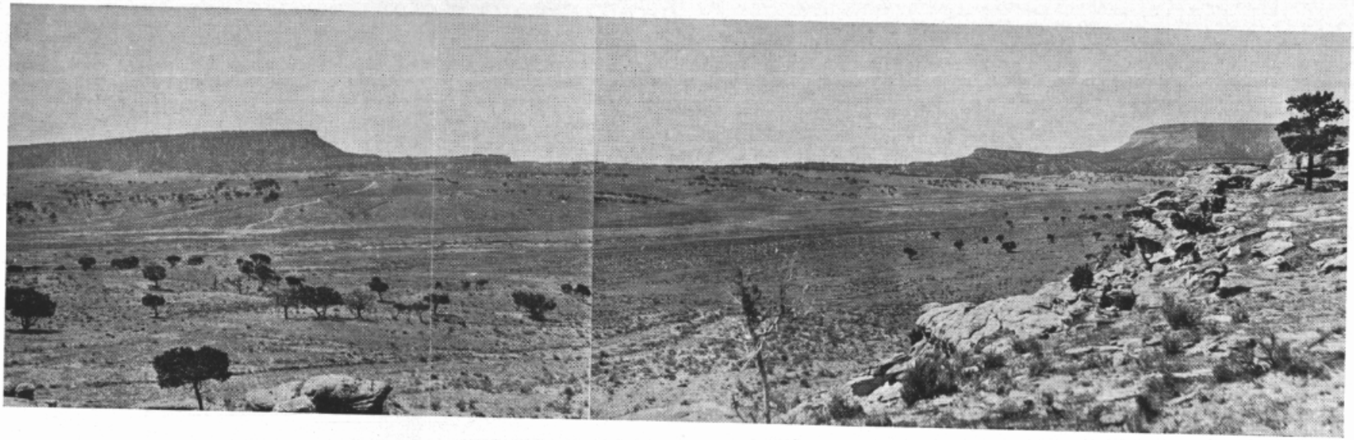
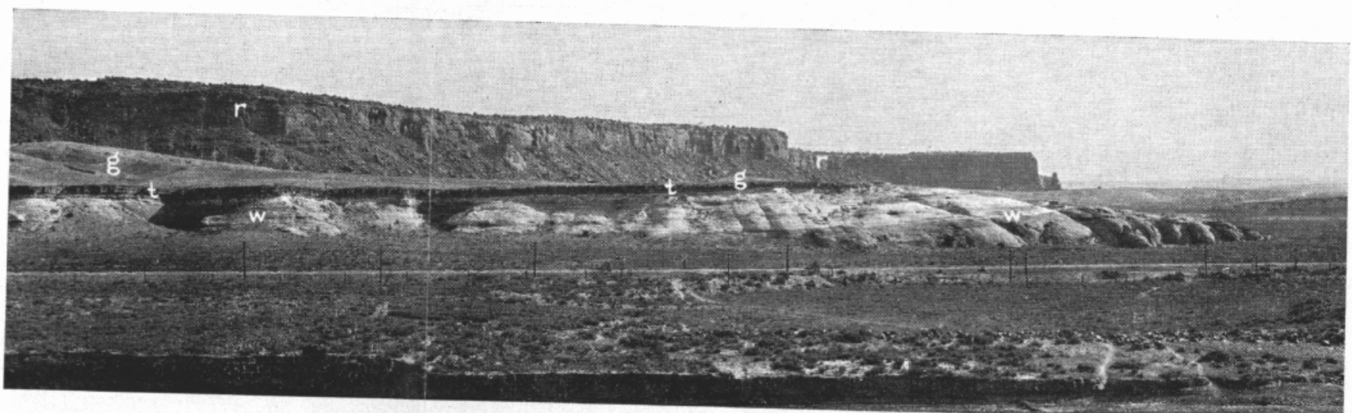
[1] Gilmore, C. W., op. cit. (U. S. G. S. Prof. Paper 119), p. 7.
[2] Reeside, J. B., jr., op. cit., p. 29.



A. Looking south across Walker dome, McKinley County. Sandstones of Mesaverde formation.



B. Wingate sandstone northeast of El Rito siding, near Laguna, Valencia County. w, Wingate sandstone, red below, white above; t, limestone member of Todilto formation; g, gypsum member of Todilto formation; r, red sandstone (lower Navajo). (Courtesy of U. S. Geological Survey.)

lite, andesite, and other igneous rocks. Most of them range from 1 to 3 inches in diameter, but some are larger. Nothing of this kind has been found in the underlying Cretaceous formations. Near the type locality the formation is from 60 to 80 feet thick. To the south it increases somewhat in thickness, reaching 125 feet on Escavada Wash. It has been traced eastward through Sandoval County, where, together with the overlying Torrejon formation, it overlaps the Kirtland, Fruitland, Pictured Cliffs, and Lewis formations. In the triangular area between Animas and San Juan Rivers the sandstone with its included shale layers is 400 feet thick. At a point about 9 miles north of Farmington it disappears under the Torrejon formation, but possibly its disappearance here is due to erosion prior to Torrejon deposition.

Many fragmentary remains of reptiles and a few poorly preserved remains of plants have been obtained from this sandstone, all of them from the vicinity of the type locality. Many silicified logs occur in places. Gilmore [1] has given a list of the animal remains, but it is believed that the paleontologic data now available are inconclusive as to the age of the beds. However, the beds are separated from preceding deposits by a pronounced and widespread erosional unconformity, which very strongly suggests that the formation is later than Montana. It is also stated by Reeside [2] that there is a great difference between the fauna of the Ojo Alamo formation and that of the Puerco formation, which follows, and some deformation attended by considerable erosion intervened between the two periods of deposition. Apparently the Puerco is absent in a wide area in which the Ojo Alamo beds are directly overlain by the Torrejon deposits.

GALISTEO SANDSTONE (TERTIARY?)

Overlying the Mesaverde formation unconformably in the Galisteo Valley, in central New Mexico, is a thick succession of sandstone and shale which has been separated as the Galisteo sandstone and classed as probably early Tertiary. At the base are coarse deposits, in large part conglomeratic, and evidently a considerable time break is represented in the unconformity. Lee [3] has described the character of these rocks at several places in the Cerrillos Basin as far south as the Una del Gato (Hagan) coal field, where he measured the following section:

Section of Galisteo (?) Sandstone in Hagan Coal Field

	Feet.
Shale and friable sandstone, purple, blue, green, yellow, etc......	2,500
Sandstone, conglomeratic, with red shale partings	
	195
Conglomerate, coarse	
Shale, sandy in places, gypsiferous, highly colored like upper shale member..	750
Sandstone, yellow, coarse, conglomeratic base, many petrified logs	345
Unconformity on shale of Mesaverde formation.	
	3,790

These beds are extensively exposed in the Cerrillos coal field and are penetrated by drill holes east of Madrid. The formation is largely covered by sand and gravel of the Santa Fe formation and by talus from the mountain slopes. The formation extends across the Atchison, Topeka & Santa Fe Railway a short distance east of Cerrillos, where it exhibits many petrified logs—a characteristic component of the formation.

[1] Gilmore, C. W., op. cit. (U. S. G. S. Prof. Paper 119), p. 9.

[2] Reeside, J. B., jr., op. cit., p. 32.

[3] Lee, W. T., The Cerrillos coal field, Santa Fe County, N. Mex.: U. S. Geol. Survey Bull. 531, pp. 286-297, 1913. See also Prof. Paper 101, pp. 201-217, 1917.

RATON FORMATION (EOCENE)

The Raton formation occupies an area of about 800 square miles in the portion of the Raton coal field that lies in New Mexico. According to detailed descriptions by Lee [1] the rocks are mainly sandstone with shale partings, but shale preponderates in the upper part. The total thickness is 1,150 feet in the central and southern part of the area, but the amount increases somewhat to the southwest. The basal member is conglomerate, 10 to 40 feet thick in the eastern outcrops, which thickens and becomes coarser to the south and west. The pebbles and boulders are of various rocks of older formations, including material from the Vermejo formation. The conglomerate lies on an irregularly eroded surface which in places descends to the Trinidad sandstone, and in the southwestern part of the Raton Mesa area it rests on Pierre shale. Next above the conglomerate are coal-bearing shale and sandstone about 100 feet thick, best developed to the north, where the principal coal bed is known as the "Sugarite coal," but the coal merges into coarse sediments to the southwest. This member is overlain by a "barren" series of sandstones, which weather yellowish brown and make conspicuous cliffs. The thickness of this series is 300 feet east of Raton and about 600 feet a few miles west of Raton. Next above is the "upper coal group," consisting of shale and friable sandstone with several coal beds, which are mined to some extent.

The principal fossils in the Raton formation are plants which have been studied by Knowlton. [2] The number of species is 148, and they afford evidence for classing the formation as older Eocene.

PUERCO FORMATION

According to Reeside [3] the Puerco formation as defined by its characteristic fauna is known only in an area about 35 miles long in the southeastern part of San Juan County. It is possible, however, that the formation is represented by the lower members of the Eocene deposits in other portions of the San Juan Basin, but the beds at this horizon appear to be barren of fossils in most of the great area in which they may possibly outcrop. It is suggested by Reeside that the Torrejon formation extensively overlaps and conceals the Puerco formation. On Escavado Wash and its branches the lower 250 feet of the series of beds that includes the Puerco and Torrejon formations consists of shale of various tints with interbedded soft light-colored sandstone. Puerco fossils occur in the lower 50 feet of these beds. The overlying 500 feet consists of light-colored sandstone separated by gray shale; these beds have yielded no fossils but have been arbitrarily placed in the Puerco formation by Sinclair and Granger.[4] The lowest Torrejon fossils are about 500 feet still higher. Near Ojo Alamo Puerco fossils occur in the lower 90 feet of a series of dark shale and soft sandstone. These strata are overlain by shale and sandstone of various colors, the proved Puerco beds being succeeded by an interval without fossils of about 100 feet. The beds regarded as Puerco show erosional unconformity, without discordance of dip at the contact with the Ojo Alamo sandstone, and an abrupt change of fauna.

The Puerco formation has yielded a large number of vertebrate remains, which have been listed by Matthew [5]and Gilmore [6]. A condensed list may be found in Reeside's report on the San Juan Basin. [7] Matthew

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[1] Lee, W. T., op. cit. (U. S. G. S. Prof. Paper 101), pp. 56-61. See also Folio 214, pp. 7-8, 1922.

[2] Knowlton, F. H., op. cit. (U. S. G. S. Prof. Paper 101), pp. 235-241, 284-349.

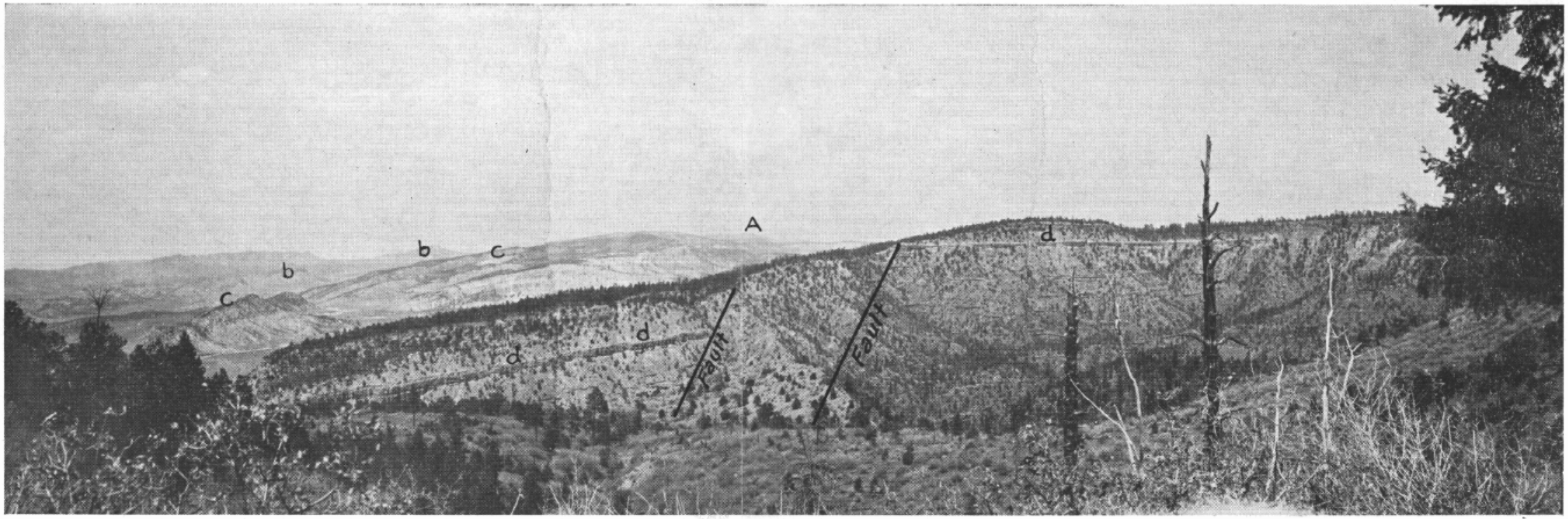
[3] Reeside, J. B., jr., op. cit., pp. 35-39.

[4] Sinclair, W. J., and Granger, Walter, Paleocene deposits of the San Juan Basin: Am. Mus. Nat. Heist. Bull., vol. 33, pp. 305-308, 1914.

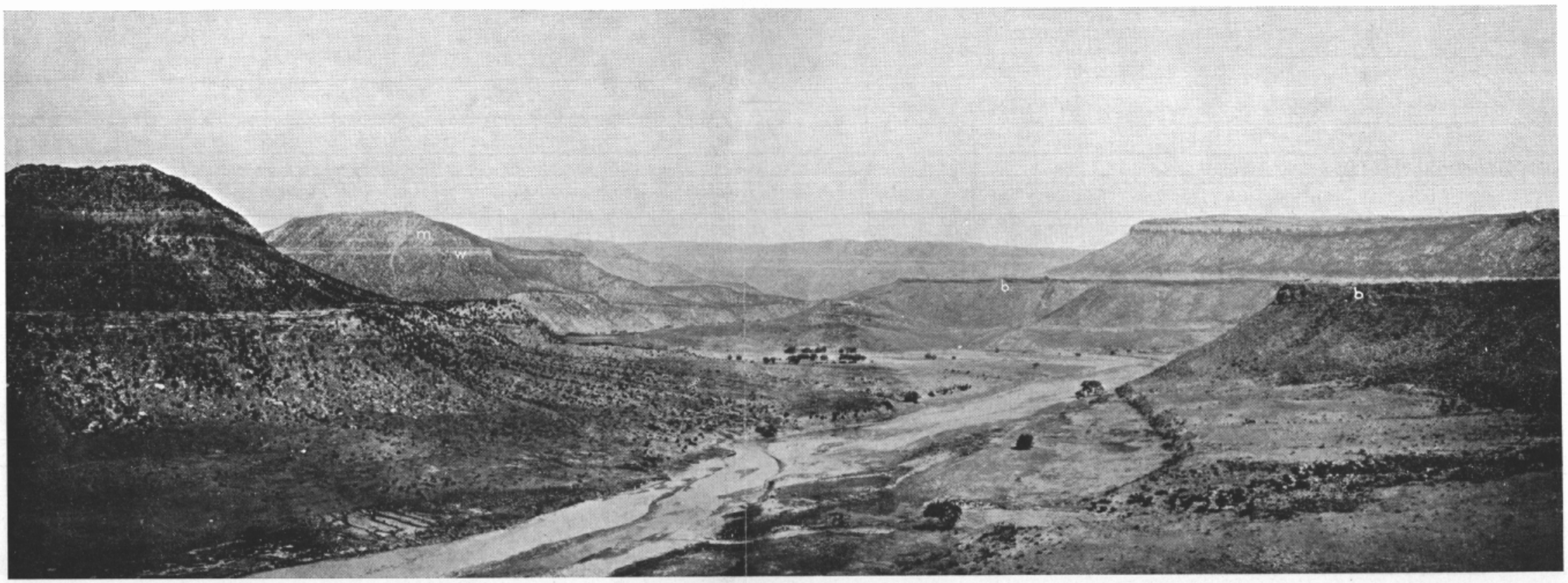
[5] Matthew, W. D., Faunal lists of the Tertiary mammalia of the West: U. S. Geol. Survey Bull. 361, pp. 91-92, 1909.

[6] Gilmore, C. W., op. cit. (U. S. G. S. Prof. Paper 119), pp. 9-10.

[7] Reeside, J. B., jr., op. cit., p. 38.



A. Looking north from crest of French Mesa anticline, Rio Arriba County. a, Gallina Mountain; b, Mesaverde sandstone; c, Dakota sandstone; d, Poleo sandstone.



B. Canadian River canyon near Sabinoso, San Miguel County. Looking north. w, Wingate sandstone; m, Morrison formation. The high plateau is capped by Dakota sandstone. The terrace b-b is capped by basalt flow from the Maxson Crater. (Courtesy of U. S. Geological Survey.)

states that the Puerco fauna is wholly unknown elsewhere and is one in which archaic placentals predominate. There are no dinosaurs, but the crocodiles, rhynchocephalians, and turtles are of the same group as those of the Judith River and Lance formations and not perceptibly more advanced. * * *

TORREJON FORMATION

According to Reeside[1] the Torrejon formation as defined by its fauna extends from Arroyo Torrejon, in Sandoval County, across the southern and western parts of the San Juan Basin almost to the Colorado State line. Eastward from Arroyo Torrejon the formation has been followed by Sinclair and Granger' to and beyond Puerco River. At the type locality, as described by Gardner,' the Torrejon formation consists of drab-gray, reddish, and black shale and gray and tan soft sandstone. The fossiliferous beds are 240 feet thick, and a barren zone 110 feet thick lies on the Ojo Alamo sandstone. On Puerco River the lowest fossil zone is overlain by shale and sandstone 660 feet thick with a barren zone 179 feet thick which Reeside includes in the Torrejon. In the Escavada Basin the Torrejon beds are 450 feet thick, including 25 feet of barren beds under the lowest fossil-bearing stratum. They are overlain by 250 feet of light-colored shale and sandstone, which Reeside provisionally regards as Torrejon. Near Ojo Alamo there is a barren interval of 110 feet of shale and sandstone between beds carrying Puerco and Torrejon fossils. The upper 50 feet of this interval is regarded as Torrejon, together with an additional 190 feet feet of shale and sandstone and 186 feet of overlying light-colored beds of uncertain age. On San Juan and Animas Rivers the Ojo Alamo sandstone is overlain by gray, olive-green, and brown shales, succeeded by 600 to 700 feet of sandstone, mostly light colored, and an equal thickness of beds in which hard brown lenticular sandstones are abundant. Torrejon fossils have been found about 150 feet above the base of this formation, all of which is regarded as Torrejon. Near Cedar Hill the fossiliferous beds are in the uppermost 300 feet of the Torrejon formation and consist of brown lenticular sandstone and variegated shale.

Matthew' has given a long list of mammals and Gilmore a long list of reptiles from this formation, which need not be repeated here. In a later paper[6] Matthew states that the Torrejon overlies the Puerco conformably and that although many of the archaic mammals are common to both, some additional ones appear in the Puerco. A few fresh-water invertebrates and poorly preserved plants are reported by Reeside from the Torrejon beds, but they throw no light on the precise stratigraphic position of the formation.

WASATCH FORMATION

The central area of the San Juan Basin is occupied by light-colored sandstone and shale of the Wasatch formation. The thickness has been estimated at 1,000 feet by Granger,' who recognized two faunal divisions— a lower one called the "Almagre beds," * * * and consisting of red, gray, and ocherous shale and sandstone, and an upper one called the "Largo

[1] Idem, p. 39.

[2] Sinclair, W. J., and Granger, Walter, op. cit., p. 312.

[3] Gardner, J. H., The Puerco and Torrejon formations of the Nacimiento group: Jour. Geology, vol. 18. pp. 714-719, 1910.

[4] Matthew, W. D., op. cit., pp. 91-92.

[5] Gilmore, C. W., op. cit. (U. S. G. S. Prof. Paper 119), p. 10.

[6] Matthew. W. D.. Evidence of the Paleocene vertebrate fauna on the Cretaceous-Tertiary problem: Geol. Soc. America Bull., vol. 25, p. 382. 1914.

[7] Granger, Walter, On the names of lower Eocene faunal horizons of New Mexico and Wyoming: Am. Mus. Nat. Hist. Bull., val. 33, p. 205, 1914. Notes on Paleocene and lower Eocene mammal horizons of northern New Mexico and southern Colorado: Idem, vol. 37, p. 824, 1917.

beds," * * * consisting of material similar to that of the lower division but with more red coloring. According to Reeside [1] the Wasatch beds in eastern San Juan County consist of a basal massive cliff-forming coarse pebbly copper-red sandstone, 50 feet thick, overlain by 150 feet of light-gray and red shale and soft white sandstone, overlain in turn by a sandstone similar to the basal member. Still higher are other shales and sandstones. There are excellent exposures in Blanco Canyon and lower Largo Canyon. Locally the basal 300 feet or more appears to be a continuous sandstone, but elsewhere beds of shale appear in it. On the divide between San Juan and Animas Rivers the Wasatch is a succession of coarse white to red sandstone, variegated purple to gray shale, and soft white sandstone. Near Cedar Hill the lower 700 feet of the formation is exposed, and on the highland to the east higher beds appear.

In southern San Juan County there is a sharp lithologic break between the Torrejon and Wasatch formations, but to the north there appears to be conformity. Near the Nacimiento Mountains the Wasatch overlaps other formations with angular discordance. * * *

TOHACHI SHALE AND CHUSKA SANDSTONE

The Chuska Mountains, north of Gallup, consist of shale and sandstone (Tohachi shale), 200 to 1,100 feet thick, overlain by the Chuska sandstone, 700 to 900 feet thick, all lying nearly horizontal. These formations have been described by Gregory [2], who suggests that they represent the Puerco, Torreion, and Wasatch formations of the San Juan Basin, but no basis for precise correlation was obtained. The Tohachi strata consist mainly of black, drab, blue, yellow, brown, and red shale, with interbedded sandstone and a few carbonaceous layers. They lie unconformably across several Mesozoic formations. As mapped by Gregory, Beautiful Mountain consists of an outlier of these formations capped by lava.

UNCLASSIFIED EARLY TERTIARY DEPOSITS

In the ridges east of Socorro the coal measures of the Upper Cretaceous are overlain unconformably by conglomerate and sandstone that are probably of early Tertiary age. In the Carthage coal field Gardner [3] found similar deposits and relations with the following succession of strata:

Section of Tertiary Strata near Carthage, N. Mex.

	Feet.
Shale and sandstone, variegated	700
Conglomerate, very coarse, boulders of granite, Carboniferous limestone, etc.	200
Shale, red; some sandstone	70
Sandstone, red, very coarse	30
Conglomerate; quartz, sandstone, granite, and chert in matrix of granite debris	3
Sandstone, red; some shale	10
Conglomerate, small quartz pebbles	5
Shale, red and drab	5
	1,023

Some bones and a tooth were collected in the lower part of the succession. * *. * A small deposit of conglomerate unconformably overlying Upper Cretaceous coal measures at the southwest end of the San Andres uplift, 23 miles northeast of Las Cruces, is regarded as Tertiary.

In the western part of New Mexico there are extensive outliers of sand

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[1] Reeside, J. B., jr., op. cit., pp. 44-45.
[2] Gregory, H. E., op. cit. (U. S. G. S. Prof. Paper 93), pp. 79-81.
[3] Gardner, J. H., op. cit. (U. S. G. S. Bull. 381), p. 454.

on the plateaus, south of Gallup and Zuni, which are doubtless of Tertiary age, but no data are available as to their correlation. * * *

In the Elephant Butte region, between the Sierra Caballo and the Fra Cristobal Range, the coal-bearing Mesaverde beds are overlain by sandstone, shale and conglomerate that * * * according to Lee [1] closely resemble the Galisteo sandstone and are probably of early Eocene age. The upper beds are in large part chocolate-brown to red, and the lower beds are white, brown and reddish with some greenish layers.

SANTA FE FORMATION (MIOCENE AND PLIOCENE)

The wide basin traversed by the Rio Grande from the Colorado State line southward to and beyond the center of New Mexico is occupied by a succession of sand, soft sandstone and conglomerate which represents a portion of later Tertiary time. These beds are overlain locally by sand and alluvium of Quaternary age and by extensive lava flows. They have long been known as the Santa Fe marl or formation, the former a name proposed by Hayden in 1869. In most places the beds lie horizontal or nearly so, and in some of the deep valleys northwest of Santa Fe a thickness of 200 feet or more is exposed. Many fossil bones have been obtained in this region, some of which are regarded as upper Miocene and others as Pliocene. It is probable that this formation extends southward along the Rio Grande Valley under Albuquerque, for in that region there are exposed two separate formations of valley fill lying nearly horizontal; and a third older one of conglomerate is well exhibited east of Socorro * * * and also on Rio Salado, where its beds are steeply tilted in the vicinity of the Lemitar and Ladrones uplifts. In Taos County the Santa Fe formation is widely overlain by the great lava flow of the Rio Grande Valley, but it is revealed in the deep trench cut by the river, and its relations are particularly well exposed in the slopes of Black Mesa and on the east side of the Rio Grande near Embudo. There is also an extensive lava cap on Santa Fe beds west of Santa Fe, which covers them to the south to points within a few miles of Cerrillos and Domingo. East of the Cerrillos Hills the formation lies on the Galisteo sandstone, and possibly some of the deposits of its southern margin abut against the igneous core of Ortiz Mountain. * * *

It is possible that the beds from which Cope [2] obtained *Aphelops fossiger* near the mouth of Dry Creek in the valley of Gila River may represent the Santa Fe formation. He states also that in the valley of the San Francisco these beds reach a thickness of 500 feet and consist of sand, soft sandstone, and conglomerate that contains pebbles of eruptive rocks.

OGALLALA FORMATION (MIOCENE AND PLIOCENE)

The mantle of gravel and sand that constitutes the surface of the High Plains over a vast extent of western Nebraska and Kansas, eastern Colorado, and northwestern Texas extends a long distance into New Mexico. It appears to be part of the Ogallala formation, of Pliocene and Miocene age, although probably in most areas only the upper (Pliocene) part is represented, and some of the surface sands may be of Quaternary age. On the Llano Estacado it forms a thick covering in most places. This high plain presents on the north a steep escarpment * * * descending to the Canadian Valley, and on the west a line of cliffs forming the eastern margin of the Pecos Valley but diminishing in altitude and distinctness toward the south in Lea County. In some parts of northwestern Texas not far east of the New Mexico line the formations of the Llano Estacado are underlain by sand and gravel which have yielded bones of Miocene and Pliocene age. Outliers of the Ogallala formation cover an extensive area of the plateau west of Fort Sumner and northwest of Elvira, and deposits

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[1] Lee, W. T., op. cit. (U. S. G. S. Prof. Paper 101) p. 33.

[2] Cope, E. D., The Loup Fork beds on the Gila River: Am. Naturalist, vol. 18, pp. 48-59, 1884.

supposed to belong to this formation extend along the east slope of the Hills of Pedernal and occupy several plateaus in the southwest corner of Santa Fe County. Small areas of sand and gravel also occur on the Canadian Plateau about Roy and east of Vernon, and possibly the high terrace remnant just north of Sapello is an outlier of this formation. In general the Ogallala formation is believed to be equivalent to part of the Santa Fe formation of the Rio Grande Basin at Santa Fe and westward.

QUATERNARY SYSTEM

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. 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. [1] 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 bene 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 beds, and deposited on the surface in crusts, which have crumbled to sand and in the

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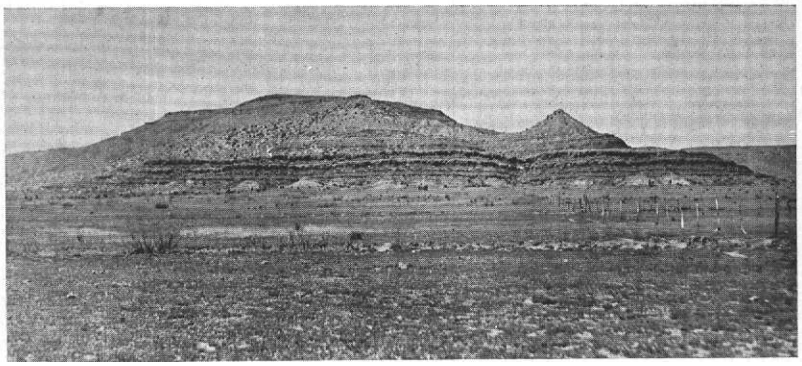
[1] In this deposit at El Paso Richardson has collected teeth identified by J. W. Gidley as Elephas columbi, Equus complicatus, and probable Tapirus haysii (El Paso folio, No. 166).

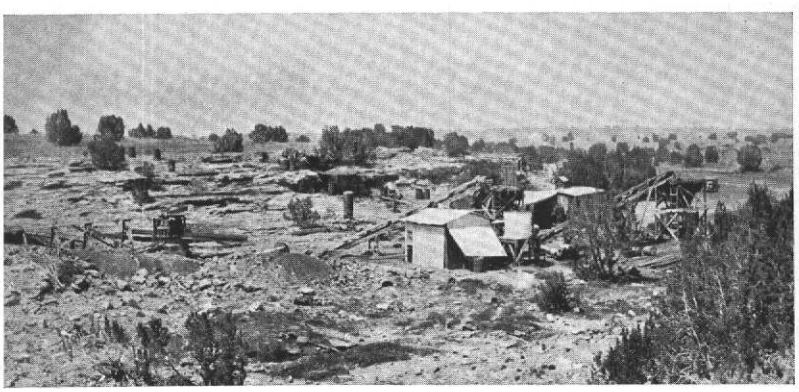
[2] Meinzer, 0. E., Geology and ground-water resources of Estancia Valley, N. Mex.: U. S. Geol. Survey Water-Supply Paper 275. 1911; Geology and water resources of the Tularosa Basin. N. Mex.: U. S. Geol. Survey Water-Supply Paper 343, 1915.

[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.



A. Escarpment near Gallegos, Harding County. Red sandstone (Wingate) capped by Dakota sandstone.

B. Bituminous sand quarry of the New Mexico Construction Co., 10 miles north of Santa Rosa, San Miguel County.



C. Bituminous sand treating plant of the New Mexico Construction Co., 10

C. Bituminous sand treating plant of the New Mexico Construction Co., 10

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, [1] 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.

GILA CONGLOMERATE

In many of the deeper valleys of southwestern New Mexico there are exposures of conglomerate believed to be the eastern extension of the Gila conglomerate of eastern Arizona. It is most extensively exposed along Gila River and its branches, but similar material appears in the valley of the Mimbres and in the valley of the Rio Grande in the vicinity of Socorro and to the south. Rocks of this kind in a portion of this valley near the Sierra Caballo have been classed as Palomas gravel by Gordon[2] and regarded as Pleistocene.

IGNEOUS ROCKS

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 not 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, ouartzite, 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.

Many descriptions of the intrusive rocks in mining regions of New Mexico are given by Lindgren. [3] The principal localities referred to are the Organ Mountains, the Tres Hermanas, the Jarilla Mountains, parts of the Sangre de Cristo Range. the Cochita district, the Cerrillos Hills, the Nogal, White Oaks, and Jicarilla districts in the Sierra Blanca region, the Little Hatchet and Pyramid Mountains, and several mining districts in the southwestern part of the State.

The igneous rocks in the Silver City quadrangle have been described in detail by Paige. [4] They comprise porphyries of several kinds, including quartz monzonite, diorite, and granodiorite, regarded as probably late Cretaceous, and intrusive stocks or dikes of rhyolite, andesite, latite, and diabase of Tertiary age. There are also pre-Cambrian granite, syenite, and

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[1] 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.

[2] Gordon, C. H., op. cit. (U. S. G. S. Prof. Paper 68), p. 237.

[3] Lindgren, Waldemar, op. cit. (U. S. G. S. Prof. Paper 68).

[4] Paige, Sidney, op. cit. (U. S. G. S. Folio 199), pp. 7-10.

porphyry. The intrusive rocks of Luna County [1] comprise the large masses of quartz monzonite and granodiorite porphyries of the Cooks Range and Fluorite Ridge, the granite porphyry of the Tres Hermanas, and dikes of diabase, keratophyre, andesite, and rhyolite.

Salinas Peak, in the San Andres Mountains, is a large mass of porphyry intruded mostly in the limestones of the Magdalena group. Gallinas Mountain consists of another large intrusive mass of porphyry in the Chupadera formation.

The Cerrillos Hills, in Santa Fe County, consist of large intrusive bodies of monzonite porphyry of various kinds, the character and relations of which have been described by Johnson [2] and Lindgre.[3] Similar intrusions in the Ortiz and San Pedro districts, southeast of Cerrillos, have been described by Lindgren. [4]

Ferguson [5] found that most of the rocks in the Mogollon Mining district were volcanic, but there are dikes of basalt and rhyolite and some intrusive andesite.

The intrusive rocks of the Raton coal basin have been described by Mertie. [6] They occur in dikes, plugs, and sills that cut and invade nearly all the Cretaceous rocks and also the Raton formation. They are mostly basaltic rocks similar to the basalt lava flows of the region, but dikes and sills of sodic vogesite also occur.

Ogilvie [7] has found that a dike cutting the Cretaceous shale 4 miles east of Las Vegas is an analcite-bearing camptonite. She also studied intrusive rocks of the Ortiz Mountains [8] and found that the main laccolithic mass is andesite and the rocks on the flanks are dacite with more or less gradation through diorite.

Dikes cut red beds 20 miles northeast of Socorro and Cretaceous strata 15 miles south of Quemado.

A long dike of olivine gabbro, described by Fisher [9], which cuts the red beds northeast of Roswell, has been studied by Semmes, [10] together with another similar dike a few miles north which is regarded as augite andesite. Semmes also describes a sill of diorite cutting Chupadera strata southwest of Dunlap and gives data regarding the character of the intrusive rocks near Capitan. In 1925 I found a dike cutting the Castile gypsum in sec. 10, T. 26 S., R. 29 E., 30 miles south-southwest of Carlsbad. An examination by C. S. Ross shows that although considerably decomposed, it is a lamprophyre of basaltic habit. A long dike cuts Chupadera strata at the Jones iron mine, west of Carrizozo.

Twin Cones, a prominent butte near the railroad 6 miles west of Gallup, consists of a dike or neck of an intrusive rock between minette and vogesite, which is flanked by a large amount of breccia. [11]

Gregory [12] found several igneous masses in the western part of the San Juan. notably the Ship Rock, Mitten Rock, and prominent dikes in Todilto

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[1] Darton, N. H., op. cit. (U. S. G. S. Bull. 618). pp. 19-23, 51-68. See also Folio 207, pp. 3-4, 7-10.

[2] Johnson, D. W., The geology of the Cerrillos Hills, N. Mex.: School of Mines Quart. vol. 25, PP. 175-203, 1904.

[3] Lindgren, Waldemar, op. cit., pp. 165-166.

[4] ldem, pp. 168-171.

[5] Ferguson, H. G., The Mogollon district, N. Mex.: U. S. Geol. Survey Bull. 715, p. 174, 1921.

[6] Mertie, J. R.. jr., U. S. Geol. Survey Geol. Atlas, Raton-Brilliant-Koehler folio (No. 214), pp. 11-12, 1922.

[7] Ogilvie. I. H. An anaicite-bearing camptonite from New Mexico: Jour. Geology, vol. 10, pp. 500-507. 1902.

[8] Ogilvie, I. H., Some igneous rocks from the Ortiz Mountains: Jour. Geology, vol. 16, pp. 230-238, 1908.

[9] Fisher, C. A. Preliminary report on the geology and underground waters of the Roswell artesian area, N. Mex.: U. S. Geol. Survey Water-Supply Paper 158, P. 8, 1906.

[10] Semmes, D. R., Notes on the Tertiary intrusives of the lower Pecos Valley, N. Mex.: Am. Jour. Ski., 4th ser., vol. 50, pp. 415-430. 1920.

[11] Darton, N. H., op. cit. (U. S. G. S. Bull. 435), p. 63.

[12] Gregory, H. E., op. cit. (U. S. G. S. Prof. Paper 93), pp. 83-107.

Park. Some of the latter are probably remains of volcanic plugs and consist in part of agglomerate. The petrology of these rocks which are mostly monchiquite, has been studied by L. V. Pirsson.[1]

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.

Ferguson[2] has studied these rocks in the Mogollon district, where the succession exposed has a maximum thickness of 8,000 feet, of which 6,400 feet represents lava flows and fragmental volcanic deposits and the remainder sedimentary deposits laid down by streams. The lava sheets in this region are very irregular in thickness and extent. The following list gives the order and the maximum thickness observed:

	Feet.
Andesite with dacite flows	600
Rhyolite tuff	400
Andesite	600
Rhyolite, coarsely spherulitic	1,200
Andesite and basalt	800
Sandstone	100
Rhyolite with quartz phenocrysts	700
Sandstone with andesite flow in lower part.	400
Rhyolite and rhyolite tuff	1,400
Rhyolite, minutely spherulitic	700

Many facts regarding the character and relations of the eruptive rocks in the mining districts of the State have been given by Lindgren,[3] from observations by himself, L. C. Graton, and C. H. Gordon. These relate mainly to the Mogollon, Cochiti, Socorro, Magdalena, Rosedale, Mimbres, Steeple Rock, and Lordsburg districts.

The lavas and associated deposits in the northern margin of the great central western volcanic area have been studied by Winchester,[4] who has proposed for them the name Datil formation.

A representative section of the succession is as follows:

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[1] Idem, pp. 107-108.

[2] Ferguson, H. G., The Mogollon district, N. Mex.: U. S. Geol. Survey Bull. 715, pp. 174-183, 1921.

[3] Lindgren, Waldemar, op. cit. (U. S. G. S. Prof. Paper 68).

[4] Winchester, D. E., op. cit. (U. S. G. S. Bull. 716), pp. 9.10.

Section of Datil Formation at North End of Bear Mountains, 6 Miles Southeast of Puertecito, Socorro County, N. Mex.

	Feet.
Quartz rhyolite	120
Conglomerate and sandstone, reddish, friable; conglomerate contains angular fragments of igneous rock	40
Sandstone	35
Conglomerate with pebbles as large as 1 foot in diameter	50
Sandstone and conglomerate in alternating beds	25
Sandstone, argillaceous	4
Tuff, conglomeratic, with pebbles and angular fragments as much as 18 inches in diameter	60
Rhyolite, vitreous, light colored	4
Andesite, light purple, vesicular	8
Agglomerate with igneous pebbles as much as 1 foot in diameter	17
Tuff, similar in composition to 65-foot bed below but gray and rather porous and slightly more basic	105
Tuff, red, compact, with groundmass of glass, iron ore, feldspar, and secondary calcite; inclusions of glassy material containing phenocrysts of feldspar, biotite, and iron ore	65
Sandstone, friable, containing earthy material	127
Covered	60
Tuff, conglomera tic, dark, slate-colored; angular fragments of igneous rock; maximum diameter of rounded pebbles 18 inches	420
Sandstone, red, argillaceous; contains streaks of gypsum	210
Covered but contains some yellow sand	190
Conglomerate like 4-foot bed below	5
Sandstone, thin bedded, with clay	1½
Clay, red, with sand and mica	12
Conglomerate, reddish, pebbles as much as 4 inches in diameter in matrix of clay, feldspar, and quartz	4
Clay, red, with sand and mica specks	15
Not exposed	175
Conglomerate, reddish gray, with well-rounded fragments of igneous and sedimentary rocks, including limestone	8
Conglomerate, white, well-rounded pebbles, maximum diameter 6 inches, of granite, obsidian, feldspar and quartz	64
	1,824½

The eruptive rocks of the Silver City quadrangle have been differentiated by Paige.[1] The flows of probable late Cretaceous age consist of rocks of the diorite-andesite group with agglomerate or flow breccias. The Tertiary lavas, which cover highland areas in different parts of the quadrangle, consist of rhyolite, andesite, quartz latite, and breccia, with interbedded deposits of ash tuff and gravel. Quaternary flows of basalt mostly less than 100 feet thick occur interbedded with gravel and sand.

In Luna County [2] the succession of volcanic rocks varies considerably from place to place and includes large bodies of agglomerate and other fragmental deposits. The thickest and most extensive sheets are rhyolite, latite, and andesite of various kinds and minor amounts of quartz basalt, keratophyre, and quartz diorite. These are mostly of Tertiary age. There are also basalt flows of Quaternary age.

Some of the volcanic rocks collected by Mearns along the Mexican

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[1] Paige, Sidney, op. cit. (U. S. G. S. Folio 199), PP. 9-10.

[2] Darton, N. H., op. cit. (U. S. G. S. Bull. 618), pp. 51-68. See also Folio 207, pp. 7-9.

boundary have been described by Lord. [1] They comprise basalt, andesite, and rhyolite and were collected in the vicinity of boundary monuments 15, 19, 20, 35, 40, and 55.

Iddings[2] has described in detail the petrography of rhyolite, tuff, andesite, and basalt (some of it quartz-bearing), collected by J. W. Powell in the Valle Grande ("Tewan") Mountain region, and Henderson[3] has given an account of some features of the great tuff deposits of this region.

The volcanic rocks of Mount Taylor and the Zuni Mountain region have been described by Dutton [4] and Johnson [5]. Herrick [6] has described relations in the Albuquerque region and about Socorro. Volcanic rocks on the Chuska Mountains, in the western part of San Juan County, have been described by Gregory. [7]

The volcanic rocks in the Raton coal field have been described by Mertie.[8] The oldest flows are mostly on the higher mesas, and nearly all the younger lavas are on the lower lands, as there was considerable erosion of the surface between the several eruptions. Some of the thicker masses consist of a succession of flows separated by scoriaceous material. The oldest lavas which are on Barilla Mesa and the west end of Johnson Mesa, are from 100 to 500 feet thick and are classed as olivine basalt. The lavas of the second period of eruption are closely similar to the older flows, but those of the later flows comprise basalt, dacite, and andesite, constituting Towndrow Peak, Hunter Mesa, Meloche Mesa, and Cunningham Butte. It is stated by Mertie that the lava flow of Mount Capulin is vesicular and glassy olivine basalt. Its cone, which is about 1,500 feet high and $1^1/_2$ miles in diameter, consists of fresh cinders and is the product of a very recent eruption on a gigantic scale. The walls of the crater in its top are 75 to 275 feet high.

The volcanic rocks of northeastern New Mexico were mapped many years ago by Prentiss Baldwin, and data from his manuscript map have been used in preparing the geologic map of New Mexico recently published by the United States Geological Survey. Some of the flows in this region are relatively young, for they extend down the bottoms of recent valleys, notably the Cimarron Valley near Folsom, Union County. The lava from the Maxson crater, north of Shoemaker, flowed down the canyon of Mora River and the valley of Canadian River, but these streams have since cut a trench through the basalt * * * .

The crater-like depression holding Zuni Salt Lake, southwest of Zuni [9], is rimmed in part by Cretaceous sandstone and in part by lava. It has two cinder cones near its center and a rim of rock fragments, some of them Carboniferous, and is believed to be an explosion crater. * * * Other craters probably caused by volcanic explosions are the Afton and Kilbourne craters, described by Lee [10], in the southwestern part of Dona Ana County, northwest of El Paso, Tex.

There are several recent lava flows in the region adjacent to the Zuni

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[1] Lord, E. C. E., Petrographic report on rocks of the United States-Mexico boundary: U. S. Nat. Mus. Proc., vol. 21, pp. 773-782, 1899.

[2] Iddings2, J. P., On a group of volcanic rocks from the Tewan Mountains, N. Mex.: U. S. Geol. Survey Bull. 66, 1890.

[3] Henderson, Junius, Geology and topography of the Rio Grande region in New Mexico: Bur. Am. Ethnology Bull. 54, pp. 23-39, 1913.

[4] Dutton, C. E., Mount Taylor and the Zuni Plateau: U. S. Geol. Survey Sixth Ann. Rept., pp. 105-198, 1886.

[5] Johnson, D. W., Volcanic necks of the Mount Taylor region, N. Mex.: Geol. Soc. American Bull., vol. 18, pp. 303-324, 1907.

[6] Herrick, C. L., The geology of the environs of Albuquerque, N. Mex.: Am. Geologist, vol. 22, pp. 23-43, 1898.

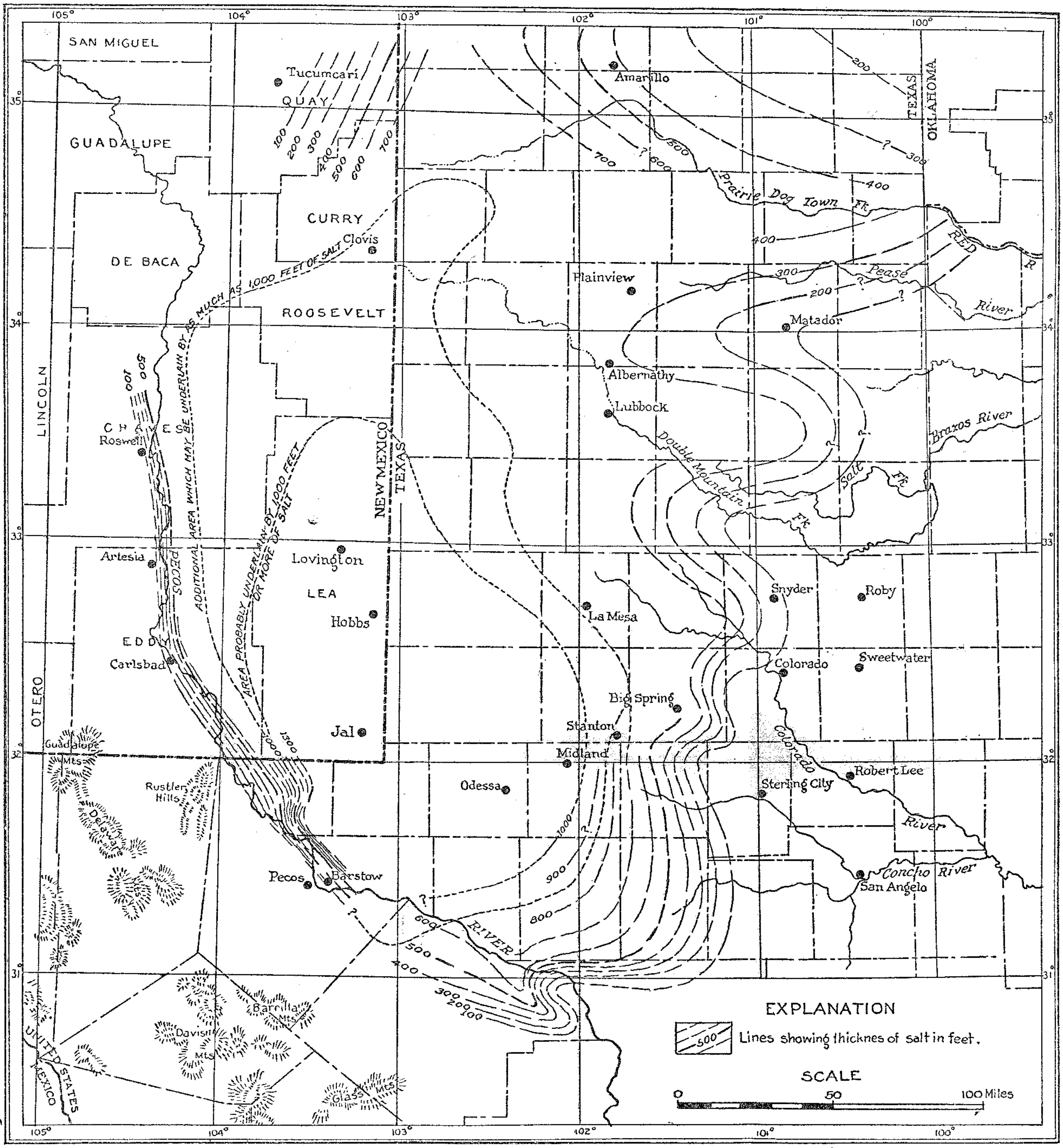
[7] Gregory, H. E., op. cit. (U. S. G. S. Prof. Paper 93), pp. 98-100.

[8] Mertie, J. B. jr., op. cit. (U. S. G. S. Folio 214), pp. 9-11.

[9] Darton, N. H., The Zuni Salt Lake: Jour. Geology, vol. 13, pp. 185-193, 1905; Explosion craters: Sci. Monthly, vol. 3, pp. 417-430, 1916.

[10] Lee, W. T., Afton craters of southwestern New Mexico: Geol. Soc. America Bull. vol. 18, pp. 211-220, 1907.

Mountains, where numerous fresh craters remain from which flows have run down the bottoms of valleys. The lava of the "malpais" strip in the Tularosa Valley, near Carrizozo, * * * and the flows on the plain northeast of Engle, about the Potrillo Mountains, in the valley near Pratt, in the valley near San Jose from Horace to Cubero, and from Cerro Verde south of Suwanne are all products of recent eruptions.



Map of Permian Salt Basin in New Mexico and Texas. (After Hoots, H. W.; U. S. Geological Survey Bull. 780.)

GENERAL GEOLOGY OF OIL AND GAS

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 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. Geophysical prospecting is discussed on pages 210-215.

Most of the anticlinal folds indicated on the Oil and Gas Map of New Mexico, Plate XXIII, were determined by studies of surface exposures and logs of wildcat wells. The location of the Hobbs pool in Lea County, however, is to be credited directly to geophysical studies.

GENERAL STRUCTURAL AND STRATIGRAPHIC FEATURES OF OIL AND GAS ACCUMULATIONS IN NEW MEXICO

Exploration for oil and gas in New Mexico has shown that their accumulation in commercial pools is due primarily to two geologic factors; (a) favorable geologic structure, and (b) lenticular porosity of the reservoir beds. The greater part of the oil produced has come from anticlinal structures (Hobbs, Eunice, Rattlesnake and Hogback fields), although there are areas where good commercial production has been developed on monoclinal structures without reversal and due largely to favorable porosity (Artesia, Cooper, Jal and Maljamar). In the largest gas area so far proven—Jal—the location of productive wells is evidently controlled by the porosity of the reservoir beds. Immense reserves of gas are also present in the Hobbs oil field.

To date oil or gas, or both, have been found in New Mexico in strata of Pennsylvanian, Permian, Triassic, and Cretaceous ages. The production of the southeastern part of the State has come largely from the upper part of the San Andres (Permian) limestone, while in the northwestern part the Dakota (Cretaceous) sandstone has yielded most of the production. Pennsylvanian and Cretaceous rocks have been proved to contain oil in commercial amounts only in the northwestern part. Carbon dioxide gas is found in the Triassic in the northeastern part of the State. No discoveries of commercial oil or gas have been made in Tertiary or Jurassic strata, in the Paleozoic formations older than the Pennsylvanian, in the pre-Cambrian rocks, or in the Tertiary intrusive and extrusive rocks.

The general geology of the State is shown on Plate II, Geologic Map of New Mexico. On this map, which is taken largely from the United States Geological Survey's "Geologic Map of New Mexico" by N. H. Darton, published in 1928, the formations are grouped under seven patterns, each representing an economic unit as regards oil and gas. The Oil and Gas Map of New Mexico, Plate XXIII, shows the axes of most of the known anticlinal folds together with the location and total depth of all wildcat wells, the oil and gas fields, refineries and pipe lines. Detailed maps of many of the more interesting areas are given in connection with the discussions of these areas.

Within the last three years intensive study of the Permian salt basin in the southeastern part of the State (see Plate XIII) in connection with the commercial development of potash salts has furnished much detailed - geologic information.

In considering the structural features and the development of oil and gas, the State has been divided into five "areas;" namely, the Median Area, Northwest Area, Northeast Area, Southeast Area and Southwest Area. (See map, Plate XIV.) In each area, except the Southwest Area, structural as well as stratigraphic features are similar over the entire area, but different from those in adjoining areas.

SUMMARY OF OIL AND GAS POSSIBILITIES

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 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, sub-surface geological conditions are obscure, and in these areas geophysical investigations will probably be of great assistance in determining structural conditions.

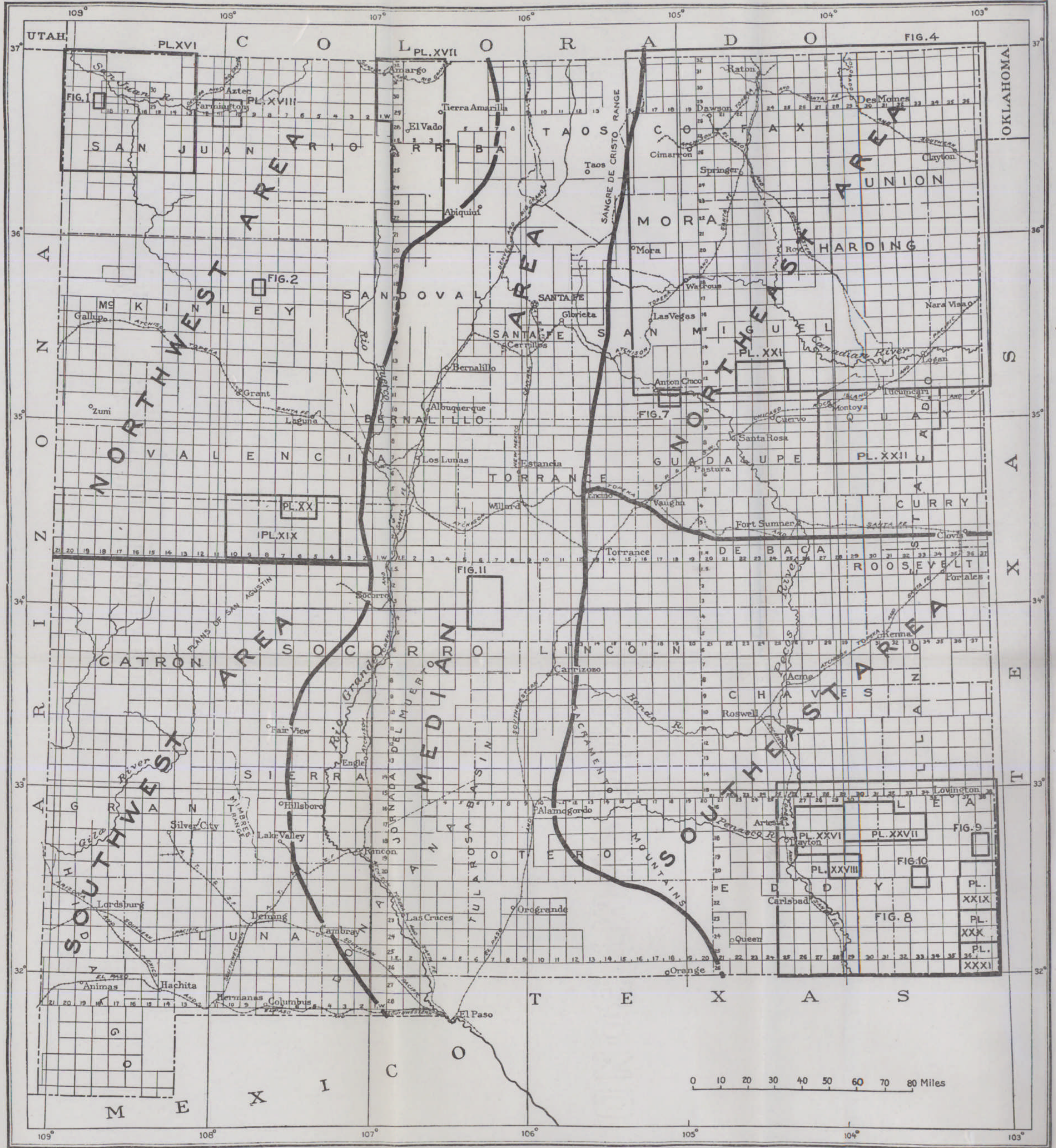
In the Southeast Area, particularly, are large areas where no hard rocks are exposed at the surface and where wildcat drilling has not yet disclosed the subsurface conditions. A few scattered wells furnish limited information, but most of these wells have not been drilled deep enough to test even the formations which are productive in the proven fields. Geophysical surveys will doubtless outline additional folds whose drilling may result in new production. Drilling of formations below those already tested should also result in additional production. In the areas already proven—Hobbs, Artesia, Eunice, Jal, Cooper, Lea, Maljamar and Getty—drilling has been carried only into the upper part of the San Andres formation, and the oil and gas possibilities of the underlying formations are unknown. Exposures of the strata below the top of the San Andres in. the mountains west of the Pecos River, indicate that they are worthy of prospecting where structural conditions are favorable to oil and gas accumulation.

The writer's interpretation of structural conditions in the southeastern part of the State, as indicated by available information, is shown on figure 8, page 141. According to this interpretation, anticlinal structures on the lagunal (north) side of the Capitan reef arrange themselves along two general lines of folding. Additional studies and drilling may locate other fields along these lines of folding, and it is suggested that other folds probably exist in the little-prospected area farther north. It is believed that additional and probably prolific fields will be found in the Southeast Area.

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 material and associated sands, which 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.



Map of New Mexico showing divisions of the State and areas covered by detailed maps.

GENERAL FEATURES OF OIL AND GAS DEVELOPMENT AND PRODUCTION

During the last twenty years geologists have studied and mapped most of the anticlinal folds which are visible in the surface rocks, and during the last five years geophysical studies have been carried on, particularly in the areas where bed rock exposures are scarce or lacking, in attempts to decipher the underground structure and locate anticlinal folds for testing with the drill. Resulting from these geological and geophysical studies, prospecting with the drill has been carried on in nearly every county in the State. Up to July, 1931, at least 1,400 wells had been drilled and commercial oil proven in 16 areas and commercial gas in 10 areas.

Since 1924 New Mexico has been a consistent producer of petroleum or oil but it was not until 1930 that the State joined the ranks of the big producing states. The table below gives the production of petroleum, natural gas and natural gasoline for the period from 1924 to 1931.

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

Year.	Petroleums, 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

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

NORTHWEST AREA

GEOGRAPHY AND GEOLOGY

The Northwest Area (see Plate X1V) 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 Ladrones 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 Ladrones 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 floor of the valleys.

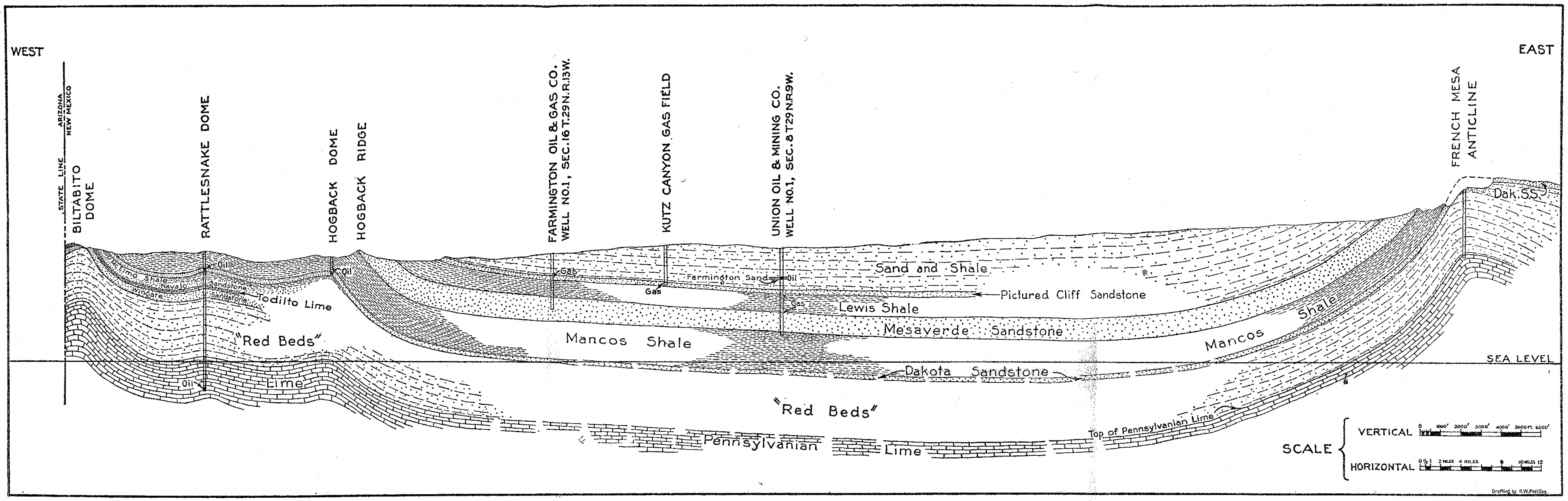
OIL AND GAS

Geologic exploration has outlined many anticlinal structures within the area, and wells have been drilled on a goodly portion of the structures. Commercial oil fields have been developed on the Hogback, Rattlesnake and Table Mesa structures and in the Bloomfield area, and possible oil pools indicated by tests on the Hospah, Cathedral Rocks and Walker structures. Commercial gas has been developed on the Barker and Ute domes and in the Aztec and Kutz Canyon areas. Gas from the latter area is transported to Albuquerque and Santa Fe as well as to Farmington. The town of Aztec gets its gas from the wells near the town, and gas from the Ute dome is taken to Durango, Colo. Commercial oil is produced from the Dakota sandstone (Cretaceous), from the Farmington sand (Cretaceous), and from Pennsylvanian rocks. Gas is produced from the Pictured Cliffs sandstone (upper part of the Cretaceous) in the Kutz Canyon area and from the Dakota sandstone on the Barker and Ute domes.

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 eastern Arizona. With the exception of the extreme eastern and southern edges the drainage is through the San Juan River



Section across the San Juan Basin.

and its many 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 present is between 12,000 and 15,000 feet. The accompanying cross section, Plate XV, shows the structural conditions as revealed by the drill across the basin from east to west, approximately through Farmington. As shown by the 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. Beyänd 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 these mountains, but because of the fact that they are known to be present in the northern and eastern part of the basin 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, and it is, suspected, therefore, that beds older than Pennsylvanian may be present in certain parts of the basin.

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 Chama basin but are steeply tilted and faulted near Abiquiu on the east side of the basin. Near Coyote in the southern part of the basin three small anticlines appear in beds of Triassic or Permian age.

The table, page 62, lists the sedimentary formations known to be present in the San Juan Basin and indicates some of their mineral resources.

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 XVI, in pocket.) Ship Rock, one of the most conspicuous of these igneous plugs, rises to an altitude of approximately 1,850 feet above the surrounding country. (See Plate IX, C.) These intrusions probably have had little or no effect upon oil and gas accumulations. It is suggested, however, that the earth movements which produced the cracks through which the igneous rocks found their way to the surface may have been influential in producing the high gravity of the oil contained in the rocks.

Geologic Formations of the San Juan Basin

Age.	Formation.	Character and Economic Features.	Thickness, feet.
Tertiary.	Wasatch formation.	Conglomerate, sandstone and shale.	500
	Puerco and Torrejon formations.	Clay, sandy shale and sandstone.	0-400
Upper Cretaceous.	Ojo Alamo sandstone.	Sandstone and conglomerate; shale lenses.	0-100
	Kirtland shale.	Shale, includes Farmington sandstone member. Small amount of high-gravity oil and gas in Bloomfield field; small quantity of gas in Aztec field.	800-1,100
	Fruitland formation.	Sandstone and shale. Some coal.	200-300
	Pictured Cliffs sandstone.	Sandstone. Commercial gas in Kutz Canyon field.	50-275
	Lewis shale.	Shale, sandy and calcareous in part.	75-500
	Mesaverde group.	Sandstone and shale. Coal beds. Oil at Hospah, Seven Lakes and Stoney Buttes structures.	1,980
	Mancos shale.	Shale, with sandstone members. Show of gas in "Tocito Sand" at Chimney Rock dome.	2,000
	Dakota sandstone.	Sandstone and some shale. Thin coal seams. Commercial oil, 55°-76° A. P. I. gravity in Hogback, Rattlesnake and Table Mesa fields; small amount of oil at Walker dome; commercial gas on Ute and Barker domes.	175-200
Cretaceous (?).	Morrison (McElmo) formation.	Shale and sandstone.	0-500
Jurassic.	Navajo sandstone.	Sandstone.	250-600
	Todilto limestone.	Limestone, gypsum locally at top.	60-80
	Wingate sandstone.	Sandstone. Show of 40° A. P. I. oil at Beautiful Mountain anticline.	400-700
Triassic.	Chinle formation.	Shale.	800-900
	Shinarump conglomerate or Poleo sandstone.	Sandstone.	50-100
	Moenkopi formation.	Shale, in part sandy.	400-900
Permian.	Chupadera formation.	Limestone, sandstone and gypsum.	200-1,200
	Abo sandstone.	Sandstone, some limestone near base.	600-800
Pennsylvanian.	Undifferentiated.	Limestone, some shale and sandstone. Commercial oil, 40° A. P. I. gravity at Rattlesnake dome.	0-2,000
Mississippian (?).			
Pre-Cambrian.		Granite and schist.	

OIL AND GAS

The accumulation of oil and gas in the San Juan Basin appears to be controlled by anticlinal folding, except in the Kutz Canyon-Bloomfield-Aztec area 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 relatively small production appears to be controlled by lenticular sand conditions in essentially flat-lying beds. A great deal of the detailed mapping of structures has been done by various geologists, and probably most of the anticlinal folds have been studied. To date 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 Pennsylvanian, finding commercial production at a depth of 6,771 feet.

In the San Juan Basin, the principal oil-producing horizon to date has been the Dakota at the base of the Cretaceous, from which a total of 3,014,850 barrels of oil had been produced up to Jan. 1, 1931. The oil from this horizon has the unusually high gravity of 55° to 76° A. P. I.

Well No. 17 on the Rattlesnake dome, which reached the deep producing zone in the Pennsylvanian, under unfavorable mechanical conditions of completion, produced in two years following completion (April, 1929) 330,375 barrels of 40° A. P. I. gravity crude oil from the Pennsylvanian and 27,559 barrels of light crude from the Dakota. The Dakota production continued for only a few days before being shut in to accommodate deeper drilling.

The table, page 64, gives the results of drilling on structures in the San Juan Basin.

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 necessary to drill to the greater depths necessary to develop this horizon. Such structures as Beautiful Mountain, Biltabito, El Vado, French Mesa, Gallina Mountain, Hogback, Table Mesa and Tocito (see maps. Plates XVI and XVII) are well worth testing for Pennsylvanian production.

The possibilities of Pennsylvanian production on structures in the southern part of the basin depend perhaps largely 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 the suggestion is made that a deep test is 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.

Principal Structures in the San Juan Basin

Name.	Surface Formation.	Lowest Formation Drilled.	Total Depth of Well, Feet.	Results.
Azotea.	Mancos.			
Barker.	Mesaverde.	Dakota.	3,365	30,000,000 cubic feet gas in Dakota (one well).
Beautiful Mountain.	Mancos.	Shinarump.	3,290	Show of 40° A. P. I gravity oil in Wingate.
Biltabito.	Wingate.			Untested.
Bonita.	Mesaverde.	Mancos.	3,275	Dry.
Carica.	Mesaverde.		3,190	Dry.
Chavez.	Mesaverde.	Dakota.	2,154	Dry.
Chico.	Mesaverde.		1,807	Dry.
Chimney Rock.	Mancos.	Dakota.		Show of gas in Tocito; water in Dakota.
Chromo.	Mancos.			Tested in Colorado.
Dulce.	Mesaverde.			Untested.
El Vado.	Dakota.			Untested.
French Mesa.	Poleo.	Pennsylvanian.	3,355	Incomplete test of Pennsylvanian.
Gallina Mountain.	Pennsylvanian.			Untested.
Hogback.	Tocito.	Wingate (?).	1,965	Several commercial wells in Dakota, oil 63° A. P. I. gravity.
Horse Lake.	Red beds.		1,785	Dry; granite reported.
Hospah.	Mesaverde.		3,282	Commercial wells in Mesaverde, oil 30° A. P. I. gravity.
Mariano Lake.				Untested.
Monero.	Mancos.	Dakota.	1,515	Dry.
Rattlesnake.	Tocito.	Pennsylvanian.	6,771	Several commercial wells in Dakota, oil 70°-76° A. P. I. gravity. One commercial well in Pennsylvanian, oil 40°-43° A. P. I. gravity.
San Mateo.	Mancos.	McElmo.	1,320	Dry.
Stoney Buttes.	Mesaverde.	Mancos.	3,060	Small amount of oil in Mesaverde, 35° A. P. I. gravity.
Table Mesa.	Mancos.	Wingate.	3,010	Commercial oil in Dakota, 57°-58° A. P. I. gravity.
Tocito.	Tocito.		3,022	Water in all sands drilled.
Ute.	Mesaverde.	Dakota.	2,428	125,000,000 cubic feet gas in Dakota (total for 3 wells).
Vogt.	Mesaverde.		1,555	Dry.
Walker.	Mancos.	McElmo.	1,460	Small amount of oil in Dakota.
Willow Creek.	Red beds.		2,054	Dry.

BARKER DOME AND SOUTHERN UTE DOME

The Barker and Southern Ute domes are located west of the great "Hogback" on the Southern Ute Indian Reservation near the north line of the State. (See map, Plate XVI.) The surface rocks of the area belong to the Mesaverde formation (Cretaceous) 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., in New Mexico. 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-southwest and is crossed by one major fault just south of the crest. The dome has been proven productive of gas in the Dakota sandstone by one well on the top of the structure, drilled by the Gypsy Oil Co. Recent drilling in southern La Plata County, Colo., suggests that oil may be present in the same formation on the sides of the structure.

A lease to acreage on the Barker dome was sold to the Gypsy Oil Co., which in 1925 completed a well through the Dakota at 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. The lease and well were later returned to the Indians and a new lease granted in 1930 to the Southern Union Gas Co.

Southern Ute dome, located to the southeast of the Barker dome, is crossed by several faults of considerable magnitude as shown by the accompanying map, Plate XVI. The axis of the Southern Ute dome is essentially parallel to that of the Barker dome. Gas in large quantity has been proven by three wells drilled near the top of the structure.

The Midwest Refining 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 2,335 feet. This well was not properly completed, but was rated at 4,000,000 cubic feet of gas per day. Well No. 2, located a short distance to the east of No. 1 in sec. 36, T. 32 N., R. 14 W., was finished by the same company 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 to the south, completed its 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. These wells were shut in until 1930, when the field was connected with a 6-inch pipe line to Durango, Colo.

The following analyses of gas from the Southern Ute dome were furnished by the United States Geological Survey.

Analyses of Gas from Southern Ute Dome

	Midwest Refining Co. Well No. 1. Depth, 2.190-2,325 feet.	Midwest Refining Co. Well No. 2 Depth, 2,340-2,428 feet.
CH_4	84.10 per cent	90.79 per cent
C_2H_6 plus	14.97 per cent	8.18 per cent
CO_2	0.32 per cent	0.44 per cent
O_2	0.22 per cent	0.44 per cent
N_2	0.38 per cent	0.20 per cent

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, elongated dome with a closure of more than 100 feet. (See map, Plate XVI.) 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 rock, 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 SW. 1/4 SE. 1/4 sec. 34, T. 31 N., R. 17 W., found the top of the "Tocito Sand" at 605 feet, with a small flow of gas (estimated at 50,000 cubic feet) at 625 to 640 feet. The Dakota was topped at 1,425 feet and contained only sulphur water. In January, 1927, the well was abandoned at 2,000 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 as a nonproducer.

HOGBACK FIELD

LOCATION

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 dome structure known as the Hogback dome. 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 good automobile road from Shiprock, about 10 miles to the northwest.

HISTORY

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 14 additional wells were drilled, which included 11 by the Midwest Refining Co., two by R. D. Compton, and one by the Santa Fe Mutual Co.

The table, page 67, taken from the report by K. B. Nowels,[1] gives a summary of drilling operations on the Hogback dome.

To January 1, 1931, the Hogback field had produced 1,136,720 barrels of oil, which amount represents a recovery of 4,372 barrels per acre from the 260 acres proven productive. At that date the field was pro-

[1]Nowels, K. B., Development and relation of oil accumulation to structure in the Ship-rock district of the Navajo Indian Reservation. New Mexico: Am. Assoc. Petroleum Geologists Bull. vol. 13, No. 2, p. 123, 1929.

ducing an average of 440 barrels per day. In 1924 the Midwest Refining Co. completed a 3-inch welded pipe line from the Hogback field to Farmington, where the oil is loaded in tank cars for shipment to the refinery of the Utah Oil Refining Co., at Salt Lake City, Utah.

Summary of Drilling for Hogback Field

Well No.	Location Sec., T. - N., R. - W.	Surface Elevation in Feet.	Depth to Top of Sand in Feet.	Total Depth in Feet.	Production in Barrels.
			Midwest Refining Co.		
1	NE¼ 19-29-16	5,133	722	988	375 oil cemented off, and made a test well. Using as water well.
2	NW¼ 19-29-16	5,132	785	795	1.276 first 24 hours.
3	NW¼ 20-29-16	5,061	1,003	1,225	3,000 sulphur water in Dakota. Plugged and abandoned.
4	NW¼ 19-29-16	5,132	837	842	1,200 sulphur water when drilled; now capable of making 5-10 oil.
5	SE¼ 19-29-16	5,125	760	763	Estimated 1,200 oil when drilled; now producing little water.
6	SE¼ 19-29-16	5,126	771	783	Oil and water; amount not determined; estimated 60 oil, 300 water; plugged and abandoned.
7	NE¼ 19-29-16	5,003	647	657	1.200 oil.
8	SE¼ 18-29-16	5,029	679	684	500 oil. Sand just touched. Would probably be as good as No. 7.
9	NE¼ 19-29-16	5,004	633	647	212 oil.
10	NE¼ 19-29-16	5,008	650	664	20 oil for two weeks. Small amount water. Plugged.
11	NE¼ 19-29-16	5,035	668	677	110 oil.
12	NE¼ 19-29-16	5,134	774	776	656 oil. Small amount water.
			R. D. Compton		
1	NE¼ 30-29-16	5,125	892	925	500 water.
2	SE¼ 13-29-17	5,081	776	799	Sulphur water. Now plugged and abandoned.
			Santa Fe Mutual Co.		
1	NE¼ 13-29-17	5,090	823	1.965	Big flow sulphur water in Dakota. Abandoned.

GEOLOGY

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 aver the heart of the structure except where eroded through by the Chaco River, which crosses the structure east to west just north of the high point.

The Dakota, from which production is obtained, as shown by the following log of the Midwest No. 1 well, is composed of alternating beds of sand and shale and some coal seams and has a total thickness of approximately 200 feet.

Log of Midwest Refining Co. *Hogback No.* 1 *Well*
NE.¼ Sec. 19, *T.* 29 *N., R.* 16 *W.*
Drilled, 1923

	Bottom, feet.
Surface sandstone, yellow, solid	40
Shale	60
Sandstone and shale	100
Sandy shale	150
?	200
Sandy shale	280
Hard shell	290
Light gray shale	330
Black shale, soft	430
Black shale, soft	470
Gray shale, soft	500
Black shale, soft	600
Soft gray shale	700
Soft gray shale; hard shell 700-705 feet	730
Soft gray shale; coarse sand 772-775 feet	775
Sand (top of Dakota) ; tested; made 350 barrels of oil and 81 barrels water on 28-hour test	779
Sand	780
Sand	788
Fine white sand	799
Sand; light gray flour sand, very fine grain	805
Sand; light gray fine grained floury sand; more water showing right along	812
Light gray fine grained floury sand; flowing oil and water	820
Coal	822
Blue shale	824
Blue shale	826
Sand, fine, white, dry	830
Coal	832
Sand, fine, white, making 2 barrels water per hour	838
Gray sandy shale	845
Black rotten shale	848
Black shale	860
Black shale, gray shale	870
Light sandy shale and coal	875
Dark gray shale	880
Coal and gray sandy shale	885
Coal and gray sandy shale	888
Gray sandy shale	890
Water sand	903
Gray shale	906
Fine white water sand making water	911
Blue shale	916
Fine white dry sand; little showing of oil and gas	921
Black shale	924
Hard fine white sand; little water	930
Gray shale	934
Sandy shale and iron pyrites	935
Fine white sand	945
White water sand, black specks	968
Hard mixed sand and iron pyrites	972
White sand (base of Dakota)	976
Hard sandy lime	980
McElmo, specked with green	988

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

STRUCTURE

The configuration of the Hogback dome, as shown by detailed mapping of the surface beds, is shown on the accompanying map, Plate XVI. The dome is asymmetric, with very steep dips to the east into the 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 260 acres have proven productive. The total closure is approximately 200 feet.

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

PRODUCTION

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 of approximately 100 pounds per square inch is held on the wells. No. 4 well orginally found only bitter sulphur 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.

Wells in the Hogback Field had an average closed-in pressure of approximately 182 pounds per square inch in 1925. The water back of the oil is sulphurous.

In drilling wells in the Hogback Field, three joints of conductor pipe are set through the "Tocito Sand," where it is cemented to shut off the surface water or water in the sand. The second or oil string is set and cemented on the top of the Dakota. The size and depths of wells so far drilled on the Hogback dome are given in the table on page 67.

RATTLESNAKE FIELD

LOCATION

The Rattlesnake Field is located on the Navajo Indian Reservation about 8 miles west and a little south of the town of Shiprock and about 3 miles northeast from the conspicuous landmark bearing the same name. (See map, Plate XVI.) Farmington, the nearest railroad point, is approximately 40 miles to the east at the terminus of the Denver & Rio Grande Western narrow-gage line. Gallup, on the main line of the Atchison, Topeka & Santa Fe railway, is approximately 100 miles to the south.

HISTORY

The Rattlesnake structure was discovered and mapped in a reconnaissance way several years before the lands were made available for drilling through the action of the tribal council for the Navajo Indians. On October 15, 1923, an exploratory lease amounting to 4,080 acres was offered for sale at public auction held at Santa Fe, N. Mex. After having been passed without bid in the forenoon, the lease was again offered in the afternoon and purchased by Mr. S. C. Munoz for $1,000.00. Mr. Munoz organized the Santa Fe Co. for the development of the property, the writer acting as consulting geologist. Arrangements were made with the Producers & Refiners Corp. to drill four wells to test the Dakota sand before starting the 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 teams and laborers were used in transporting casing and materials, yet 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 sale and only 37 days

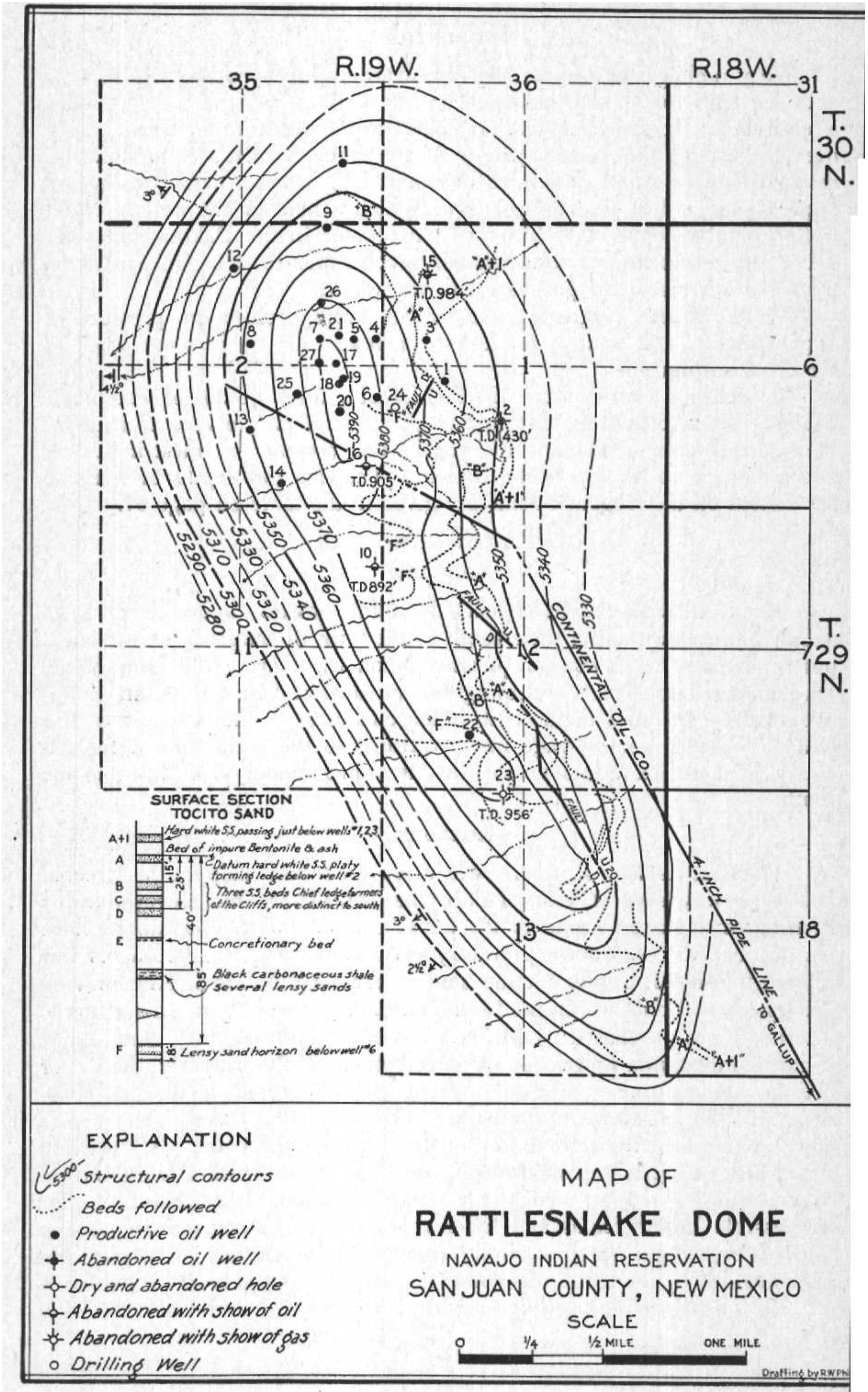

R.19W.
R.18W.
T. 30 N.
T. 29 N.
SURFACE SECTION
TOCITO SAND
Hard white S.S. passing just below wells #1, 2, 3
Bed of impure Bentonite & ash
Datum hard white S.S. platy forming ledge below well #2
Three S.S. beds Chief ledge formers of the Cliffs, more distinct to south
Concretionary bed
Black carbonaceous shale several lensy sands
Lensy sand horizon below well #6
CONTINENTAL OIL CO.
4 INCH PIPE LINE TO GALLUP
EXPLANATION
Structural contours
Beds followed
Productive oil well
Abandoned oil well
Dry and abandoned hole
Abandoned with show of oil
Abandoned with show of gas
Drilling Well
MAP OF
RATTLESNAKE DOME
NAVAJO INDIAN RESERVATION
SAN JUAN COUNTY, NEW MEXICO
SCALE
0 1/4 1/2 MILE ONE MILE

Figure 1.

after the drilling contract was signed with the Producers & Refiners Corporation. 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, 1932, 26 wells had been drilled to test the shallow Dakota sands, and one deep test to the Pennsylvanian had been completed. Early in 1925 a 2-inch pipe line was laid 13 miles to connect with the Midwest Refining Company's 3-inch line from Hogback 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 is delivered to standard gauge tank cars for transportation to refineries. To January 1, 1931, the Rattlesnake lease had produced 1,932,436 barrels of oil for market. There is at the lease an excellent camp, modern in every respect.

In the fall of 1925 drilling was commenced on Well No. 17 to explore the formations below the Dakota. After more than three years of operation, during which many serious difficulties were encountered, the well was carried to a total depth of 6,771 feet, penetrating a new producing zone in the Pennsylvanian. The well had an initial production of nearly 800 barrels of oil of 40°-43° A. P. I. gravity coming from just below a prolific water horizon. In spite of the fact that it has never been possible to shut off this water, the well was a consistent producer. It was still making 250 barrels of oil per day on May 1, 1931. By September production had fallen off to 150 barrels per day. Measurements showed approximately 150 feet of cavings, and it was therefore decided to clean out and later to deepen. On January 23, 1932, the hole had reached a depth of 6,985 feet without encountering additional gas or oil showings.

GEOLOGY

The Rattlesnake field is located on the western slope of a low ridge formed by the "Tocito Sand" member of the Mancos shale (Cretaceous). East of the crest of this ridge the surface is essentially an unbroken dip slope on the top of the sand. To the west the beds are truncated and well exposed for a short distance, but are largely covered by recent sand dune deposits beyond the axis of the structure. Logs of wells drilled within the field show the "Tocito" sandstone to have a total thickness of 60 to 80 feet. The sand in places is quite shaly and split by shale partings. Below the "Tocito" is 740 to 760 feet of drab shale and some thin limestone strata. The Dakota, which underlies the Mancos, has in the Rattlesnake area, a total thickness of 215 to 225 feet and is separated into at least three benches in most wells. Any one or all of the sand benches may contain oil or water. They are separated from each other by shale, and in some places coal is present.

The section below the Dakota is shown by the log of the deep test Well No. 17, given on pages 72-74. The Pennsylvanian formation was encountered at a depth of approximately 5,200 feet and the oil and gas horizon at 6,769 to 6,771 feet.

Log of Continental Oil Co. *Rattlesnake No.* 17 *Well*
SE. ¼ NE. ¼ Sec. 2, *T.* 29 *N., R.* 19 *W.*
Drilled, 1925-1928

	Bottom, feet.		Bottom, feet.
Tocito sand	25	Red rock shale	1495
Blue sandy shale	230	Red rock shale, sandy	1520
Black shale	350	Red rock, shale	1525
Gray shale	565	Sand; water	1530
Shale and shells	590	Red shale; sandy	1540
Gray shale	710	Hard shell sand	1550
Sand, oil and gas	712	Hard shell	1555
Shale	720	Red shale	1560
Broken sand and shale	730	Red sand, soft; water	1580
Sand; oil and gas increase	747	Red shale	1600
Sand; big flow oil and gas, rated 2,000 barrels per day	752	Sand	1610
		Red shale	1640
		Red and white sand	1645
Sand; increase oil and gas	785	Gray sand, hard	1700
Shale	790	Sand, white; water	1768
Sand	842	Light blue shale	1770
Shale and coal	860	White sand	1788
Sand; large increase oil and gas	868	Red sandy shale	1803
		Red shale	1806
Sand; increase oil and gas	920	Gray lime	1810
Sand; water at 923 feet	925	Pink shale, streaks of bentonite	1822
Shale	932		
Gray shale	935	Red sand and water	1880
Shale	943	Red shale	1885
Hard shell	948	Red sandy shale	1905
Shale and shells; little gas at 958 feet	958	Red shale	1913
		Red sand and shale	1925
Shale	975	Red shale	2179
Sand, some gas	990	Gray lime	2180
Shale	1005	Red shale	2185
Shell	1010	Red sandy shale	2195
Broken shells and shale	1025	Red shale	2200
Sand and water	1050	Red sandy shale	2206
Green shale	1065	Red sand, some shale	2214
Hard shale	1070	Red sandy shale	2220
Green shale	1090	Red shale	2245
Sand; water	1150	Red sandy shale	2270
Shale, greenish	1155	Red shale	2280
Sana; water	1170	Red sandy shale	2290
Hard sand	1210	Red shale	2295
Hard sand; soft	1320	Red sandy shale	2325
Shale	1325	Red sand, fine, hard	2330
Sand	1335	Red sandy shale	2365
Hard sand	1340	Broken shale, red and blue	2375
Sand, soft; water	1350	Red shale	2450
White sand	1375	Hard shell	2455
Pink shale	1380	Red shale	2765
Hard shell	1385	Red and blue shale	2775
Hard white sand	1410	Red shale	2780
Red rock, hard	1435	Pink shale	2785
Gumbo, red	1445	Gray lime	2803
Red sand, hard	1460	Red shale	2810
Red rock, shale	1475	Red lime	2823
Hard sand, red and white	1490	Red sandy shale	2835

	Bottom, feet.
Red shale	2930
Red sandy shale	2940
Red shale	3060
Gray lime	3063
Red shale	3210
Red shale and shells	3220
Red shale	3240
Hard sandy shale	3245
Red shale	3263
Red and blue shale	3270
Blue shale	3280
Red shale	3305
Red shale and shells	3310
Red shale	3375
Black shale	3383
Red shale with shells	3395
Black shale	3402
Red shale	3445
Red shale with shells	3455
Red shale	3480
Red shale, shelly	3490
Blue sandy lime	3493
Gray lime	3515
Gray sandy lime shell	3520
Brown shale	3535
Gray shale	3570
White shale	3605
Gray shale	3610
Gray and red shale	3640
Red shale	3685
Red and gray shale	3705
Red shale	3725
Gray shell, hard	3727
Gray sand	3745
Broken lime, sandy	3760
Red water sand	3775
Dark brown floating sand; on top hard shell showing gas	3785
Red sand; water	3793
Red sand; water	3800
Red sand	3807
Sand	3812
Red sand	3853
Light red shale	3855
Red sand	3885
Red sandy shale	3905
Red sand; water	392
White sandy shale; water	3958
Hard streak	3962
White sandy shale	3975
Light sandy shale, reddish	4005
Sand, slightly colored	4030
Sandy shale	4045
Red sand	4050
Sandy shale, red	4056

	Bottom, feet.
Sand, red and coarse	4070
Red shell, red fine sand	4080
Fine red sand	4088
Red sand, hard	4092
Red rock	4097
Red sand, coarse	4112
Red sand	4120
Hard strata	4122
Red sand	4126
Yellow shale	4129
Red shale	4140
Light reddish sand	4144
Red sandy shale	4175
Red sand	4184
Red sandy shale	4245
Red shale	4270
Red sandy shale	4277
Red shale, sandy lime shell	4285
Red shale	4308
Red rock	4310
Red limey shell, hard	4313
Red shale	4330
Red shale, softer, sandy	4635
Hard limey shale, mixed color	4352
More sand	4354
Sandy shale	4398
Red shale	4403
Limey shale, hard, mixed	4406
Red shale	4480
Shell	4482
Red shale	4507
Bluish gray limey shale	4508
Red shale	4722
Red rock	4725
Red rock, limey	4730
Red rock	4734
Red shale	4774
Red rock, limey	4781
Red shale, limey	4788
Red shale and limey shells	4800
Red shale	4830
Red rock	4883
Red shale	4918
Red shale, muddy	4930
Red shale	4973
Red rock	5035
Red and gray lime	5047
Red rock, limey	5058
Red rock	5070
Red shale, mixed green	5089
Red sand rock	5107
Red rock, mixed colors	5128
Red shale, mixed colors	5132
Red shale mixed with green	5156
Red shale mixed with gray	5161

	Bottom, feet.
Red and gray lime	5176
Lime, brown, mixed with gray	5180
Red lime	5195
Brown lime	5218
Brown and gray lime	5255
Brown lime, sandy	5265
Brown lime	5316
Brown and gray lime	5397
Brown lime, hard	5412
Brown shale, limey	5457
Brown and gray lime	5487
Brown shale, limey	5507
Gray lime	5511
Gray and brown lime	5539
Gray lime with red	5548
Brown lime, hard	5556
Gray lime	5562
Brown lime	5595
Gray lime	5609
Gray lime with brown	5614
Gray lime, sandy	5617
Gray lime with brown	5625
Brown lime	5635
Gray lime with brown	5638
Gray lime	5667
Brown shale, gray lime shells	5677
Brown and gray lime	5744
Gray lime	5800
Gray lime shell, hard	5802
Gray lime, dark	5820
Gray lime	5830
Gray limey shale	5845
Gray and white lime	5882
Gray lime	5897
Gray lime, sandy	5900
Gray lime	5910
Dark gray shale, limey	5925
Gray lime	5931
Gray lime, almost white	5944
Gray lime, bright color	5958
Gray lime	5960
Green and brown shale	5966
Gray lime	5975
Lime, mixed colors	5985
Sandy gray lime	5989
Gray lime	5997
Brown and green shale	6014
Lime, mixed colors	6021
Gray lime, sandy	6038
Gray lime, softer	6041
Shale, brown, gray, limey	6050
Gray lime, some mixed colors	6055
Gray lime	6070
Brown lime	6078
Gray and white lime	6100
Gray lime	6119
Black shale, limey	6134
Black lime	6138
Gray lime	6185
Gray lime, darker colored	6193
Gray lime	6211
Gray lime, sandy hard shell	6228
Brown and gray lime	6250
Gray and white lime	6260
Gray lime, hard	6262
Gray and white lime	6268
Gray lime, white specks shelly	6276
Gray and white lime	6288
Gray and white lime; oil and gas	6294
Gray lime	6342
Dark gray lime	6354
Gray lime	6400
Gray lime, sandy	6413
Gray lime, limey shale streaks	6418
Dark gray lime	6468
Gray lime, slightly sandy	6473
Gray lime	6478
Dark gray lime, slightly sandy	6480
Black lime	6485
Black shale, shelly gray lime	6495
Black lime	6497
Gray lime, hard	6499
Gray lime, show of gas	6561
Dark gray lime	6593
Black lime	6595
Black lime and grayish; shows light oil	6610
Gray lime	6666
Gray limey shale, darker	6668
Gray lime	6730
Gray shale; hole full of water	6746
Gray limey shale; oil and gas 6769-71 feet	6771

STRUCTURE

The geologic structure, as indicated by the surface beds, is generally anticlinal. (See map, figure 1.) The axis trends slightly west of north, and the highest point of the structure is located in the NE.¼ SE.¼ sec. 2, T. 29 N., R. 19 W., (unsurveyed). The structure is widest at the north end. Dips are low toward the east or basinward, but reach as high as 4½° on the opposite side. The total structural closure amounts to about 350 feet, but the closure above the water line in the Dakota sand is less than 75 feet.

Minor faulting occurs at the surface at three places, but drilling to date has not been sufficient to determine the effect of these faults on the Dakota sand.

DEVELOPMENTS

The discovery well on the Rattlesnake dome was completed as a 10-barrel well at 826 feet on February 27, 1924. To January 1, 1932, 27 wells had been completed; one, No. 17, to the deep Pennsylvanian horizon. A second deep test, No. 24, had a total depth of 7,370 feet in June, 1932. Of the 27 wells, five were edge wells and were ultimately abandoned as too small to be produced economically. Two of the edge wells were afterward deepened to supply water for the lease. One, No. 16, started as a deep test, was abandoned when the Dakota failed to produce. The Dakota sand is more lenticular at the Rattlesnake dome than at the Hog-back dome to the east, and in some wells exists in two or three benches, any of which may carry oil or water. The benches are separated by shale breaks or hard shells. In two or three of the wells the top member carried small amounts of oil, the second bench was full of water, and the third contained oil which flowed from the wells. The north end of the field has been the most extensively drilled, but Well No. 22 has proved the southern end of the anticline to be oil-producing, and good wells are anticipated. According to Nowels,[1] the initial production of the wells has varied from 30 to 1,500 barrels a day. Well No. 5 was originally drilled to a depth of 758 feet in September, 1924, and its initial production was 300 barrels of oil. When the lower bench of the Dakota was found to be oil-bearing, the well was deepened to 839 feet in May and June, 1926, and started flowing at the rate of 1,500 barrels per day. In July, 1927, the well was capable of producing 420 barrels of oil and 285,000 cubic feet of gas per day. Almost all of the producing wells have since been deepened, and an increase in production has resulted.

The table, page 76, taken from Nowels' paper [2] and brought up to date by D. E. Winchester, gives details of the drilling operations at the, Rattlesnake dome.

CHARACTERISTICS OF THE OIL AND GAS

The oil from the Dakota sands, 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

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[1]Vowels, K. B. Development and relation of oil accumulation to structure in the Ship- rock district of the Navajo Indian Reservation, New Mexico: Am. Assoc. Petroleum Geologists Bull., Vol. 13, No. 2, page 128, 1929.

[2] 0p. cit., p. 132.

weathers to 60° to 63° A. P. I. In summer the fresh oil in tanks is in constant agitation because the atmospheric temperature is ordinarily higher than the initial boiling point of the oil. Some idea of the unstable nature of the oil may be gained from the following data given by Nowels:[1]

Three samples of fresh oil were taken from the Loraine separator under 50 pounds pressure at 8:00 A. M., April 14, 1926. Engler gasoline distillations were made after sample No. 1 had been left in an open can for two hours, and samples No. 2 and No. 3 had weathered slightly over 24 hours. Sample No. 2 was set inside the Rattlesnake warehouse annex,

Summary of Drilling in Rattlesnake Field to July **1, 1932.**

Well No.	Location, Sec., T. - N. R. - W.	Surface Elevation in Feet.	Depth to Top of Sand in Feet.	Total Depth in Feet.	Oil Production in Barrels.
1	SW. ¼ 1-29-19	5,377	821	2,013	Small amount oil. Later deepened for water well.
2	SW. ¼ 1-29-19	5,364	810	1,430	Water in Dakota. Using as water well.
3	NW. ¼ 1-29-19	5,376	811	826	Initial, 30.
4	NE. ¼ 2-29-19	5,355	785	961	Initial, 100. Later deepened from 808 feet to 961 feet. Production, 46.
5	NE. ¼ 2-29-19	5,312	731	839	Initial, 300. Deepened from 758 feet to 839 feet. Increased to 1,500.
6	SE. ¼ 2-29-19	5,303	725	788	Initial, 25. Originally drilled to 752 feet. Deepened to 788 feet. Production, 80.
7	NE. ¼ 2-29-19	5,283	715	797	Initial, 805. Deepened from 760 feet to 797 feet.
8	NE. ¼ 2-29-19	5,240	682	727	Estimated, 100.
9	NE. ¼ 2-29-19	5,286	740	767	Initial, 480.
10	NE. ¼ 11-29-19	5,303	758	892	Small amount oil. Abandoned. Water.
11	SE. ¼ 35-30-19	5,313	792	818	Initial, 80.
12	NW. ¼ 2-29-19	5,216	702	736	Initial, 125.
13	SE. ¼ 2-29-19	5,216	672	703	Initial, 50.
14	SE. ¼ 2-29-19	5,244	703	860	Initial, 110.
15	NW. ¼ 1-29-19	?	815	954	Plugged and abandoned. Showing oil and gas. Water.
16	SE. ¼ 2-29-19	5,264	720	905	Commenced as deep test. Abandoned when Dakota failed to produce.
17	NE. ¼ 2-29-19	5,294	710	6,771	Good production in Dakota. Completed at 6,771 feet for 800, gravity 40°-43° A. P. I. Being deepened, Jan. 1, 1932.
18	SE. ¼ 2-29-19	5,281	710	711	Initial, 1,100. Show of water.
19	SE. ¼ 2-29-19	5,285	708	886	Initial, 1,200 to 1,300.
20	SE. ¼ 2-29-19	5,264	706	872	Initial, 820.
21	NE. ¼ 2-29-19	5,307	721	788	Initial, 450 from first and second sands.
22	SW. ¼ 12-29-19	5.302	740	849	Initial, 739.
23	NW. ¼ 13-29-19	5,323	772	1,092	Drilled into McElmo. Water in Dakota with showing of oil. Water in McElmo.
24	SW. ¼ 1-29-19	5,310	715	7,370	Not completed, June, 1932.
25	SW. ¼ 2-29-19			855	Initial, 75, in third sand.
26	NE. ¼ 2-29-19			869	Initial, 75, and 10 barrels water in third sand.
27	SE. ¼ 2-29-19			870	Initial, 405, and no water in third sand.
28	SW. ¼ 12-29-19			958	Plugged back to 764 feet, 10, no water.

[1]Op. cit.. op. 133. 134.

where it was away from air drafts and direct sunlight. Sample No. 3 was set on the ground by one of the oil-receiving tanks, where it would be exposed to as little wind and sunshine as outside conditions would permit. With sample No. 1, it was impossible to make the distillation at the time the sample was taken, and it was furthermore impossible to hold any sample in an ordinary container at room temperature without weathering considerably. In the distillation standard charges of 100 cc. were used.

Distillation Data of Rattlesnake Crude (Dakota Sand)

When first drawn.	Sample No. 1	Sample No. 2	Sample No. 3
Gravity at 60° F. Temperature	76.3° 8° F.	76.3° 8° F.	76.3° 8° F.
When distillation was made.	Apr. 14, 1926, 10:00 A. M.	Apr. 15, 1926, 10:30 A. M.	Apr. 15, 1926, 12:00 noon.
Gravity	69.3° A. P. I.	63.5° A. P. I.	60.0° A. P. I.
Oil temperature.	52° F.	70° F.	69° F.
Room temperature.	61°-65° F.	70° F.	70° F.
Condenser temperature.	34° F.	34° F.	34° F.
Initial boiling point.	70° F.	82° F.	96° F.
Maximum recovery.	79.5 cc. at 62° F.	93 cc. at 68° F.	93.5 cc. at 68° F.
Distillate gravity.	65.1° A. P. I.	64.5° A. P. I.	61.3° A. P. I.
Residue.	4 per cent	4 per cent	4 per cent
Loss.	16.5 per cent	3 per cent	3 per cent

The initial boiling point of the oil in Sample No. 1 was 70° F. two hours after it was taken from the well. In 24.5 hours the initial boiling point had increased to 82° F., and in 28 hours it was 96° F. Fresh from the well, however, the boiling point of the oil is approximately 32° F. These data are sufficient to indicate the rapid rate of weathering.

An Engler distillation test of the crude which had been shipped through 33 miles of pipe line from Rattlesnake to the refinery at Farmington on February 14, 1928, shows 62.5° A. P. I. at 47° F., or 64.1° A. P. I. at 60° F.

Engler Distillation Test of Crude (Dakota Sand)
Rattlesnake Field

Temperatures

Crude	47° F.
Room	66°-68° F.
Condenser	-30°-40° F.
Receiving bath	56°-60° F.

Results of Distillation

Initial boiling point	70° F.
10 per cent	120° F.
20 per cent	149° F.
30 per cent	179° F.
40 per cent	211° F.
50 per cent	245° F.
60 per cent	284° F.
70 per cent	350° F.
80 per cent	447° F.
87.2 per cent	566° F.
End point	566° F.
Overhead recovery	87.2 per cent
Residue	3.8 per cent
Loss	9.0 per cent
	100.0 per cent

It is practically impossible to gauge the amount of Rattlesnake crude in a tank by means of the ordinary wooden gauge pole, especially if the oil has just been produced. This is due to the fact that when the pole, which is usually of atmospheric temperature, is lowered into the tank, the entire tank of oil begins to boil, and the surface of the fluid is in such violent motion that an accurate gauge reading cannot be made. In order to use a gauge pole satisfactorily in fresh oil, it would have to be left immersed in the oil long enough for it to become thoroughly chilled.

Most of the tank gauges are taken by steel tape and plumb bob, as there is little body to the tape and it chills very quickly. In order to get a clear reading the tape must be dusted with a piece of chalk or clod of dirt at about the position that the oil surface in the tank will reach. The oil is so light and of such low viscosity that it will not leave a mark without the use of chalk or dirt.

Difficulties were experienced when Rattlesnake crude was first sent through the pipe line. The Shiprock region is quite arid, and in the summer months atmospheric and ground surface temperatures are high. Because of the extremely high gravity and volatile nature of the oil, it begins to vaporize as soon as it enters a warm pipe line, and to such an extent that it is almost impossible to pump it through the line or to flow it by gravity. Gas from the oil collects in pockets at high points, and the line becomes "gas locked." Even in the field it is impossible to successfully transfer oil by gravity drainage from a 500-barrel tank situated on the side of a hill to other tanks 700 feet distant and 30 feet lower in elevation. As soon as the sun goes down and the cooler evening hours arrive the movement of oil starts and can be completed in a short time without difficulty.

The oil from the Dakota is accompanied by gas which consists of 61 per cent propane, butane and heavier hydrocarbons. The following analysis of casinghead gas taken from Well No. 21 in July, 1927, was made by the United States Bureau of Mines laboratory at Fort Worth, Tex.

Analysis of Casinghead Gas, Rattlesnake Field

	Per cent
Carbon dioxide	0.00
Oxygen	0.18
Nitrogen	1.14
Methane	9.83
Ethane	27.58
Propane	41.57
Butane plus	19.70
	100.00

According to Nowels,[1]

A fairly large proportion of the casinghead gas accompanying the oil in the Rattlesnake field is in a liquid state in the producing sand under the temperature and pressure conditions which exist. The gas analysis mentioned previously shows 41.57 per cent propane and 19.70 per cent butane, and it is this latter gas which exists as a liquid. * * *

Propane under a temperature of 75° F. requires about 132 pounds pressure to liquify, whereas in the sand the propane has only 112.23 pounds of effective pressure against it; therefore, it exists in the gaseous state, as do the lighter hydrocarbon gases, ethane and methane.

In an open-flow test in July, 1927, Well No. 5 produced 291,000 feet of gas and 454 bbls. of oil every 24 hours. With the gas in Rattlesnake consisting of 19.70 per cent butane, 57,327 feet of the daily amount produced

[1] Nowells, K. B., Oil production in the Rattlesnake Field: Oil and Gas Jour., June 7, 1928, pp. 107, 143, 144.

is butane vapor, which in the liquid state would be equivalent to 1,760.6 gallons. One gallon of butane vaporizes to approximately 32.56 feet of *gas.* Every 24 hours, therefore, 1,760.6 gallons, or 41.91 bbls. of butane is produced in Well No. 21, as represented in the gas when flowing wide open. However, from the above discussion and from a knowledge of the behavior of butane, it may be seen that some of the butane even reaches the surface in liquid form along with the oil. It is the presence of liquid butane, changing over into vapor or gaseous form that accounts for the boiling of the oil at atmospheric temperature and for its being so difficult to handle.

PRODUCTION FROM THE PENNSYLVANIAN ROCKS

Oil was found in Pennsylvanian rocks in April, 1929, when Well No. 17, drilling with a hole full of water, developed an 800-barrel flow of 40° A. P. I. gravity crude at 6,771 feet. Attempts to shut off the water failed, 4 3/4 inch casing was set at 6,497 feet, and the well was allowed to flow unrestricted. The ratio of two parts of water to one part of oil has remained practically constant, and the gas-oil ratio has not changed. Because of this constant relationship, it is assumed that the decrease in flow through the period of two years was due largely, if not wholly, to condition of the hole rather than to exhaustion of the oil. The following record of the total monthly production from No. 17 well was furnished by the Continental Oil Co.

Production of Rattlesnake Well No. 17

Month	Production, barrels.
1929	
April	1,424.80
May	13,528.45
Tune	22,653.56
July	21,878.06
August	22,034.46
September	19,898.15
October	19,498.02
November	18,608.72
December	18,464.35
1930	
January	16,807.43
February	14,409,76
March	15,110.98
April	13,826.06
May	13,235.41
June	12,414.05
July	11,747.20
August	11,062.15
September	9,959.03
October	9,051.81
November	8,244.97
December	8,217.90
1931	
January	7,806.96
February	6,872.20
March	7,028.56
April	6,592.40
Total heavy oil	330,375.44
Light oil production from No. 17 Well	27,559.74
Total production	357,935.18

The oil from the deep Pennsylvanian sand has a gravity of 40° to 43° A. P. I. and contains a very low percentage of sulphur. The following analysis was made by the Continental Oil Co. laboratory at Ponca City, Okla.

Analysis of Crude Oil from Rattlesnake No. 17 Well
(Total Depth 6,771 feet)

Engler Distillation.

Gravity of crude	43.0° A. P. I.
Initial Boiling Point	116° F.
10 per cent	266° F.
20 per cent	323° F.
30 per cent	390° F.
40 per cent	468° F.
50 per cent	546° F.
60 per cent	626° F.
70 per cent	684° F.
75 per cent	706° F.
80 per cent	729° F.
85 per cent	750° F.
89 per cent	760° F.
Recovered	89 per cent

Stratford Distillation for Gasoline Yields.

Gravity crude	43.0° A. P. I.
Gasoline yield	47.0 per cent
Gravity gasoline	56.6° A. P. I.
Kerosene yield	6.1 per cent
Gravity kerosene	41.3° A. P. I.
Flash	190+
Sulphur	.04 per cent
Bottoms	46.5 per cent

PRODUCTION METHODS

Wells Nos. 1, 2, 3, 4, and 16 which was started for a deep test, were drilled with standard rig and tools. No. 17, the first deep test completed, was drilled mainly with standard tools, but rotary equipment was necessary for part of the work. Well No. 24, the second deep test, is being put down with rotary equipment. All other wells have been. drilled with a machine drilling outfit.

For the Dakota production it is necessary to only set a few joints of surface pipe through the "Tocito Sand" and then an oil string on the top of the Dakota. No water is found above the Dakota. Nearly all of the Dakota wells would flow naturally, but it has been found advisable to pump them by power, band wheel and jack. 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, part or all of which is probably in liquid form in the sand at the bottom of the hole. Dakota wells in the Rattlesnake Field, when flowing wide open, have a pressure at the casinghead varying from 20 to 30 pounds. Rock or reservoir pressure, as determined by Nowels[1] by special study in March, 1928, is approximately 270 to 280 pounds per square inch.

In the summer time a tank of fresh Dakota oil is in constant turmoil, as the atmospheric temperature is usually above the initial boiling point of the fresh oil. Aluminum-painted vapor-proof receiving tanks are used throughout the field, hut even with such protection there is an unavoidable loss of unstable volatile fractions from the oil. The flow lines, oil-gas separators and tanks, up to the height of the contained oil, are always covered with frost and moisture, even in summer time when ground and atmospheric temperatures are rather high.

Because of the nature of the crude oil as it comes from the wells in the Dakota sand on the Rattlesnake lease, it has been found necessary to install on the lease an elaborate plant (see Plate XXXII, C) for the weathering or stabilizing of the crude before it can be put through the pipe lines and shipped in tank cars. Excess gas produced on the lease is returned to the Dakota sands through one of the edge wells under approximately 350 pounds of pressure.

[1]Op. cit., p. 135.

Nowels[1] states that, "Because of the extremely light oil and the fact that edge water, which is in the producing sand under a fairly high head, can be used as a water drive if properly controlled, a large percentage of recovery (from the Dakota) is looked for at Rattlesnake lease."

Up to December 31, 1930, the Dakota sand production in the Rattlesnake Field had amounted to 1,612,631 barrels and the oil produced from the deep sand had amounted to 302,075 barrels.

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 and about 48 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 approximately 400 feet to the syncline at the southwest as shown on the map, Plate XVI. The dome includes approximately 2,500 acres within the lowest closing contour. On all sides except the west, the McElmo 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 producing in the deep well on the Rattlesnake structure to the east can be reached on the Biltabito dome by a well approximately 4,150 feet deep, 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 approximately 1,000 to 1,200 feet.

Lands on the Biltabito dome are owned by the Navajo Indians, who sold an exploratory lease of 3,120 acres on the structure at the auction sale in 1926, but no drilling has yet been done. The structure deserves a test of the deep sand in the Pennsylvanian, which probably will he found to contain oil of good grade.

TABLE MESA FIELD

LOCATION

The Table Mesa field is about 9 miles southwest of the Hogback field and just west of the Hogback ridge. The productive portion of this structure, consisting of approximately 160 acres, is located in sec. 3, T. 27 N., R. 17 W., (unsurveyed). The lands belong to the Navajo Indians. The field is east of the Shiprock-Gallup highway about 13 miles south of the town of Shiprock.

HISTORY

An exploratory lease on the Table Mesa structure was sold to Mr. 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 to the total depth of

[1]Op. cit.. p. 144.

3,000 feet, in the NW. ¼ SW ¼ 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 in 1925, and on September 1, 1925, this company brought in a 325-barrel well of high-gravity oil in the Dakota at 1,317 feet in the SE.¼ SW.¼ sec. 3, T. 27 N., R. 17 W. Following this discovery, the Continental Oil Co. completed ten more wells of which five were producers. The lease is connected with the Continental Oil Co.-Santa Fe Co. pipe line from the Rattlesnake field to Gallup, and had up to December 31, 1930, produced 265,509 barrels of oil.

GEOLOGY

The surface of the Table Mesa dome consists of drab shale of the Mancos formation, which weathers to rounded forms and includes very few marker beds. Table Mesa, a conspicuous topographic structure southwest of the field. is capped by the Point Lookout sandstone of the overlying Mesaverde formation.

The "Tocito" sandstone member of the Mancos is found at depths of a little over 500 feet in the wells, and the Dakota sand series, which furnishes the production, is topped at around 1,300 to 1,400 feet. The Dakota, which has an aggregate thickness of about 200 feet, consists of alternating beds of sandstone and shale, and some coal.

South and west of the field and approximately in the syncline between the Table Mesa dome and the Tocito dome to the south, a number of igneous plugs occur. These plugs and their connecting dike have a linear arrangement in a general northwest-southeast direction.

The following log of the deep well drilled by the Producers & Refiners Corp. shows the character of the formations to a depth of 3,000 feet under the dome. The deeper formations have not yet been explored.

Log of Producers & Refiners Corp. Table Mesa No. 1 Well
NW.1/4 SW.1/4, Sec. 3, T. 27 N., R. 17 W.
Drilled, 1924

	Bottom, feet.		Bottom, feet.
Shale	530	Shale and bentonite, light	1664
Sand	680	Sand, gray; water at 1,685 feet	1695
Shale, brown	1175	Shale, light	1710
Shale	1404	Sand	1760
Sand	1445	Shale, red streaks	1775
Sand, hard	1497	Sand	1790
Coal and shale, green	1510	Shale	1800
Shale, dark	1518	Sand	1850
Shale, light	1531	Shale	1860
Shale and sand, dark	1546	Sand; water	1875
Shale, dark	1556	Sand	1885
Sand and shale, dark	1575	Shale, light	1895
Sand and shale, light	1586	Sand	1930
Caving	1591	Shale	1940
Calcareous shaly sand	1605	Sand	1985
Sand, light; red sand at 1,614 feet	1615	Shale	1990
Bentonite, light	1618	Sand, red	2045

	Bottom, feet.		Bottom, feet.
Sand	2055	Shale, white	2460
Shale, red	2070	Sand, red	2505
Sand	2105	Sand, gray, hard	2535
Sand, red	2170	Sand, white	2587
Shale, red	2185	Shale, red	2616
Sandy lime, white	2196	Sand, red	2715
Sand, brown	2200	Sand, red, fine	2720
Shale, red	2210	Sand, red, coarse	2743
Shale, brown	2225	Shale, red	2778
Sand, red	2335	Lime	2792
Sand with hard shells, white	2370	Shale, pink	2838
Sand, white	2373	Lime, gray	2842
Shale, red	2376	Shale, pink	2895
Sand, white	2445	Shale, red	2945
Sand, red	2455		3000
Quartz, white	2459	Abandoned.	

STRUCTURE

The Table Mesa dome is an almost symmetrical fold with its major. axis trending in a general northeast direction. (See map, Plate XVI.) It is reported to have a closure of about 150 feet, although there was a structural difference of only about 15 feet between the water line in, the producing sand of November 1, 1928, and the crest of the dome.

A single fault of considerable magnitude has been mapped. This fault has a throw of about 50 feet just west of the east line of sec. 3, T. 27 N., R. 17 W., and has a general east-west trend. It has not been traced as far west as the crest of the structure.

THE OIL

The oil at the Table Mesa dome has a' gravity of 57°-58° A. P. I., which is somewhat lower than that from the Hogback and Rattlesnake fields. No gas occurs with the oil, and all wells have to be pumped. All of the wells produced some water with the oil as early as Nov. 1, 1928. The following analysis of Table Mesa crude was made in the Ponca City laboratory of the Continental Oil Co.

Analysis of Table Mesa Crude Oil

Engler Distillation	
Gravity	48° A. P. I.
Initial boiling point	210° F.
10 per cent	256° F.
20 per cent	288° F.
30 per cent	324° F.
40 per cent	364° F.
50 per cent	400° F.
60 per cent	460° F.
70 per cent	520° F.
75 per cent	548° F.
80 per cent	594° F.
85 per cent	650° F.
90 per cent	712° F.
95 per cent	760° F.
Recovered	95 per cent

Stratford Distillation for Gasoline Yields	
Gravity crude	48.0° A. P. I.
Gasoline yield	58.0 per cent
Gravity gasoline	57.4° A. P. I.
Kerosene yield	16.2 per cent
Gravity kerosene	42.2° A. P. I.
Flash	190+
Sulphur	.04 per cent
Bottoms	24.3 per cent

TOCITO DOME

The Tocito dome is located on the old Shiprock-Gallup highway about 25 miles south of Shiprock. It was considered one of the most favorable structures offered for sale at Santa. Fe, N. Mex., 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 as shown on the; map, Plate XVI. The total closure is approximately 300 feet and the area within the lowest closing contour approximately 17,000 acres. The structure is crossed by an east-west fault with a down-throw on the north, of approximately 50 feet. This fault results in two independent highs on the dome, both of which 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 at 842 feet in the Gypsy Oil Co. well on the south high.

The Gypsy well, drilled under the terms of the original lease, went to 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 second 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 is 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 attained sufficient depth to reach the equivalent of the deep Pennsylvanian horizon which is producing at the Rattlesnake field. Such a test has much in its favor, and it is quite probable that production will be found. An adequate deep test would require a hole between 6,700 and 6,800 feet deep.

BEAUTIFUL MOUNTAIN ANTICLINE

The Beautiful Mountain anticline is located on the Navajo Indian Reservation approximately 30 miles southwest of Shiprock Agency and. 5 miles west of the Tocito dome. The structure is a long, relatively narrow anticlinal fold with its axis running in a general north-south. direction. (See map, Plate XVI.) 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 heart of the anticline is in a topographic basin, which is bounded on all sides by cliffs of "Tocito" sandstone.

An exploratory lease on some 4,800 acres located on the south end of the structure was sold at Santa Fe, N. Mex., 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, having a gravity of 40° A. P. I., but no commercial oil or gas was developed to a total depth of 3,290 feet. 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.

At the sale at Santa Fe in 1926, a lease on the north end of the Beautiful Mountain anticline was offered for sale, but no well has yet been drilled on this part of the structure.

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 E. It is 34 miles north of the Crown Point Indian school and 60 miles north of Thoreau on the Atchison, Topeka & Santa Fe railway.

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 these faults has a throw of more than 50 feet.

Three test wells have been drilled on the anticline, the one by the Midwest Refining Co. in the SE. cor. sec. 36, T. 22 N., R. 14 E., drilled in 1928, having been carried to a total depth of 3,060 feet, after finding a good show of oil at 780-790 feet, and another at 833-860 feet. The latter show is reported to have tested 42 barrels of oil per day of 35° A. P. I. gravity. A 5,000-barrel flow of warm water was encountered in the well at 2,965 feet, and the well was finally sold to the Indian Department for a water well.

In the NE.¼ sec. 18, T. 21 N., R. 13 W., a well drilled by R. R. Burke had a show of oil amounting to perhaps 7 barrels per day at 300 feet, but the well was abandoned at 1,006 feet where it struck a flow of water with a small show of oil and gas.

The Reserve Oil Co. in 1929 drilled a well in the SE. ¼ NE. ¼ sec. 1, T. 21 N., R. 14 E. This test had an oil sand at 718 feet, but went into water at 725 feet. The well was abandoned at 780 feet. In 1931 the same company drilled a test in the SE.¼ sec. 36, near the Midwest well, and on June 16, 1931, reported a small show of 36° A. P. I. oil at 770 feet.

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 around 3,800 feet.

SEVEN LAKES AREA

The Seven Lakes area in T. 18 N., Rs. 10 and 11 W., McKinley County, was probably the second area in New Mexico in which oil was found. 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 real 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, at least 30 wells have been drilled within an area embracing secs. 17, 18 and 19, T. 18 N., R. 10 W., and secs. 13, 24, 25 and 26, T. 18 N., R. 11 W. Of these, 11 found small amounts of oil, the maximum reported being 20 barrels, and the reported composite initial production of the eleven wells amounted to only 76 barrels per day. The deepest well in this small area was one drilled by the San Juan Coal & Oil Co. in the NE¼ SE. ¼ sec. 18, T. 18 N., R. 10 E. which struck a flow of 5,000 barrels of water at 2,002 feet. It was abandoned at this depth.

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, Wyo., June 16, 1921.

Analysis of Crude Oil from Seven Lakes Area

Summary

Gravity	26.5° Baume	Sulphur	0.82 per cent
Crude naphtha			1.3 per cent
Water white (kerosene)			14.9 per cent
Gas oil			5.5 per cent
Wax distillate (rerun)			35.3 per cent
Gravity, 33.7° Baume; flash, 270° E.			
Fuel oil residue			40.5 per cent
Loss			2.5 per cent
			100.0 per cent

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.

BONITA (CATHEDRAL ROCKS) ANTICLINE

The Bonita anticline is a relatively small dome-like structure located in the southwest part of T. 20 N., R. 10 E., 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.

[1] Gregory, Herbert H., Geology of the Navajo country: U. S. Geol. Survey, Prof. Paper 93, p. 145, 1917.

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. drilled a well in sec. 30, T. 20 N., R. 10 W., 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 to 3,268 feet in sandy shale, and drilling was stopped in a hard sandy shell at 3,275 feet without testing the Dakota.

HOSPAH DOME

-The Hospah dome is located in Tps. 17 and 18 N., Rs. 8 and 9 W., McKinley County. It is about 40 miles northeast of Thoreau on the Atchison, Topeka & Santa Fe railway, the nearest railroad point, with which it is connected by a good automobile road. The surface of the area, consisting of sandstones and shales of the Mesaverde formation, is rather rough. The dome (see map, figure 2) is slightly elongated in a north-south direction, and its high point is located in the NW.% sec. 1, T. 17 N., R. 9 E. The structure is crossed by a major fault cutting the southeast corner of sec. 1 and trending in a northeast direction. The dome has a closure of approximately 100 feet between its crest and the syncline, which is located approximately a mile to the west. Within the lowest closing contour there is an area of approximately 3 square miles.

In 1925-26, Hurst, Welch et al. drilled the first well in sec. 1 to a depth of 1,405 feet. This well was afterward taken over by the Midwest Refining Co., carried to a total depth of 1,610 feet, and made a small producer.

To date 12 wells have been drilled within the area covered by the map, of which three developed commercial oil and one had a small amount of oil. The table, page 89, shows data on all wells so far drilled. Production is coming from a sand in the Mesaverde formation known as the "Hospah Sand."

The oil from the Hospah dome is a low-sulphur oil of about 30° A. P. I. gravity. An analysis made from a 5-barrel sample shipped to the Casper laboratory of the Midwest Refining Co. in 1927, is as follows:

Analysis of Crude Oil from Hospah, Dome

		Distillation	
Gravity	29.7° A. P. L	Initial	219° F.
Sulphur	0.15 per cent	Heavy naphtha	11.4 per cent
Water	None	Kerosene	12.6 per cent
Cold test	36° F.	Car oil	13.4 per cent
flash	125	Heavy distillates	61.6 per cent
		Coke	1.0 per cent
			100.0 per cent

Up to June 1, 1932, there was no outlet for Hospah crude except by truck, and consequently very little oil has been produced. From time to time reports had been circulated that pipe-line connections were to be made to the Atchison, Topeka & Santa Fe railroad to the south, but no construction has been started, although the line has been surveyed.

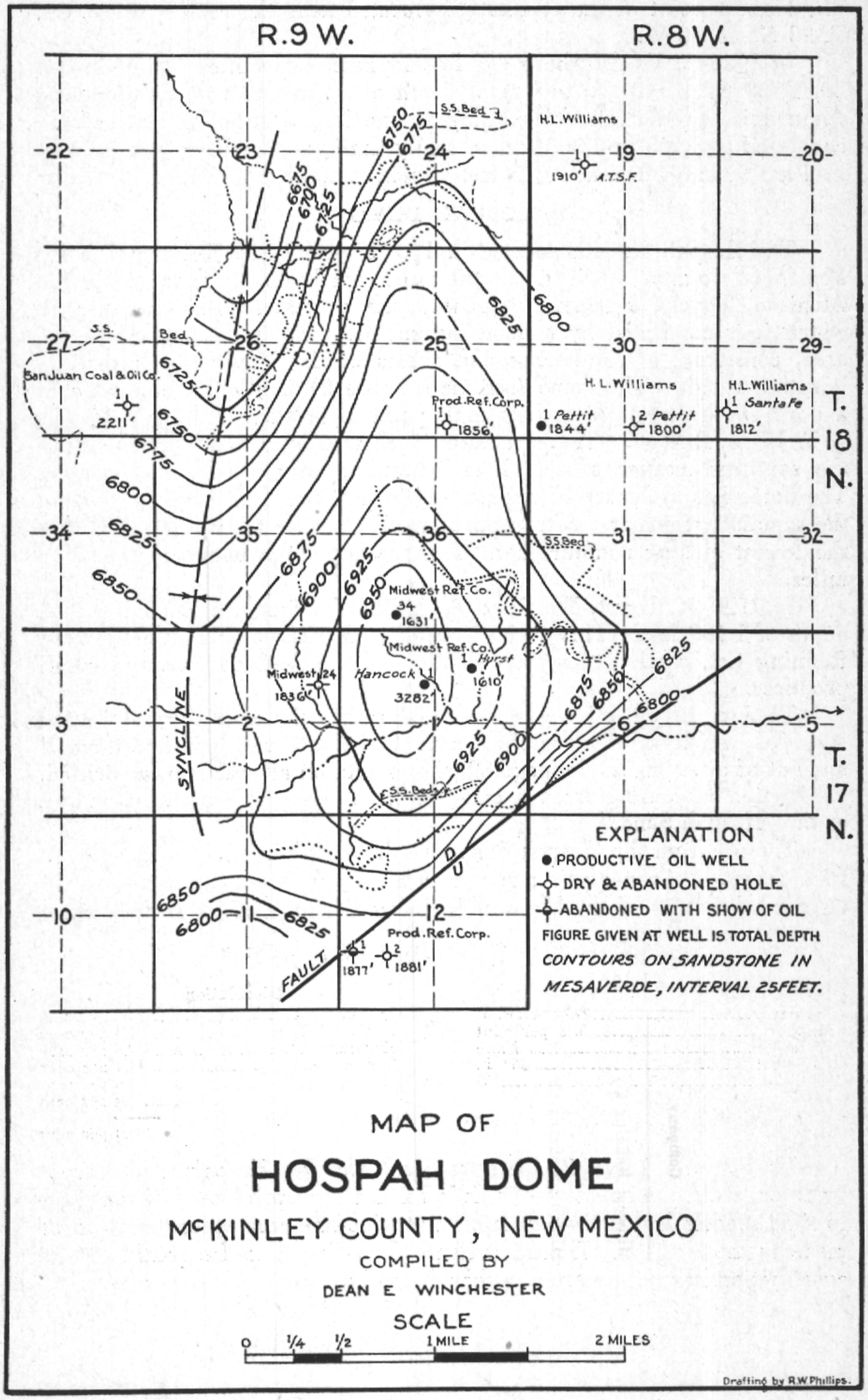

R.9 W.
R.8 W.
T. 18 N.
T. 17 N.
H.L. Williams
1910' A.T.S.F.
San Juan Coal & Oil Co.
2211'
Prod. Ref. Corp.
1856'
H. L. Williams
1 Pettit 1844'
2 Pettit 1800'
H.L. Williams
1 Santa Fe 1812'
Midwest Ref. Co.
34 1631'
Midwest Ref. Co.
1 Hurst 1610'
Midwest 24 1836'
Hancock 1 3282'
Prod. Ref. Corp.
1877'
1881'
SYNCLINE
FAULT
EXPLANATION
PRODUCTIVE OIL WELL
DRY & ABANDONED HOLE
ABANDONED WITH SHOW OF OIL
FIGURE GIVEN AT WELL IS TOTAL DEPTH
CONTOURS ON SANDSTONE IN MESAVERDE, INTERVAL 25 FEET.
MAP OF
HOSPAH DOME
McKINLEY COUNTY, NEW MEXICO
COMPILED BY
DEAN E WINCHESTER
SCALE
0 1/4 1/2 1 MILE 2 MILES
Drafting by R.W. Phillips.

Figure 2.

Wells Drilled on Hospah Dome

Company.	Well.	Location, Sec., T. -N., R. -W.		Total Depth, feet.	Date Completed.	Remarks.
Midwest Refining Co.	No. 1 Hancock.	NE. cor. SE. ¼ NW. ¼	1-17-9	3,282	Oct. 5, 1927.	Pumped 161 barrels oil before deepening; 65 barrels per day on 30-day test at 1,578 feet.
Midwest Refining Co.	No. 1 Hurst.	SE. cor. NW. ¼ NE. ¼	1-17-9	1,610	Aug. 3, 1927.	Initial production, 8 barrels oil. Drilled to 1,600 feet by Hurst & Welch in 1925-26.
Midwest Refining Co.	No. 34.	SW. cor. SE. ¼ SW. ¼	36-18-9	1,631	Aug. 17, 1927.	Initial production, 60 barrels oil.
Midwest Refining Co.	No. 24.	NE. ¼ SE. ¼ NE. ¼	2-17-9	1,636	June 21, 1927.	Dry and abandoned.
Producers & Refiners Corp.	No. 1 Espe.	SW. ¼ NW. ¼ SW. ¼	12-17-9	1,877	Dec. 2, 1927.	Dry and abandoned.
Producers & Refiners Corp.	No. 2.	Cen. SW. ¼	12-17-9	1,881	Apr. 1, 1928.	Dry and abandoned.
Producers & Refiners Corp.	No. 1.	SW. cor. SE. ¼	25-18-9	1,856	Aug. 20, 1927.	Show oil 632-714, 738, 1,777-1,788 feet. Abandoned.
San Juan Coal & Oil Co.	No. 1.	SE. ¼ SE. ¼	27-18-9	2,211	Apr. 1, 1931.	Dry.
H. L. Williams	No. 1 Pettit.	SW. cor.	30-18-8	1,844	Oct. 27, 1927.	Initial production, 5 barrels oil, and water, 1,800 feet.
H. L. Williams	No. 2 Pettit.	SW. cor. SE. ¼	30-18-8	1,800	Mar. 28, 1928.	Dry and abandoned.
H. L. Williams	No. 1 Santa Fe.	SW. ¼ SW. ¼	29-18-8	1,812	Jan. 10, 1929.	Dry and abandoned.
H. L. Williams	No. 1 A. T. & S. F.	NW. cor. NE. ¼ SW. ¼	19-18-8	1,910	Apr. 1, 1931.	Shut down.

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., 10 miles east of the Hospah field. 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 E., 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. The log of this well follows.

Log of Continental Oil Co. *Carica* No. 1 *Well SW.*$^1/_4$ *SW.* $^1/_4$ *Sec.* 9, *T.* 17 *N., R. 7 W. Drilled,* 1927-28

	Bottom, feet.
Surface soil	2
Lime, gray	15
Sand rock, limey	30
Sand, gray	63
Shale, gray sandy	88
Sand, gray, dry	95
Lime, blue, hard.	97
Shale, gray	167
Sand	174
Lime	193
Shale, gray	315
Sand, gray	320
Lime, gray; water, 6 barrels per hour	336
Shale, gray	354
Sand, gray; increased water	372
Lime, sandy	384
Sand; water	413
Shale, gray	453
Sand, gray	467
Shell, hard	471
Shale, gray blue	499
Sand	502
Shale, gray	572
Sand and lime, hard	585
Shale, gray	599
Sand, medium hard	610
Shale, gray	650
Sand, hard, gray	670
Shale, gray	685
Coal	686
Sand, gray	700
Shale, gray	715
Sand, gray	720
Shale, gray	736
Sand	750
Shale, gray	815
Sand, hard	829
Shale, gray	839
Sand, hard, gray	847
Coal	849
Shale, gray	854

	Bottom, feet.
Sand, gray; water, 10 barrels per hour	868
Shale, gray	892
Sand	898
Shale, gray	904
Coal	908
Shale, gray	955
Sand, hard	970
Coal	978
Shale with streaks of coal	995
Sand; water	1012
Shale, gray	1015
Sand; water	1077
Shale, gray, caving	1080
Sand, gray	1102
Shale, gray	1132
Sand, gray, very hard	1143
Shale, gray	1540
Sand; salt water	1563
Shale, gray	1610
Sand, hard	1613
Shale, gray	1673
Sand	1677
Shale, gray	1799
Sand, gray, dry	1815
Shale, gray	1918
Lime shell	1922
Shale, gray	2010
Sand; water	2030
Shale, blue	2040
Shale, brown	2052
Sand; water	2074
Shale, brown	2076
Sand, gray	2081
Shale, brown	2091
Sand	2101
Shale, brown	2108
Sand; water	2145
Shale, blue, sandy	2155
Shale, gray	2162
Shale, blue	2202
Shale, gray	2616

	Bottom, feet.
Lime, blue	2617
Shale, gray, caving	2861
Shell, hard	2863
Shale, gray	2895
Shell, hard sandy	2902
Shale, gray	2950
Lime, hard, gray	2953
Shale, gray	3075
Sand and water	3092
Gray sand, hard	3137
Gray shale	3143
Hard gray sand	3144
Gray shale	3155
Sand	3189
Green shale	3190

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. The area is very rough, and the structure is surrounded by high sandstone-capped mesas. (See Plate X, A.) The structure is a general domal uplift truncated on the south by a series of major east-west faults, and has a second major fault located west of the axis which strikes north-south. It has 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.

In 1923 the Midwest Refining Co. drilled a well near the middle of the west line of sec. 13, T. 15 N., R. 10 W., on top of the dome. A show of oil and gas at 963 to 970 feet, and a show of oil with water at 1,376 to 1,382 feet were reported. The hole was abandoned in the McElmo formation at 1,460 feet. The log of this well is given below.

Log of Midwest Refining Co. *Ambrosia Lake No.* 1 *Well*
W. $^1/_4$ *Cor. Sec.* 13, *T.* 15 *N., R.* 10 *W.*
Drilled, 1923

	Bottom, feet.
Sandy shale	28
Brown sandy shale	55
Sandy shale	140
Very white sand	219
Blue shale	230
Gray sand	235
Black dobe	250
Sandy blue shale	258
Gray sandstone	290
Dark shale	428
Gray sand	430
Dark shale	557
Coarse grained sandstone	565
Dark shale	670
Blue shale	745
Gray shale	956
Coarse gray sand; dry	963
Fine gray sand; show of *oil* and *gas*	970
Fine sand; tested 2 gallons water per hour	1025
Fine sand	1035
Gray shale	1074
White sand; small amount of water; 40 gallons per hour	1093
Blue shale	1125
Gray sand; hole caving	1166
Fine grained gray sand, caving	1263
Black shale.	1268
Red and green shale	1354
Coarse gray sand	1376
Gray sand; show of *oil*, 800 feet, water	1382
Light green shale, caving	1386
Gray sand	1415
Red, green, black shale (McElmo)	1442
Red gravel; show of water	1451
Red gravel, sand; total depth	1460

In 1925-26 a second well was drilled one-half mile southwest of the Midwest location in the SW. 1/4 sec. 14 and was abandoned in sand at 1,100 feet. The Ealker Dome Oil Co. later drilled a well just west of the Midwest location. The log of this well shows oil in coarse gray sand at 998 to 1,012 feet. The Johnswood Oil Co. in June, 1931, spudded its No. 1 Hannett in the SE. 1/4 sec. 12.

SAN MATEO DOME

The San Mateo dome is located in the center of T. 14 N., R. 8 E., about 6 miles north of the village of San Mateo and 18 miles northeast of Grants on the main line of the Atchison, Topeka & Santa Fe railroad.

The dome is a small, 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 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 near the east quarter corner sec. 14, T. 14 N., R. 8 W., to a total depth of 1,320 feet, finishing in the McElmo formation. The top of the Dakota was reached at 1,075 feet. No oil or gas was reported.

CHAVEZ (MIGUEL CREEK) ANTICLINE

The Chavez anticline is located on the Chavez and Tafoya Grants in Tps. 15 and 16 N., R. 6 W., about 20 miles northeast of San Mateo village and 40 miles northeast of Grants on the Atchison, Topeka & Santa Fe railway.

The structure has a closure of some 500 feet and an enclosed area of approximately 5,750 acres. The axis extends in a general northeast direction from sec. 18, T. 15 N., R. 6 W., to the high point located in the NE.1/4 of 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.

In 1923 the Midwest Refining Co. drilled a test well in the northeast corner of sec. 4, T. 15 N., R. 6 W., and found the top of the Dakota at a depth of 1,914 feet. No oil or gas shows were encountered to a total depth of 2,154 feet.

FRENCH MESA ANTICLINE

French Mesa anticline (see map, Plate XVII, in pocket) 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 red beds. (See Plates VI, B and XI, A.) The red beds, 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. The following generalized section of formations is by Darton.[1]

Formations in Southeastern Part of Rio Arriba County

Age.	Group and Formation.	Characteristics.	Thickness (feet).
Upper Cretaceous.	Mesaverde formation.	Sandstone and shale, with coal beds.	800
	Mancos shale.	Shale and sandstone.	500-1,000
	Dakota sandstone.	Sandstone, massive, hard, gray to buff.	150-250
Cretaceous (?).	Morrison formation.	Shale, massive, greenish gray, buff, maroon; some sandstone.	100-180
Jurassic.	Navajo (?) sandstone.	Sandstone, chocolate-brown	150
	Todilto formation.	Gypsum member	60
		Limestone in thin layers, locally very sandy	4-12
	Wingate sandstone.	Sandstone, very massive, fine grained; red below, white and buff at top.	200
Triassic.	Chinle (?) formation.	Red shale.	250
	Poleo sandstone.	Sandstone; maker of prominent ridges, plateaus, and cliffs.	50-150
Permian (?).		Red shale and red and brown sandstone.	250-550[a]
Pennsylvanian.	Magdalena group.	Limestone mainly; sandstone at base and top.	60-450[a]
Pre-Cambrian.		Granite.	

[a]Note by D. E. Winchester.—The Red Beds between the Poleo sandstone and the top of the Magdalena limestone are at least 2,500 feet thick on French Mesa (see log, p. 94) and the Magdalena is at least 700 feet thick, as granite was not reached.

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.

[1]Darton, N. H., Geologic structure of parts of New Mexico: U. S. Geol. Survey Bull. 726, p. 244, 1922.

In 1925 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. The log of this well follows.

Log of Continental Oil Co. *French Mesa No.* 1 *Well*
SE. Cor. *SW.* 1/4 *Sec.* 25, *T.* 24 *N., R.* 1 *E.*
Drilled, 1925

	Bottom, feet.
Surface	3
Red clay	15
Red clay with grit	20
Gray sand	85
Yellow sand, coarse at base	115
Yellow sand, streaks of clay	156
Coarse gray sand; water	170
Blue shale	200
Blue lime	205
Blue shale	240
Light blue shale	245
Gray sand; water	260
Red shale	285
Red shale, sandy	480
Red shale	515
Red sandy shale	637
Red sand, streaks shale	870
Red sand	985
Fine light sand	1000
Red shale	1320
Sand	1350
Chocolate brown shale	1425
Dark brown shale, gritty	1450
Coarse sand	1485
Fine sand	1490
Limy shale	1500
Dark brown shale, gritty	1550
Coarse brown sand	1580
Fine brown sand	1585
Dark brown shale, gritty	1630
Brown sandy shale	1660
Red sand	1700
Brown shale	1790
Sand; water	1833
Brown shale	1873
Hard dark fine sand	1875
Brown shale	1925
White sand	1995
Shale	2000
Gray sand	2033
Brown sand	2045
Sandy shale	2150
Sticky mud	2170
Sand	2177
Shale	2210
Sticky brown shale	2225
Brown shale	2240
Sandy brown shale	2248
Shell	2249
Sandy brown shale	2255
Brown shale	2328
Rotten lime	2332
Fine loose soft shale and pepper sand	2340
Sand, dry	2361
Blue shale	2365
Gray sand, some shale	2375
Brown shale	2402
Blue shale, gritty	2410
Brown shale	2417
Sand, red and white	2422
Brown shale	2436
Red sand, hard	2443
Gray sand	2455
White and black sand	2461
Fine gray sand	2477
Blue shale	2479
Fine gray sand	2503
Coarse sand, mixed with red	2515
Red sand	2527
Sandy brown shale	2535
Gray sand	2540
Red sand; show of water	2568
Brown sand and shale	2579
Gray sand with red and blue shale	2615
Sandy blue shale	2620
Gray sand with blue shale streaks	2623
Blue shale	2640
Black shale	2660
Lime shell	2662
Blue shale	2665
Fine gray sand	2673
Gray sand	2688
Brown shale	2752

	Bottom, feet.
White sand	2775
Brown shale	2795
Fine hard sand	2800
Fine gray sand	2817
Brown shale	2830
Hard lime shell	2833
Broken shale	2856
Sandy shale	2860
Gray sand	2876
Thin shell	2880
Sand and shale	2890
Gray sand	2905
Gray sandy shale	2920
Brown shale and sandy shells	2935
Brown shale	2945
Brown shale with sand	2965
Brown shale	3010
Brown shale and sand	3025
Hard lime shell	3027
Blue shale and lime	3043
Black shale and lime	3055
Gray lime	3070
Lime with streaks sand	3082
Lime and blue shale	3085
Black slate with sandy shells	3095
Light gray sand	3105
Gray sand with blue shale	3112
Blue shale with fine sand	3120
White sand	3130
Gray sand with blue shale	3140
Sandy brown shale	3245
Black slate	3255
Gray lime	3258
White sand	3265
Sandy black shale	3270
Sandy blue shale	3295
Sandy shale	3307
Gray sand	3315
Brown sandy shale	3322
Blue sandy shale	3330
Gray sand	3335
Blue sandy shale	3343
Sand, blue, lime; total depth	3355

Abandoned; tools lost in hole.

French Mesa anticline cannot he considered as having been completely tested until at least 1,000 feet of additional strata area 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 test.

GALLINA MOUNTAIN ANTICLINE

The Gallina Mountain anticline is located in T. 26 N., Rs. 1 and 2 E., Rio Arriba County, between the El Vado anticline on the north and the French Mesa anticline on .the south. (See Plate XVII.)

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 so far as known to the writer no detailed structure map of the fold has ever been made. The Dakota sandstone and overlying formations which surround the anticline have very steep dips, especially on the west side. It is reliably reported[1] that the top of the Pennsylvanian limestone series is exposed in the heart of the anticline. This fact would make a complete test possible 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.

EL VADO ANTICLINE

The El Vado anticline is located on the Tierra Amarilla Grant in Rio Arriba County 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 & Rio Grande Western narrow-gauge rail-

[1] Packard, Henry L. (deceased), personal communication.

road, is the nearest rail shipping point. The branch line of the Denver & Rio Grande Western, which formerly operated between El Vado and Lumberton, was abandoned a few years ago. 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 XVII.) Each dome is represented by a hill whose shape and size corresponds 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 5 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 Shinarump conglomerate, 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 will adequately test all of the formations which have oil and gas possibilities. The formations which may be expected beneath the surface are given in the log of the Rattlesnake deep test, pages 72-74, and the log of the well on the French Mesa anticline, pages 94 and 95.

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 XVII.) 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 southeast corner 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 NE. ¼ NE. ¼ 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. No oil or gas shows were reported. In 1926 Ache & Co. drilled a second well to the Dakota near the fault on the east side of the Monero dome in 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. No test has been drilled on the Dulce dome, and since it is separated from the Monero dome by a fault having a throw of about 300 feet and is not shut off from the basin to the west by known faults or other structures, there is a possibility that it may prove productive in the Dakota. Corresponding formations are somewhat deeper on the Dulce dome than on the Monero dome.

BLOOMFIELD OIL FIELD

The Bloomfield oil field (see Plate XVIII) is in San Juan County in the broad valley of the San Juan River. 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, Colo. The highways to these towns and to Albuquerque, N. Mex., are all good.

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

Interest in the area dates back to November 15, 1924, when the Bloomfield Oil & Gas Co. brought in a well in the northeast corner of NW.¼ NW.¼ sec. 22, T. 29 N., R. 11 W., which yielded 5 to 6 barrels of 64° A. P. I. gravity oil at 706 feet. Since then more than 40 wells have been drilled to the Farmington sand in the area immediately surrounding the town of Bloomfield. Several small producing wells have been drilled, but some of the wells which offset producers have found the sand dry. Small amounts of gas occur in some of the oil wells.

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 indicates sufficient folding to explain the accumulation. According to Boyer and Hansen,[1]

[1] Boyer, W. W., and Hansen, E. A., The Bloomfield Mesa Oil and Gas Field: U. S. Geol. Survey Press Notice 4548, Jan. 8, 1926.

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.

The gas produced from some of the wells in the field was used locally for drilling purposes, and some of the oil was used as a motor fuel as it came from the wells. More recently a small topping plant has been operated in the field, and early in 1931 when the writer last visited the area, six or eight wells were being pumped, giving a combined yield of 10 to 15 barrels of oil per day. Gasoline produced by the "refinery" is marketed in Bloomfield, Aztec and Farmington.

The following analysis of crude oil from the Bloomfield oil field was furnished by the United States Bureau of Mines.

Analysis of Bloomfield Crude Oil

Sample Number 25507

Harry E. Kauns No. 1
West Coast Gasoline Co.
700-712 ft.

New Mexico.
San Juan County.
Section 20, T. 29 N., R. 11 W.

General Characteristics

Specific gravity 0.751
Per cent sulphur less than 0.1
Saybolt Universal viscosity at 100° F., less than 32 sec.

A. P. I. gravity 56.9°
Pour point below 5° F.

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			

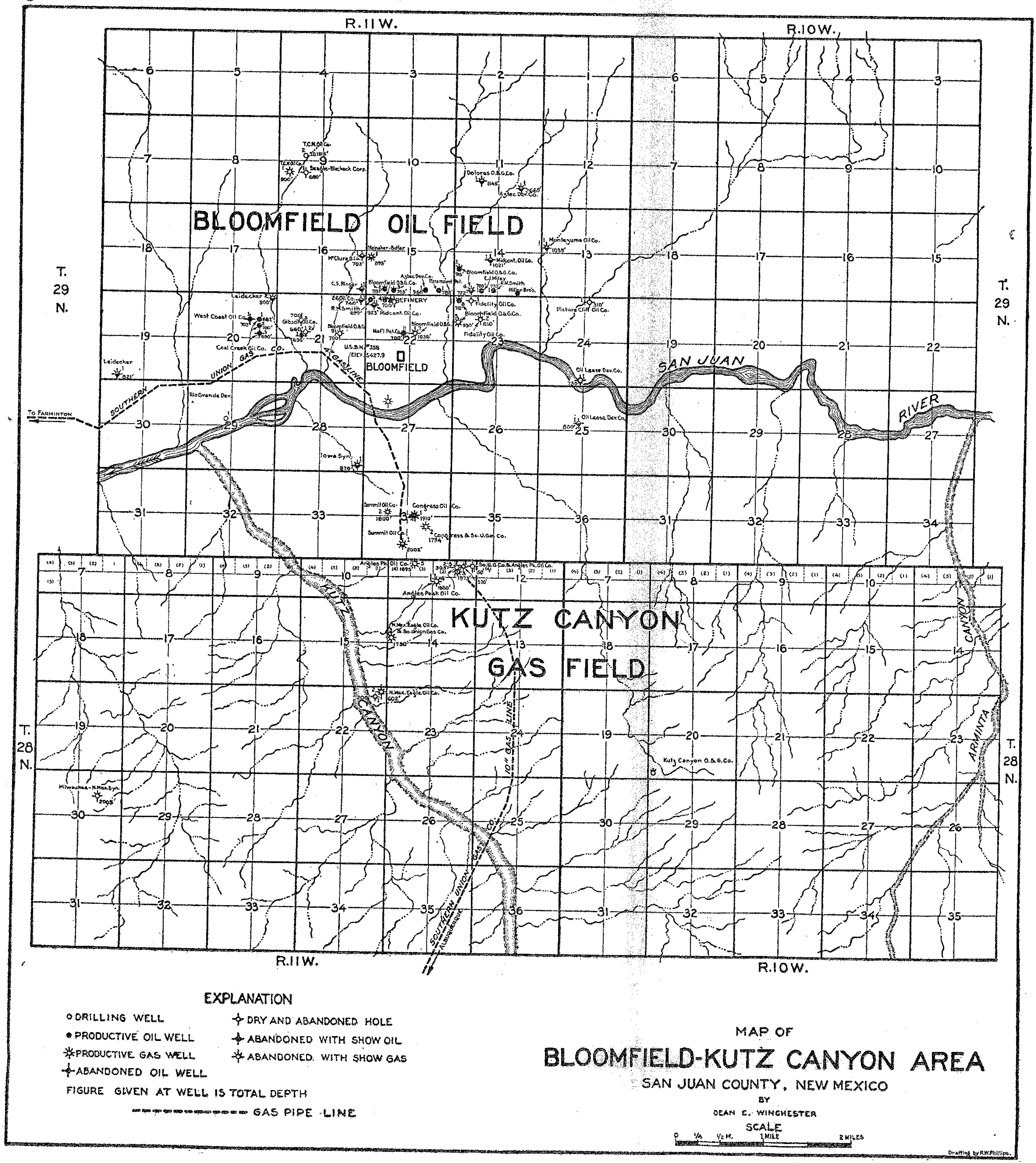
Carbon residue of residuum 4.8 per cent. Carbon residue of crude 0.1 per cent.

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	—	—	—

The town of Aztec, San Juan County, has for a number of years received its gas supply from two or three wells drilled a short distance south of town. The production of these wells comes from the Farmington sand of the Kirtland shale. Well No. 2 was drilled in 1920 with an initial production of 250,000 cubic feet of gas. From 1920 to the fall of 1928 it was practically the only well furnishing gas to Aztec. The average consumption of gas in the town in 1928, according to L. G. Snow,[1]

[1] Personal communication, October 23, 1928.


R.11W.
R.10W.
T. 29 N.
T. 28 N.
BLOOMFIELD OIL FIELD
KUTZ CANYON GAS FIELD
BLOOMFIELD
SAN JUAN RIVER
KUTZ CANYON
ARMINTA CANYON
SOUTHERN UNION GAS CO. GAS LINE
10" GAS LINE
To FARMINGTON
Albuquerque
EXPLANATION
DRILLING WELL
PRODUCTIVE OIL WELL
PRODUCTIVE GAS WELL
ABANDONED OIL WELL
DRY AND ABANDONED HOLE
ABANDONED WITH SHOW OIL
ABANDONED WITH SHOW GAS
FIGURE GIVEN AT WELL IS TOTAL DEPTH
GAS PIPE LINE
MAP OF
BLOOMFIELD-KUTZ CANYON AREA
SAN JUAN COUNTY, NEW MEXICO
BY
DEAN E. WINCHESTER
SCALE
0
1/4
1/2 M.
1 MILE
2 MILES
Drafting by R.W. Phillips.

district engineer of the United States Geological Survey, was 50,000 cubic feet per day. Well No. 2 still tested 50,000 cubic feet shortly before Mr. Snow's letter was written.

The following analysis shows the character of the gas of the Aztec gas area.

Analysis of Sample of Gas from Aztec No. 2 *Well*
NE.¼ SW. ¼, Sec. 16, *T.* 30 *N., R.* 11 *W.*

CO_2	0.52 per cent
O_2	3.30 per cent
CH_4	63.53 per cent
C_2H_6	20.49 per cent
N_2	12.16 per cent
	100.00 per cent

BLANCO DISTRICT

Several wells have been drilled in the vicinity of Blanco, about 10 miles east of Bloomfield in eastern San Juan County. Two of these wells, Huntington Park Oil Co. No. 1 Goede, in sec. 29, T. 30 N., R. 9 W., and Union Oil and Mining Co. No. 2 Pine in sec. 8, T. 29 N., R. 9 W.. were drilled to the Mesaverde sand, the first having a total depth of 4,550 feet and the second 4,289 feet. Each well found some gas in the Pictured Cliffs sandstone at around 2,100-2,200 feet depth, and each found gas in the Mesaverde at 3,800-4,200 feet depth. The following analysis of the gas from the Mesaverde from the Huntington Park Oil Co. well was furnished by the United States Geological Survey.

Analysis of gas from Huntington Park Oil Co. Goede No. 1 *Well,*
Sec. 29, *T.* 30 *N., R.* 9 *W. Depth* 4,152-4,157 *feet.*

CH_4	73.25 per cent
C_2H_6 plus	25.69 per cent
CO_2	0.59 per cent
O_2	0.32 per cent
N_2	0.15 per cent

In 1931 the well of the Huntington Park Oil Co. was supplying gas to the town of Aztec.

The surface beds in this area belong to the Puerco and Torrejon formations (Eocene), and no evidence is available regarding the structure, aside from the fact that, in general, formations are essentially horizontal.

KUTZ CANYON GAS FIELD

The Kutz Canyon gas field, in San Juan County, is located south of the San Juan River and about 2 miles south of Bloomfield. Several wells in this area (see Plate XVIII) have found gas in the Pictured Cliffs (Cretaceous) sand. 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 at the top of the casing at the several wells range from 5,518 to 6,000 feet.

The first well was drilled in this area in 1927 by the Congress Oil Co. in sec. 34, T. 29 N., R. 11 W. It was completed at a depth of 1,910 feet for about 1,500,000 cubic feet of gas. Up to March 1, 1931, 11 wells had been completed and two were drilling. The maximum tested initial

Miscellaneous Anticlinal Structures in the San Juan Basin

Name.	Location.			Surface Formation.	Remarks.
	T.-N.	R.	County.		
Azotea anticline.	31	2 E.	Rio Arriba	Mancos shale.	300 feet of closure; two wells to Dakota; dry.
Cabezon anticline.	16	2 W.	Sandoval	Mancos shale.	Untested.
Canada de las Milpas anticline.	15	1 E.	Sandoval	Jurassic.	Untested.
Chico anticline.	17	6 W.	McKinley	Mesaverde fm.	100 feet of closure; one well to Dakota, 1,807 feet; dry.
Chromo anticline.	32	2 E.	Rio Arriba	Mancos shale.	Mostly in Colorado.
Guadalupe anticline.	15	3 W.	Sandoval	Mancos shale.	Untested.
Horse Lake anticline.	29	1-3 E.	Rio Arriba	Cretaceous (?).	Long faulted anticline; one well, 1,783 feet; dry.
La Ventana anticline.	18	1 W.	Sandoval	Mancos shale.	Questionable closure; one well, 2,003 feet; dry.
Mariano Lake anticline.	15	13 W.	McKinley	Mancos shale.	Untested.
McGaffey anticline.	13	17 W.	McKinley	Triassic (?).	Untested.
North Horse Lake anticline.	30	1 E.	Rio Arriba	Mesaverde fm.	Untested.
Olguin anticline.	17-18	1 W.	Sandoval	Mancos shale.	Untested.
Rio Puerco anticline.	12-13	1-2 W.	Sandoval	Mancos shale.	Untested; faulted; two highs.
Rio Salado anticline.	16	1 E.	Sandoval	Permian.	Faulted; one well, 2,008 feet; dry.
Sarca anticline.	30	1 E.	Rio Arriba	Mesaverde fm.	Untested.
South Ambrosia Lake dome.	14	10 W.	McKinley	Mancos shale.	Drilled to 668 feet.
Tierra Amarilla anticline.	15	1 E.	Sandoval	Jurassic.	Untested.
Vogt anticline.	16	10 W.	McKinley	Mancos shale.	Drilled to Dakota, 2,350 feet; dry.
Willow Creek anticline.	30	2 E.	Rio Arriba	Cretaceous.	Drilled to 2,054 feet; dry.

production was 4,050,000 cubic feet at the No. 4 Angels Peak well in sec. 11, T. 28 N., R. 11 W. The aggregate initial gas production of all wells so far drilled is slightly in excess of 18,000,000 cubic feet per day. Rock pressures average about 500 pounds per square inch.

A study of the logs of the wells does not show a closed structure on the top of the gas sand and only a gentle north-northeast dip. The Pictured Cliffs sand, 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 closed structure to explain the gas accumulation makes it necessary to assume that the accumulation is caused by lenticularity of the porous sand members.

The gas produced has the following analysis:

Analysis of Gas from Kutz Canyon Gas Field, San Juan County

CH_4	86.46 per cent
C_2H_6	13.08 per cent
CO_2	0.21 per cent
O_2	0.10 per cent
N_2	0.15 per cent

In 1929 the Southern Union Gas Co. built a 4-inch gas line from the Kutz Canyon field to Farmington and later a 10- and 12-inch gas line across the Continental Divide to Albuquerque with an 8-inch side line to Santa Fe. No booster stations are required, the well pressure of 550 pounds being sufficient to force the gas to these towns. In April, 1931, approximately 1,000,000 cubic feet of gas per day was being drawn from the field through the Albuquerque-Santa Fe pipe line.

MISCELLANEOUS STRUCTURES

Numerous other anticlinal structures have been mapped in the San Juan Basin and several have been tested with the drill. However, information as to their magnitude and details regarding their contour and possibilities are too meagre to justify individual discussion, and they are therefore briefly described in the table, page 100.

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 the Chupadera, which is of Permian age, exposed on the east and west sides. The formations are folded in places into anticlines (see cross sections, figure 3) 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 Pinon Springs and Ojo Caliente anticlines to determine the possibilities of beds below the Cretaceous.

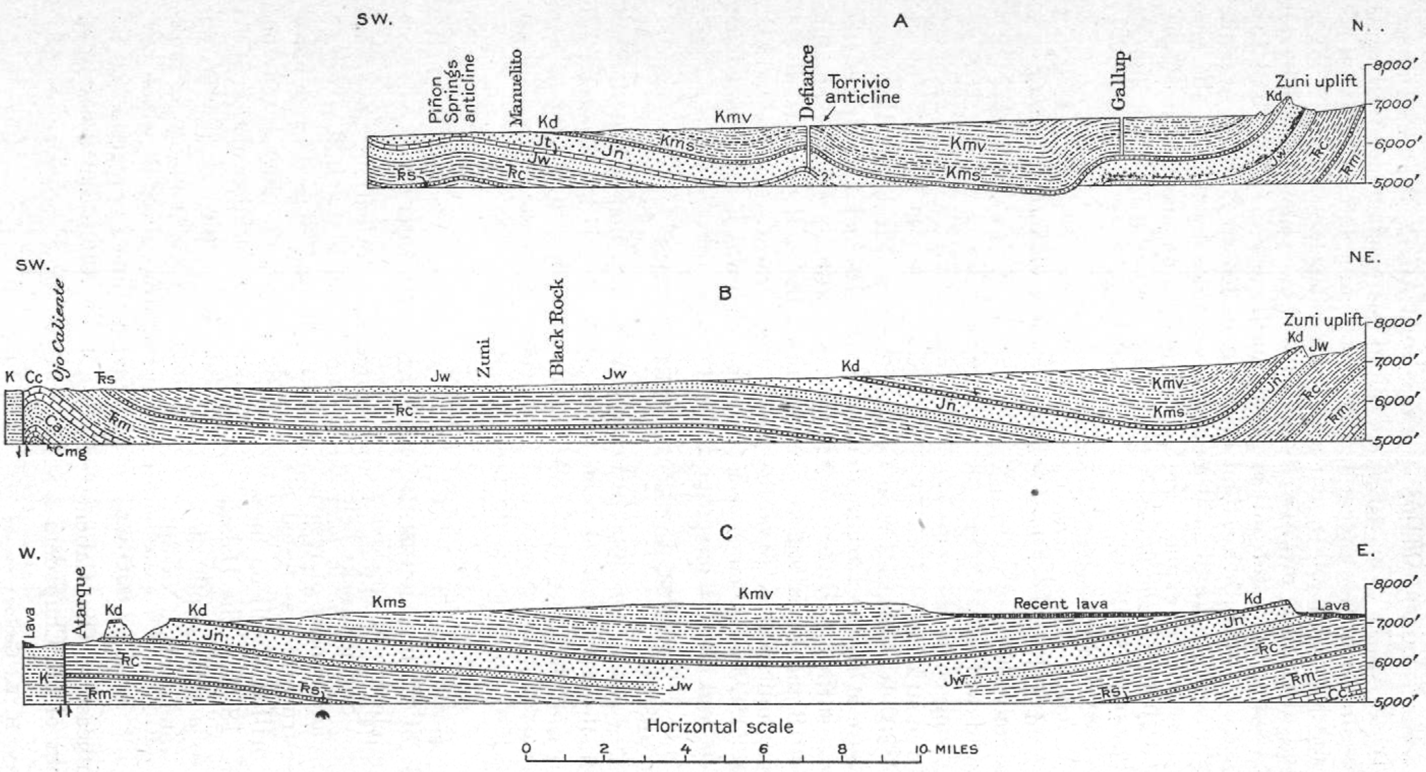


Figure 3. Sections across the Zuni Basin, McKinley and Valencia Counties. A, through Gallup; B, near Zuni; C, through Atarque. K, Cretaceous; Kmv, Mesaverde formation; Kms, Mancos shale; Kd, Dakota sandstone; Jn, Navajo sandstone; Jt, Todilto limestone; Jw, Wingate sandstone; Trc, Chinle formation; Trs, Shinarump conglomerate; Trm, Moenkopi formation; Cc, Chupadera formation; Ca, Abo sandstone; Cmg, Magdalena. group. (Courtesy of U. S. Geological Survey.)

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 E., about 8 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 Colo., 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 shale 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 SW.¼ 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 completed in the Navajo sandstone. Neither oil nor gas was found, but a good fllow of artesian water was obtained at a depth of 1,030 feet.

After a re-study of the anticline, the Marland Oil Co. of Colo., in 1926 drilled on the crest south of the railroad in sec. 5, T. 14 N., R. 19 W. This 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 2 miles southeast of Gallup, consists of 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 portion of the Mesaverde formation and consist of resistant sandstones, organic shales and coal.

The structure was tested by the Producers & Refiners Corp., which in 1923 drilled a well on the crest of the dome in the SW. ¼ sec. 25, T. 15 N., R. 18 W. The Dakota was struck at 1,185 feet. The hole was carried to a total depth of 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 Chupadera formation (Permian) are exposed in an

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1Gregory, H. E., Geology of the Navajo country: U. S. Geol. Survey Prof. Paper 93, p. 110, 1917.

anticlinal fold which according to Darton[1] has its highest point about 2 miles southeast of Ojo Caliente pueblo and flattens towards 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 upper members of the Chupadera are present. If present the structure is worth testing.

PINON SPRINGS (MANUELITO) ANTICLINE

The Pinon Springs anticline is the longest in the basin and is developed on the west side of the major syncline. It crosses the railroad between Manuelito and the State line and extends southeastward to near Blackrock on the Zuni Indian Reservation. Sears [2] gives the following added 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 Pinon 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.

The Carter Oil Co. in 1919 drilled a test in the SW. ¼ sec. 17, T. 11 N., R. 19 W., to a total depth of 1,980 feet. Concerning this test Sears [3] makes the following statement:

In 1919 a well was drilled in the SW. ¼ sec. 17, T. 11 N., R. 19 W., near the highest part of the Pinon Springs anticline. Beginning a short distance below the top of the Chinle formation, this well reached a depth of 1,980 feet. According to Darton [4] the log of the well should be interpreted as follows:

Log of Well in the SW. ¼. Sec. 17, T. 11 N., R. 19 W., as Interpreted by N. H. Darton

	Feet.
Chinle, Shinarump, and Moenkopi formations:	
Shale, all red.	0-1,006
Sandstone, gray to white	1,006-1,010
Shale, red	1,010-1,070
Chupadera formation:	
Limestone	1,070-1,100
Sandstone, gray	1,100-1,355
Shale, red	1,355-1,630
Abo sandstone;	
Limestone, very hard; some grit.	1,630-1,650
Shale, red	1,650-1,980

The writer is doubtful whether the Abo sandstone could be reached at a depth of 1,630 feet, unless the thicknesses of the Chinle, Moenkopi, and Chupadera formations as shown in Darton's table [5] and corroborated by

[1] Darton, N. H., "Red Beds" and associated formations in New Mexico: U. S. Geol-Survey Bull. 794, p. 154, 1928.

[2] Sears, Julian D., Geology and coal resources of the Gallup-Zuni Basin, N. Mex.: U. S. Geol. Survey Bull. 767, p. 22, 1925.

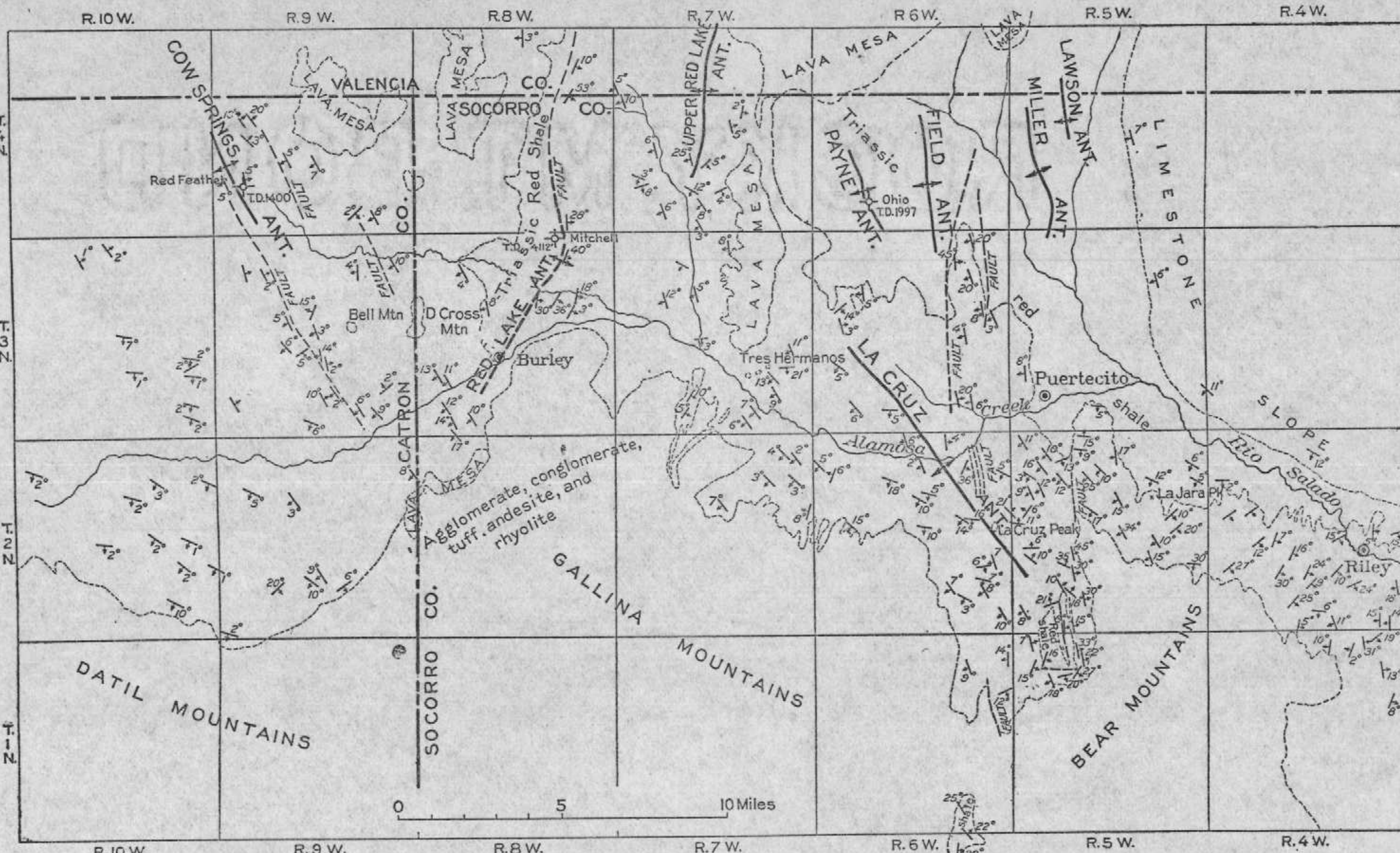
[3] Sears, J.D., op. cit. p. 52. -

[4] Darton, N. H., Geologic structure of parts of New Mexico: U. S. Geol. Survey Bull. 726, p. 262, 1922.

[5] Op. cit., p. 259.

NEW MEXICO SCHOOL OF MINES
STATE BUREAU OF MINES AND MINERAL RESOURCES

BULLETIN 9
PLATE XIX



Map showing geologic structure in valleys of Rio Salado and Alamosa Creek, Socorro and Catron Counties.

Winchester are much too great. Drilling was stopped mainly because the drillers supposed the bottom of the hole to be near the base of the sedimentary rocks. It is unfortunate that drilling did not continue far enough to test all the possibilities of the Permian rocks and the Pennsylvanian beds if present.

ACOMA BASIN

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 Ladrones 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 Ladrones Mountains to the east. The topography of most of the basin is exceedingly rough, erosion having produced narrow canyons bordered by impassable 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 badly 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 Ladrones Mountains on the east and the Continental Divide on the west. The results of a detailed study of the district made by the writer[1] in 1913 and 1914 were published in 1920. At about the same time a detailed report on a small part of the area by E. H. Wells[2] was issued. The following descriptions are taken largely from these publications.

As indicated by the name of the district, 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 above sea level 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 in the area numerous hogback ridges and cuestas formed by beds of resistant sandstone and deep canyons and valleys cut in the softer

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[1] 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. (Chapter "A" published May 12, 1920.)

[2] 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. (Issued Apr. 1, 1920.)

beds below. High lava-capped mesas form conspicuous landmarks at several places in the area.

The nearest railroad point is Magdalena, 35 miles to the southeast at the end of a branch line of the Atchison, Topeka & 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.

GEOLOGY

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 Ladrones Mountains. Successively younger formations found to the west include Permian and Triassic "Red Beds," Cretaceous Dakota sandstone, Mancos shale (Miguel formation) and 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 beds. The following composite detailed section measured by the writer shows the character of the Cretaceous beds exposed in the area.

Composite Section of Cretaceous Formations in Alamosa Creek and Rio Salado Valleys.

Section of Chamiso Formation (Mesaverde?) North of Blue Mesa, in T. 2 N., R. 8 W.

	Feet.
Sandstone, yellow to greenish, soft, and shale, sandy, yellow to green	440
Sandstone, gray, coarse	4
Coal and carbonaceous shale	1½
Shale, and sandstone, soft	46
Coal and carbonaceous shale	2
Shale	20
Shale, yellow, and sandstone, thin bedded	175
Sandstone, massive, yellow, cross-bedded	30
Shale, greenish yellow and drab, argillaceous; fossils	50
Share and sandstone	145
Sandstone, coarse, massive	25
Sandstone, gray, thin bedded, with thin beds of indurated brown sandstone	205
Sandstone, yellow, massive, coarse	3
Shale, yellow and drab, sandy	20
Sandstone, gray, soft, thin bedded	15
Shale, carbonaceous at the top	25
Shale and sandstone, with beds of hard brown concretions	126
Sandstone	4
Sandstone, thin bedded; fossils	5
Covered	106
Sandstone, yellow to brown, coarse	7
Sandstone, thin bedded, and shale	100
Shale, drab	50
Sandstone, thin bedded to shaly	97
Sandstone, yellowish gray, coarse	5
Sandstone, yellow, coarse, soft, thin bedded	103
Total Chamiso formation	1,809 ½

Section of Miguel Formation (Mancos Shale?) 2 Miles West of I. N. M. Ranch

	Feet.
Sandstone, thick bedded, yellow to gray, coarse; *Halymenites* at the top, *Inoceramus* at the base (Bell Mountain sandstone member)	79
Shale, greenish and drab, fissile, containing hard brown concretions near the top; fossil shells 10 feet below the top	175
Sandstone, brown, hard	2
Sandstone, yellow, shaly, slightly carbonaceous at the base	34
Shale, yellow to drab, with thin beds of sandstone	35
Sandstone, brown, hard, coarse	1
Sandstone, yellow, massive	25
Shale, yellow and drab, with thin beds of sandstone	584
Sandstone, yellow, and dark to yellow shale, with 10 feet of carbonaceous shale at the top	80
Sandstone, yellow, thin bedded, and drab shale, sandy at the top, carbonaceous below, containing leaf fragments and 6 inches of coal near the top	47
Sandstone, yellow, massive, containing *Halymenites* (Gallego sandstone member)	93
Sandstone and shale, mostly covered	380
Sandstone, yellowish, massive, coarse, gray; fossil shells, 20 feet above the base	78
Sandstoneand shale	6
Shale, yellowish gray and drab, fissile	134
Covered	50
Sandstone, with gastropods	15
Shale, drab, with oysters and shark teeth	50
Sandstone, yellowish gray, conglomeratic and cross bedded	23
Shale, drab, argillaceous, with oysters 10 feet below the top	82
Covered, mostly shale	109
Total Miguel formation	2,082

Section of Dakota Sandstone South of Puertecito

Sandstone, massive, angular grains	26
Sandstone, gray, thin bedded.	5
Total Dakota sandstone	31

The character of beds below the Dakota starting perhaps 500 feet below the top of the "Red Beds" is shown by the log of the Mitchel well on the Red Lake anticline given on pages 108 and 109 in connection with the description of that structure.

The sedimentary formations are intricately folded and faulted within the district as will be seen by references to the map, Plate XIX. Descriptions of the major structural features are given on the following pages.

RED LAKE ANTICLINE

East of D-Cross Mountain in Tps. 3 and 4 N., R. 8 E., is the large faulted Red Lake anticline. This structure has a closure of several hundred feet against a profound fault on the east. Triassic "Red Beds" 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 "Red Beds" 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.

Log of L. H. Mitchel & Sons, Red Lake No. 1 *Well NW.*$^1/_4$ *NW.*$^1/_4$ *Sec.* 2, *T.* 3 *N., R.* 8 *W. Drilled,* 1924-25

	Bottom, feet.
Lime shell	781
Gray shale	820
Red rock	835
Red shale	845
Lime	850
Red shale	885
Lime	894
Red shale	910
Brown lime	920
Sand; 8 barrels water per hour	929
Red shale	934
Lime	944
Soft dark lime	957
Red shale	1004
Sand	1008
Red shale	1028
Talc	1055
Gray slate	1090
Gyp sand	1096
Gray lime; water	1109
Gray lime, very hard	1130
Dark lime	1135
Gray sandy lime; water	1140
Dark lime	1155
Gray lime; water	1167
Hard sharp sand; dry	1190
Lime	1196
Gray shale	1200
Lime and sand.	1240
Sandy lime; water.	1244
Lime, hard	1266
Talc	1267
Lime	1271
Hard sharp sand	1291
Gray lime, cavey	1316
Gray fine water sand.	1339
Hard gray sand	1347
Dark brown lime	1360
Gray hard lime	1367
Sand; water	1369
Gray shale	1371
White sand	1456
White shale	1458
Fine gray sand.	1555
Red sand	1612
Blue shale	1614
Brown sand	1635
Conglomerate	1640
Red shale	1655
Lime shells and red shale	1685
Red shale	1700
Red sand	1710
Red shale	1720
Gray shale	1732
Pink shale	1740
Red sand	1747
Gray shale	1754
Gray sand	1166
Gray slate	1770
Red shale	1780
Pink sand	1805
Red shale	1815
Red sand	1818
Red shale and sand	1840
Gray lime	1848
Gray shale	1868
Pink sand	1885
Red shale	1890
Red sand	1920
Red shale	1928
Red sand	1945
Gray shale	1960
Brown shale	1965
Black lime	1977
Gray lime	1995
Red and gray shale with some red sand	2000
Red sand	2015
Red shale	2023
Red sand	2028
Red shale	2035
Brown shale	2043
Gray lime	2048
Gray shale	2060
Red shale	2070
Red sand	2071
Red shale	2080
Red sandy shale	2085
Red shale	2090
Red sand	2102
Red shale.	2108
Red sand	2114
Red shale	2124
Red sand	2130

	Bottom, feet.
Sand	2140
Red shale	2175
Gray lime	2200
Hard gray lime	2205
Gray sand	2240
Red sand	2250
Red shale	2260
Gray sand	2280
Red shale	2295
Red sand	2305
Red shale	2310
Red sand	2330
Red shale	2345
Red sand	2360
Red shale	2370
Red sand	2375
Red shale	2380
Red sand	2400
Red shale	2405
Red sand	2415
Red shale	2420
Red sand	2427
Red shale	2432
Red sand	2444
Red shale	2450
Red sand	2455
Red sandy shale	2480
Red sand	2520
Red shale	2545
Brown-black sand; water	2590
Red shale	2610
Red sand	2623
Gray lime	2631
Red sand	2670
Red sandy shale	2685
Red sand	2730
Red shale	2770
Red sand, very hard	2823
Gray shale	2843
Red shale	2858
Sandy red shale	2870
Hard red shale	2907
Hard rock	2913
Very hard red shale	2927
Red shale with shells, gray rock	2940
Gray rock	2950
Red shale, shells, gray rock	2990
Sandy red shale	3008
Red shale	3013
Red shale and lime shells	3037
Red shale	3040
Lime and shale	3050
Sand	3060

	Bottom, feet.
Brown shale	3065
Red shale and lime shells	3085
Red shale	3100
Red shale and lime shells	3110
Red shale and lime; water	3122
Sticky red shale	3135
Red shale	3155
Sticky red shale	3165
Red shale	3220
Brown shale	3232
Red shale	3257
Red shale and shells	3269
Red shale	3410
Sandy lime	3425
Gray lime	3440
Sandy lime, shells and gray shells	3455
Gray shale, hard shells	3470
Gray shale, thin lime shells	3485
Gray shale	3560
Lime	3565
Gray shale with lime shells	3600
Gray lime	3612
Gray shale	3625
Lime; hole full of water	3630
Gray lime	3640
Lime with water	3650
Hard lime	3658
Gray shale	3661
Lime and shale	3675
Shale	3680
Lime	3705
Shale	3760
Lime	3765
Shale and lime shells	3790
Sand and pink shale	3810
Water sand	3825
Shale	3865
Sand	3882
Shale	3885
Lime	3886
Sand	3890
Very soft sand	3900
Shale	3922
Hard sand	3924
Very hard sandy lime	3933
Sand	3952
Very hard	3976
Quartz sand, hard	3978
Very hard	3979
Hard rock	3980
Very hard	3986
Granite	4012

According to Darton,[1] the Red Lake No. 1 well probably encountered the base of the Triassic at about 1,028 feet, the base of the Chupadera at 2,205 feet, the base of the Abo at 3,410 feet, and the bottom of the Magdalena at 3,952 feet.

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 southeast corner NE ¼ 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 have been the Dakota sandstone was reported.

LA CRUZ ANTICLINE

The La Cruz anticline is a long, irregular fold that trends northwest-southeast 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 Chaves 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 possible to separate this fold into 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 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.

PUERTECITO DISTRICT

Topography.—The Puertecito district, described by Wells [2] 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 on the west. 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 of the accom-

[1] Darton. N. H., "Red Beds" and associated formations in New Mexico: U. S. Geol. Survey Bull. 794, p. 132, 1928.

[2] Wells, E. H., op. cit.

panying map, Plate XX, include maroon, purplish red and gray shales, purplish red sandstones and thin conglomerate beds of Triassic and Jurassic age. The series is from 1,150 to 1,250 feet thick, and is called by Wells the Puertecito formation.

Unconformably overlying the Puertecito formation is the Dakota sandstone 5 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 contain abundant fossil life and belong to the Mancos shale. Unlike the Mancos in its type locality in Southwestern Colorado, the formation contains thick persistent sandstones amounting to more than 50 per cent of its total thickness. (See section, pages 106 and 107.) Capping the high mesas to the north and east, is a considerable thickness of hard basaltic rock. Dikes, sills and plugs of similar rock are found at several places in the area. Subsurface formations in the Puertecito district to a depth of nearly 2,000 feet are disclosed by a well drilled by the Ohio Oil Co. on the Payne anticline, and are shown in the log, page 112.

Structure.—The sedimentary formations in the Puertecito district are considerably folded and faulted (see map and cross section, Plate XX.) Wells has mapped several minor folds with anticlinal axes trending in a general north-south direction. Faulting, in general parallel to the axes of folding, is evident in the area east and south of the Field anticline, where the resistant Cretaceous sandstones are involved in a downthrow block. but the faults are not evident in the surface Puertecito shales far into the Basin area. The following detailed description of local structures is taken from Well' report.[1]

Payne Anticlinal Dome.—The Payne anticlinal dome Is one of the chief structures of the Puertecito district. It is a well-defined upfold occupying the western part of the Puertecito basin. The anticline lies mainly in the southwestern part of T. 4 N., R. 6 W., but part of it extends into the northwestern part of T. 3 N., R. 6 W. A road from Puertecito to the Payne ranch crosses the structure near the apex of the dome. Except during the summer months this road is in fair condition. * * *

The shape and extent of the Payne anticlinal dome are shown by the structure contours on the map of the district. It is a fairly symmetrical fold trending north-northwest. The dips on the east side are between 2° and 5°. The dips on the west side average nearly the same as those on the east side, but locally they increase to as much as 10° or decrease nearly to horizontal. The width of the east limb, measured from the crest line to the bottom of the syncline lying between it and the Field anticline is about one mile, whereas the width of the west limb is at least 4 miles in the narrowest place. From the apex the axis dips to the north at an angle of 1° to 2° for more than a mile. Farther to the north the structure is obscured by erosional products from the mesa escarpment. To the south of the apex the dip of the axis is 1½° to 2½° for about a mile. The south and southwest dips continue in these directions for an additional distance of at least 15 miles. The apex of the dome is in the NE. ¼ sec. 32, T. 4 N., R. 6 W. The north closing in the rocks of the Puertecito formation, as shown by the structure contour lines, is at least 175 feet, while the east closing appears to be about 275 feet.

The surface rocks of the Payne anticlinal dome consist of the purplish-

[1] Wells, E. H., op. cit.

red shales and purplish-gray sandstones of the middle part of the Puertecito formation. The surface is roughened by numerous cuestas which are capped by the sandstone members of the formation, and the structure is excellently delineated by the successive lines of cuesta escarpments surrounding the apex. The escarpments are in places 60 feet high, but the prevailing surface elevation is quite uniform throughout and varies from 6,125 to 6,275 feet above sea level.

No igneous rocks are known near the axis of this anticlinal dome, but several small sills occur below the Dakota sandstone at the foot of the mesa to the west, and intrusive rocks are found near the base of the mesa on the north. No distinct evidence of deep-seated faulting was discovered, but steep dips a short distance west of the apex may have been produced in part by surficial faulting. * * *

The Ohio Oil Co. in 1926 drilled a well to the 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 been the cause of the surface structure and if so this structure would not be reflected in underlying beds.[1] An excellent flow of artesian water was developed, and the well is being used by Mr. N. A. Field for watering stock and irrigation.

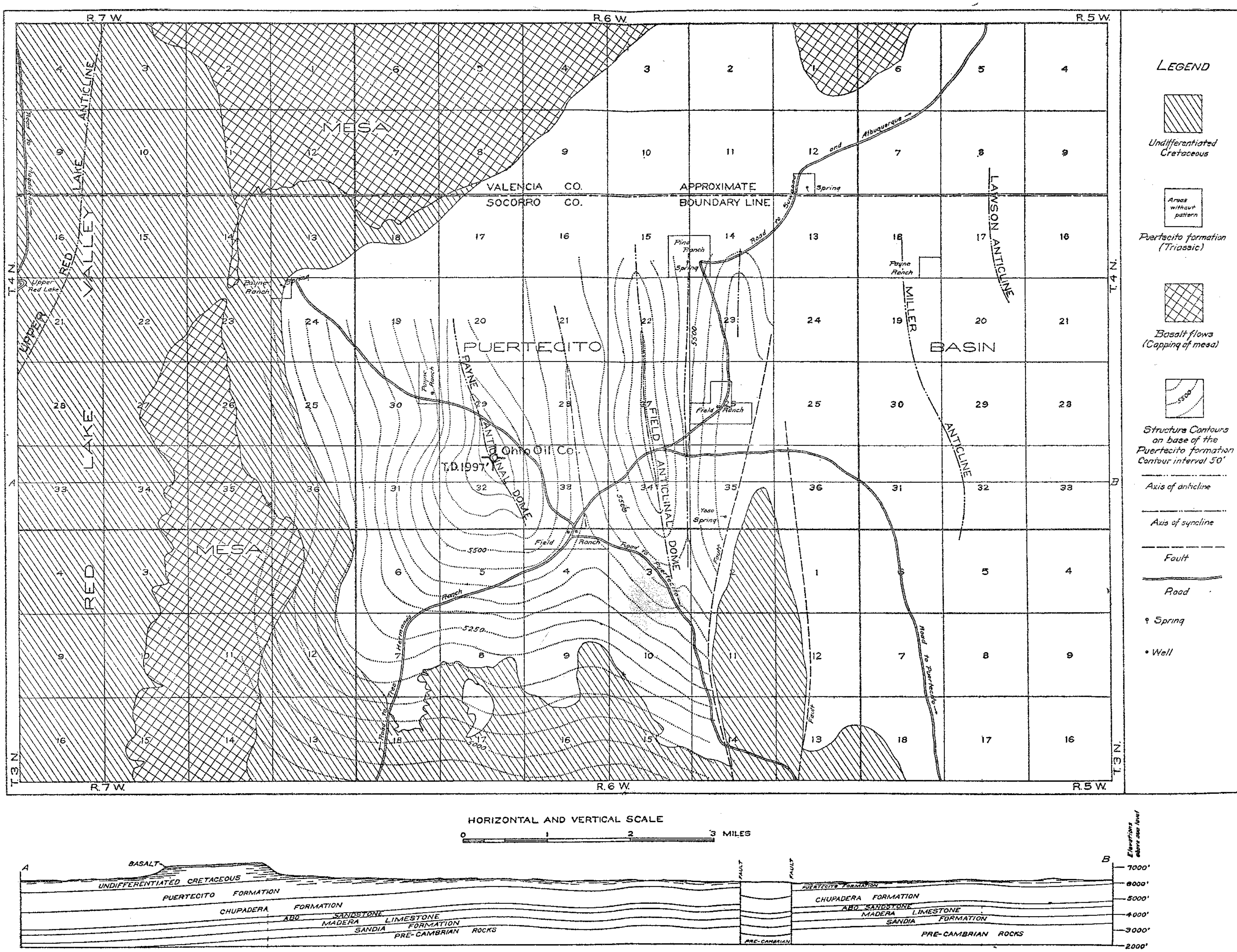
Log of Ohio Oil Co. McDonald No. 1 *Well*
NW. ¼ NE. ¼ Sec. 32, *T.* 4 *N., R.* 6 *W.*
Drilled, 1926

	Bottom, feet.
Red and purple shale	325
Gray sand	347
Red shale	355
Gray sand; water	375
Gray shale	380
Gray sand; 4,000 barrels artesian water	470
Red shale	573
White and blue lime; 6,000 barrels water	630
Sandy blue shale	680
Sand and gypsum	700
White lime	745
Red shale	770
Black lime	875
White sand	895
Yellow sand	900
White lime	920
Black lime	945
Hard shells anu gypsum	975
Gypsum and sand	990
Glorieta (?) sand; 20 barrels artesian water	1185
White soft lime	1225
Red sandy lime	1260
Red sand	1280
Black lime	1325
Black sandy lime gypsum	1370
Sandy lime; some water	1405
Lime and gypsum	1410
Igneous rock, volcanic, mica and quartz (probably a sill)	1997

Field Anticlinal Dome.—The Field anticlinal dome is situated in the Puertecito Basin east of the Payne anticlinal dome. It lies in secs. 15, 16, 21, 22, 27, 28, 33 and 34, T. 4 N., R. 6 W., and secs. 3 and 4, T. 3 N., R. 6 W. * * *

As shown by the structure-contour lines on the map of the district, the Field anticline is a symmetrical and notably regular northward-trending fold whose axis extends from the southern part of sec. 15, T. 4 N., R. 6 W., to the southern part of sec. 3, T. 3 N., R. 6 W. The west limb is about a mile in width throughout, and the dips vary from 2½° to 6°. The east limb has a width of one-third to three-fourths of a mile and slightly greater dips than the opposite limb. At the south end the anticlinal dome merges into the homocline proper, the south dips persisting for 12 or 15 miles beyond

[1] Emery, W. B., personal communication.



GEOLOGIC MAP AND SECTION OF THE PUERTECITO DISTRICT, NEW MEXICO

By E. H. Wells

the structure. The apex of the dome is nearly at the quarter corner on the section line between secs. 27 and 34, T. 4 N., R. 6 W. The axis is almost horizontal for a distance of nearly a mile north of the apex. Farther to the north, it exhibits a dip of about 1°, but the structure is indeterminate beyond the southern part of sec. 15, T. 4 N., R. 6 W., where the sandstone escarpments cease. The north closure in the rocks of the Puertecito formation is at least 100 feet and may be somewhat greater than that. Near the east boundary of sec. 34, T. 4 N., R. 6 W., the axis of the syncline to the east approaches to within one-third of a mile of the axis of the anticline, and the closure to the east in this vicinity is apparently not more than 150 feet.

The Field anticlinal dome has many characteristics In common with the Payne anticlinal dome adjoining it on the west. The same series of Puertecito sandstones and shales crop at the surface and the cuesta escarpments on both sides of the axis and at the ends of the anticline are very similar. The Field anticlinal dome is the narrower structure of the two. Except for the cuestas and a few arroyos, the monotony of the nearly flat basin bottom is unbroken. Elevations range from 6,050 to 6,175 feet. * * *

Faulting seems to be entirely lacking throughout the Field anticline, and no igneous rocks are known to occur. There are, however, areas of marked igneous activity a mile or more to the east.

Miller Anticline.—In the main, the (Miller) anticline is a distinct upward bulge having a length of 4 miles or more. It occupies all or part of secs. 18, 19, 29, 30, 31 and 32, T. 4 N., R. 5 W., and secs. 5 and 6, T. 3 N., R. 5 W. The axis, as shown on the map of the district, begins in the NW.1/4 sec. 5, T. 3 N., R. 5 W., and trends in a general northerly direction for about a mile, then swings to the west and takes a course of about north-northwest for a short distance, and finally swings back to a course of nearly due north which continues to the end of the anticline in sec. 18, T. 4 N., R. 5 W.

The Miller anticline is the only anticline in the Puertecito district whose structure is reflected in the topography. The position of the anticline is marked by a hill rising 75 to 125 feet above the surrounding country, the crest of the hill corresponding in general with the axis of the anticline. This hill is the most prominent topographic feature of the eastern part of the district. In many places the dips of the strata agree with the slope angles of the hillside. The anticline is fairly symmetrical, dips varying from 2° to 8° on both sides. The width of the upfold is 1½ to 2 miles. In common with the other anticlines of this area, the south dips continue for a number of miles in that direction. The north closure also seems to be good. The highest part of the axis is in secs. 19 and 30, T. 4 N., R. 5 E. The thickness of the sedimentary rocks above the pre-Cambrian appears to be between 2,500 and 2,800 feet.

The sandstone and shales of the Puertecito formation, which are the surface rocks of the Miller anticline, contain a number of large igneous sills, and are also cut by occasional dikes and intrusions of irregular shape. Faulting of small displacement has occurred in places, and in some parts of the structure the strikes and dips are subject to wide variation. * * *

Lawson Anticline.—A minor flexure designated as the Lawson anticline lies northeast of the Miller anticline in secs. 8, 17 and 20, T. 4 N., R. 5 W. Its length is about 1½ miles. The axis has a trend of nearly due north, and throughout most of its length the east and west dips are distinct, though at small angles. To the north the anticline merges into the homocline of the district without an apparent closing, the homocline in this vicinity dipping to the west at angles of 1° to 2½°. Igneous intrusions are present only in small amounts throughout most of the structure at the surface, but the south end extends into an area of vigorous volcanic activity where the structure is very irregular and largely indeterminate.

(Upper) Red Lake Anticline.—The (Upper) Red Lake anticline is an upfold trending in a general northerly direction. It has a length of 7 miles

or more. About half of the structure lies to the north of the district proper. The surface rocks in the mapped area consist mainly of shales and sandstones belonging to the lower part of the Mancos shale. In places the sandstones outcrop prominently, but in the main either the soft clay shales are the only surface rocks or the sandstones are obscured by valley fill. Dips in the shales and sandstones of several small isolated buttes are almost valueless in determining structure. In the northern part of the anticline arroyos have cut through the Mancos shale and Dakota sandstone and into the upper strata of the Puertecito formation. Near the north end several hundred feet of the Puertecito formation has been removed by erosion in places.

No detailed work was undertaken in this part of the district, and only general statements can be made regarding the structure of the anticline.

* * * The approximate position of the axis is shown on the map. The average dip of the axis to the south in secs. 9, 16 and 21, T. 4 N., R. 7 W., is about 2°. The west limb is well defined, and the strata dips to the west at angles of 3° to 6° for several miles. The east limb is clear cut in the southern part, but near the north boundary line the attitude of the sedimentary beds is not readily determinable. The width of the east limb in the latitude of sec. 16, T. 4 N., R. 7 W., is nearly 2 miles, the average dip angle being about 2½°.

The field evidence slightly suggests a terrace along the anticline in secs. 2, 3, 10 and 11, T. 4 N., R. 7 W., and there is a slight possibility of a north closure near the edge of the mesa or farther to the north beneath the flows. If so, the (Upper) Red Lake anticline really consists of two anticlines. A more likely supposition is that the anticline changes its direction and that the axis is continuous as shown. Detailed work might lead to more positive conclusions, but the structure is in part a difficult problem. Much of the east limb lies beneath the basalt flows.

The axis of the (Upper) Red Lake anticline continues to rise to the north for several miles beyond the district. Near the center of T. 5 N., R. 7 W., the axial dip appears to change to the north, resulting in the development of a dome along the axis. How much the north and east closures amount to cannot be stated, but they do not promise to be very large. In the southern part of the anticline pre-Cambrian rocks are thought to be 3,600 to 4,000 feet below the surface along the axis, and at the north end they are probably several hundred feet nearer the surface. No igneous intrusive rocks are known to occur along the anticline.

MISCELLANEOUS ANTICLINAL STRUCTURES

Although comparatively little -detailed mapping has been done in the Acoma Basin outside the areas above described, several anticlinal folds are indicated on published maps and wells have been drilled to test some of these structures. Details of structure are lacking and it is possible therefore only to give the most meagre information about the structures.

ACOMA ANTICLINE

This anticline, in Tps. 8 and 9 N., R. 7 W., is as yet untested. Triassic rocks form the surface.

J. Q. MEYERS ANTICLINE

An anticline called the J. Q. Meyers anticline is located in T. 11 N., R. 11 W., on the east flank of the Zuni Mountains. Permian (?) rocks form the surface, and the structure is untested.

MESA LUCERO ANTICLINE

At this anticline in T. 7 N., R. 3 W., Permian rocks are exposed at the surface. One well 700 feet deep has been drilled.

SOUTH SUWANEE DOME

Triassic red beds are exposed at the surface at 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 finished in granite at 5,065 feet.

NORTHEAST AREA

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. 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 the Magdalena limestone (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. (See figure 4.) The table, page 118, by Darton[1] gives data on the general character and thickness of formations in northeastern New Mexico.

OIL AND GAS

Many of the local structures of the Northeast Area have been partially tested by drilling, but up to July, 1932, 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. Carbon-dioxide gas in commercial amounts has been found in the Santa Rosa sandstone on the Abbott dome on the line between Colfax and Mora counties, on the Baca anticline in Harding County, and on the Wagon Mound anticline in southern Mora County. Granite is reported to have been reached in wells on the Cimarron dome in Union County, the Abbott dome in Colfax County and on the Esterito dome in northwestern Guadalupe County. However, it is the writer's opinion that "granite wash" or arkose was mistaken for granite in each of these wells. Deep wells in San Miguel and Quay counties have found considerable arkose in the Permian, with thick beds of limestone and shale below, and none has reached the basement granite.

In spite of the lack of favorable results so far obtained from drilling in northeastern New Mexico, it is believed that additional drilling is justified. It seems quite probable that additional carbon dioxide gas may be developed on structures where the Santa Rosa sandstone is under cover, and the commercial utilization of carbon dioxide for refrigeration purposes appears to have a bright future.

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[1]Darton, N. H., Geologic structure of parts of New Mexico: U. S. Geol. Survey Bull. 726, p. 176, 1922.

Deeper drilling is warranted on a number of the more pronounced structures to test the lower Permian and underlying Pennsylvanian rocks. These have not yet been tested except in one or two places. The finding of "granite wash" or arkose does not condemn a structure, although several areas have been condemned in the past because granite (probably "granite wash") was reported in wells.

SIERRA GRANDE UPLIFT AND ASSOCIATED STRUCTURES

GENERAL RELATIONS

The principal anticlinal fold of northeastern New Mexico is a broad, elongated uplift known as the Sierra Grande uplift, whose axis extends in a southwest direction from southeastern Colorado well into New Mexico. (See maps, Plate XXIII and figure 4, and cross section, figure 5.) It occupies parts of Colfax, Union, Mora and Harding counties. The axis of folding passes between Folsom and Des Moines near the north line of the State and continues southwest to Abbott and Roy and possibly on to Cherryvale in San Miguel County. The highest part of the fold appears to be near Capulin Mountain and Des Moines. Numerous minor domes and anticlines have been worked out along this general line of folding, and several have been drilled. Detailed descriptions of the local domes and anticlines are given on the following pages.

The surface formations over nearly the entire area belong to the Cretaceous series, but the underlying Jurassic beds are exposed in some of the deeper canyons.

CIMARRON DOME

So far as known, the first local structure to be tested in this area was the Cimarron dome located near the north line of the State in Union County and several miles to the 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 NE.¼ NE.¼ 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-southwest direction.

CAPULIN ANTICLINE

Southwest of the Cimarron dome and on the west side of the main axis of folding is a small domelike structure called the Capulin anticline. 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 belonging to the Carlile formation (Cretaceous) occupy the surface along the crest of the dome, and a well drilled in 1926 by the Red Feather Oil Co. in the NW ¼ SW.¼ 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.

Formations in Northeastern New Mexico.

Age.	Group and Formation.		Character and General Relations.		Average Thickness (feet).
Recent.	Alluvium.		Sand, gravel, and clay.		50
Pliocene and Miocene.	Santa Fe formation.		Sand, silt, gravel, and conglomerate.		150
Eocene.	Raton formation.		Conglomerate and sandstone; local coal beds.		1,200-1,600
Eocene (?).	Galisteo sandstone.		Sandstone and conglomerate. Relations to Raton formation unknown.		700
Upper Cretaceous.	Montana group.	Vermejo formation.	Sandstone and shale, with coal beds.		0-375
		Trinidad sandstone.	Sandstone, gray to buff.		0-100
		Pierre shale.	Shale, mostly dark colored; upper beds sandy.		(?)
	Colorado group.	Apishapa shale.	Shale, in part limy.	Niobrara formation where not differentiated.	500
		Timpas limestone.	Limestone, mostly impure.		50
		Carlile shale.	Shale, with concretions.	Benton shale where not differentiated.	250
		Greenhorn limestone.	Limestone, slabby, and dark shale.		60
		Graneros shale.	Shale, dark.		150
	Dakota sandstone.		Sandstone, gray to buff, hard.		100
Lower Cretaceous.	Purgatoire formation.		Sandstone, overlain by shale.		140
Cretaceous (?).	Morrison formation.		Shale, massive, mostly greenish gray, and intercalated sandstones.		150
Jurassic.	Todilto limestone.		Limestone; weathers thin bedded; locally overlain by 60 feet of gypsum.		0-85
	Wingate sandstone.		Sandstone, massive, light gray.		100
Triassic.	Dockum group.		Shales and sandstones, mostly red, containing locally, near the lower part, the Santa Rosa sandstone.		800
Permian.	Manzano group.	Chupadera formation.	Limestone, sandstone, and gypsum.		600-1,200
		Abo sandstone.	Sandstone, mostly hard, slabby, brownish red.		600-800
Pennsylvanian.	Magdalena group.		Limestone, some shale and sandstone.		600-1,200
Pre-Cambrian.			Granite, schist, etc.		

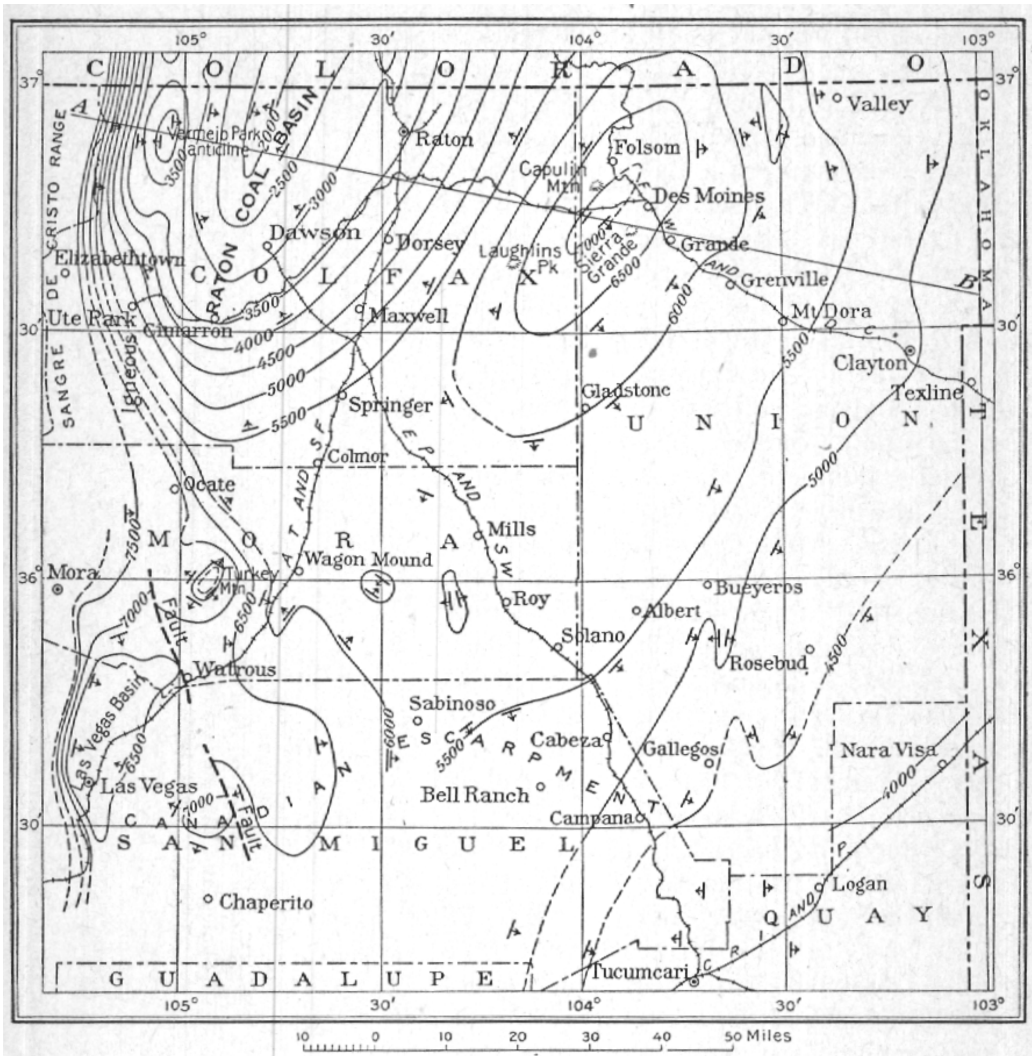

Figure 4.—Map showing the larger structural features of northeastern New Mexico, by contours on the surface of the Dakota sandstone. Contour interval 500 feet. Elevations approximate. A-B, line of section in figure 5. (Courtesy of U. S. Geological Survey.)

ABBOTT, CHICO, JARITAS, LUNSFORD AND RITO DEL PLANO STRUCTURES.

In southern Colfax County and northern Harding and Mora counties, a series of small irregular folds occur, which are known as the Abbott, Chico, Jaritas, Lunsford and Rito del Plano structures.

The Rito del Plano anticline is an elongated uplift whose axis trends northeast-southwest 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 highest point is located 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.

The Chico dome is a small north-south elongated structure showing about 80 feet of closure with the high point located in the NW.¼ sec. 6, T. 24 N., R. 24 E. Cretaceous beds in the zone of the Greenhorn limestone form the surface. The Frontier Oil Co. in 1927 drilled a well to a total depth of 1,326 feet in sec. 6. The top of the Dakota was found at 190 feet and the well was abandoned without favorable results.

The Lunsford, Jaritas and Abbott domes are three small local domes along a single axis of folding. The lowest formation exposed is the Dakota sandstone. The Lunsford dome has an independent closure of only about 10 feet and is located in secs. 13, 14, 23 and 24, T. 24 N., R. 24 E. The Jaritas dome, located in secs. 15, 16, 21 and 22, T. 23 N., R. 24 E., has a closure of about 40 feet; and the Abbott dome, with its highest part in sec. 30, T. 23 N., R. 24 E., has a closure of 30 feet. In 1925 the California Co. drilled a test well in the southwest corner sec. 15, T. 23 N., R. 24 E., on the Jaritas dome. At a depth of 1,509 feet this well struck about 500,000 cubic feet of non-combustible gas which contained 67 per cent carbon dioxide, 4.1 per cent oxygen, 28.7 per cent 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[1] makes the following statements:

> 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, extended 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,

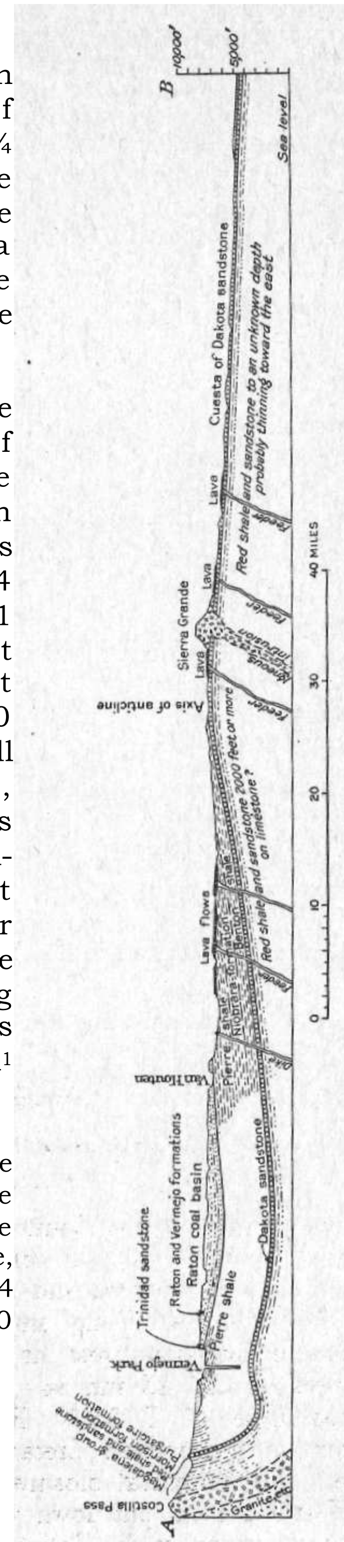

Figure 5. Section across Colfax and Union counties, along line A-B, figure 4. (Courtesy of U. S. Geological Survey.)

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[1]Darton, N. H., op. cit. al S. G. S. Bull: 794), p. 310.

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 5 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.

It is the opinion of the writer that the material found from 1,979- 2,556 was arkose.

CANADIAN ANTICLINE

The Canadian anticline is located in Tps. 21 and 22 N., R. 23 E., at the east end of the high lava-capped mesa which continues westward to the town of Eagon 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 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.

WAGON MOUND ANTICLINE

The Eagon Mound anticline, in Mora County, is about 8 miles south of the town of Eagon Mound, which is located on the main line of the Atchison, Topeka & Santa Fe railroad. 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-south, 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 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 SE.¼ NE.¼ 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 per cent carbon dioxide, at 1,420 to 1,425 feet, an additional flow estimated to be 2,000,000 cubic feet at 1,620 to 1,675 feet, and about 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.

Log of Arkansas Fuel Oil Co. Kruse No. 1 *Well*
SE. ¼ *NE.* ¼ *Sec.* 11, *T.* 19 *N., R.* 21 *E.*
Drilled, 1925-26

	Bottom, feet.
Lime, sandy hard	6
Lime, hard	51
Soapstone	71
Slate, white	90
Shale, pink	170
Lime, sandy, pink	230
Lime, pink	240
Lime, sandy, pink	245
Sand, white	247
Lime, sandy	275
Lime	325
Red rock	330
Lime, pink	355
Red rock	365
Lime, pink	385
Sand, pink	410
Lime	425
Red rock	440
Lime	460
Red rock	500
Lime, pink	505
Red rock	515
Red mud	520
Red rock	545
Red mud	550
Lime, pink	560
Red rock	620
Lime, pink	635
Red rock	660
Lime, pink	680
Red rock	690
Lime, pink	730
Lime, sandy	735
Red rock	745
Lime, pink	750
Red rock	950
Slate, blue	955
Lime, broken	965
Shale, blue	975
Red rock	1040
Lime, pink	1100
Lime, sandy	1105
Shale, gray	1120
Lime, gritty	1140
Lime, sandy	1160
Sand; *gas* estimated 500,000 cubic feet, noninflammable	1190
Shale, blue	1195
Sand, gray	1210
Sandy lime, gray	1225
Lime, gray	1230
Red rock	1275
Lime, brown	1278
Sandy lime, red	1290

	Bottom, feet.
Lime, red	1300
Shale, green	1305
Lime, sandy	1310
Slate, blue	1325
Slate, green, gritty	1330
Sand, gray, hard	1370
Lime, gray, hard	1385
Shale	1390
Lime	1412
Sand, hard, white	1420
Sand; *gas* estimated 12,000,000 cubic feet, non-inflammable	1425
Lime, sandy, and boulders	1438
Lime, blue	1440
Sand	1460
Lime, sandy	1465
Lime, hard	1470
Lime, hard, sandy	1475
Sand, hard	1508
Sand, hard, yellow	1515
Sand, hard, blue	1537
Lime, hard, blue	1540
Sand, yellow, close and hard	1550
Sand, hard, yellow	1598
Sand rock, hard, yellow	1603
Sand, hard	1607
Lime, sandy, gray	1620
Lime, sandy, sharp and gritty; *gas* at 1,670 feet estimated 2,000,000 cubic feet	1675
Lime, hard, sandy	1710
Lime, sandy; 2,000,000 cubic feet *gas* at 1,795 feet	1800
Sand, yellow	1808
Lime, sandy	1855
Lime, hard, red	1912
Lime, red, sandy	1955
Lime, red, with hard white shells	1975
Lime, hard, close, sandy	1995
Lime, red, very close	2050
Lime, hard, red	2070
Lime, hard, glassy red	2090
Lime, hard, red	2100
Lime, red with breaks of red shale	2130
Lime, broken, shale and shells	2170
Shale, broken, dark color	2190
Sand, gray and red	2195
Lime, broken and shale	2220
Lime, gray sandy; *gas* estimated 10,000,000 cubic feet	2225
Lime and sand, very hard	2240

	Bottom, feet.
Lime, sandy	2245
Lime, hard, sandy	2250
Lime, hard, gray, sandy	2256
Lime, hard, close, sandy	2276
Lime, hard, gritty, close	2300
Lime, close, hard, sandy	2308
Lime, pink, sandy	2312
Lime, hard, gray, sandy	2325
Lime, hard and glassy	2335
Lime, hard, pink	2341
Lime, red glassy	2358
Sand, very sharp; 4 to 6 barrels fresh water per hour	2361
Sand, sharp, gray, very close and hard, making 5 barrels water in 12 hours, 2358-61 feet	2370
Lime, sandy, hard, red	2390
Lime, red, sandy	2395
Lime and mica flakes	2400
Sand, yellow; water	2405
Lime, red, hard, glassy	2415
Lime, pink, granitic	2420
Lime, hard, red, sandy	2425
Shale, gray, soft.	2428
Lime, sandy	2431
Lime, hard, red, sandy	2448
Lime, sharp, hard	2460
Lime, red, sandy	2470
Sand, hard, red	2475
Lime, hard, red and gray	2480
Lime, hard, red glassy	2488
Lime, red, sandy	2495
Lime, hard, red glassy	2498
Lime, close, red, sandy	2505
Lime, pink, close, sandy.	2510
Lime, light pink, sandy; hole full of water, 1,000 feet of water at 2,513 feet	2515
Lime, hard, red, sandy	2520
Lime, red, sharp	2535
Lime, hard, red glassy	2605
Lime, hard sandy; total depth	2613

Note.—Formation 2,220-2,613 feet metamorphosed formations and fresh undisturbed granite, classified by drillers as "limes" and "sands" from its action on the drilling bits.

Early in 1931 the Santa Fe Diox Ice Co. started a second well on the structure in the northeast corner of sec. 14, T. 19 N., R. 21 E., and by July 1 a depth of 1,316 feet had been reached. It is the purpose of this company to develop a supply of carbon dioxide gas for the manufacture of solid carbon dioxide (dry ice) for refrigeration.

CHERRYVALE DOME

The Cherryvale dome, in San Miguel County, 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. It is bounded on the west by a north-south fault located about 2 miles west of the crest of the dome, which has a down-throw 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 the most of the area, except where deep canyons have cut through into lower formations, consisting of the Morrison, Wingate and the Dockum group. The structure is unusually large, with some 35 to 40 sections of land within the closing contour. In January, 1931, the Con-O-Kul Oil Co. began drilling a well in the NE ¼ sec. 34, T. 17 N., R. 21 E., and by July 1, had reached a depth of 973 feet.

CONCLUSIONS REGARDING THE SIERRA GRANDE UPLIFT

The Dakota sandstone and 2,000 feet of underlying strata have been tested on a number of local structures on the Sierra Grande arch. No oil has been obtained, but several of the wells have found non-inflammable gas which is largely carbon dioxide and which may be developed for the manufacture of solid carbon dioxide (dry ice). None of the test wells have been drilled deep enough to reach and test the Pennsylvanian, but several have reported granite. Most if not all of this so-called granite is probably redeposited granite or arkose, and sedimentary rocks may exist below the so-called granite which are well worth testing on some of the stronger structures.

A well being drilled on a small structure in the syncline between the Sierra Grande uplift and the main mountain uplift to the west intersected a good thickness of limestones and organic shales below the red-bed series. This well, Adams No. 3 of the Starr Oil Co. in sec. 25, T. 17 N., R. 16 E., topped the Dakota at 255 feet, passed out of the "Red Beds" at about 3,800 feet, and by the end of 1931 had reached a total depth of 5,092 feet after having passed through several hundred feet of limestone, organic shale, and some coal below a thick arkose series. (See log below.) This well is located only a few miles west of the Cherryvale structure and furnishes the best information available on the lower sedimentary section of the area.

Log of Starr Oil Co. Adams No. 3 *Well*
Sec. 25, *T.* 17 *N., R.* 16 *E.*

	Bottom, feet.
Lime, (Greenhorn)	20
Black shale	235
Sand and shale	260
Sand; water	395
Lime	420
Shale	435
Hard lime	525
Brown lime	535
Brown lime and sand	545
Brown sand; water at 560 feet (Dakota)	590
Red clay	620
Red sandy shale	635
Sand and shale	650
Water sand (Navajo)	665
Sand and lime	670
Hard lime	715
Lime and sand	725
Hard sandy lime	770
Gray shale	790
Dark red lime	800
Gray sandy lime	840
Soft brown sand	890
Red lime	1240
Red shale	1253
Red lime	1300
Gray shale	1410
Redshale	1435
Water sand	1445
Red shale	1450
Gray sand	1460
Gray sandy lime	1520
Red shale	1705
Gray lime	1715
Red shale	1765
Gray lime	1805
Hard gray sand.	1815
Red shale	1890
Red shale and lime shells	1910
Hard sandy lime	1920
Hard lime	1950
Hard white sand	1960
White sand	1980
Water sand	2000
Hard sand	2005
Soft gray shale	2050
Pink and purple shale	2055
Pink shale	2060
Pink and purple shale	2100
Gray shale	2135
Red rock	2180
Hard red lime	2300
Gray lime	2325
Dry sand	2340
Sand	2350
Hard gray sand	2502
Hard brown sand.	2543
Blue sand	2545
Hard white sand	2571
Hard, pure white sand	2575
Hard white sand	2577
Talc	2643
Lime	2655
Gray and red sand	2688
Red sandy shale	2722
Sand and red lime	2738

	Bottom, feet.
Red sand; *gas* and show of *oil*	2825
Red sandy lime	2960
Sandy pink (?)	2968
Sandy red tight (?)	3016
Sandy lime	3017
Sandy red tight (?)	3040
Water sand	3055
Tight sand	3070
White sand	3087
Hard lime	3090
Hard red sand; water	3120
Brown sandy lime	3134
Lime and sand	3180
Sandy lime and streaks of lime and shale; showing some *gas*	3260
Red shale	3270
Hard red lime	3304
Red sandy lime	3308
Hard gray lime	3316
Broken gray lime and red sand	3321
Hard brown lime	3329
Brown shale	3340
Red shale	3342
Red shale; showing of *oil* and *gas*	3362
Red sandy shale; showing of oil and *gas*	3375
Red shale; showing of *oil* and *gas*	3383
White sand; water	3390
Red sand; showing of *oil* and *gas*	3397
Water sand	3402
Red sandy shale; strong showing of *oil* and *gas*	3418
Broken white sand	3420
Red shale	3430
Hard lime, showing of *oil* and *gas*	3433
Hard brown lime	3436
Broken gray lime and red shale	3440
Lime and red shale	3455
Brown lime and red shale	3465
Hard brown lime	3468
Brown sandy lime	3478
Broken brown lime and red shale	3503
Red shale	3510
Red shale and broken lime	3517
Hard gray lime	3521
Hard gray lime and red shale	3523
Red shale	3528
Broken gray lime and red shale	3530
Hard blue lime	3538
Soft white chalky lime	3540
Red shale	3542
Broken lime and red shale	3568

Sample Log below 3568 *feet*

	Bottom, feet.
Light red shale	3580
Maroon limy shale	3605
Coarse arkose and maroon limy shale interbedded	3831
Maroon-purplish gray and black lime, sandy in places	4005
White quartz sand with feldspar and mica	4035
Purple to black micaceous lime	4137
Coarse gray to white arkose	4146
Gray to lavender and black lime, slightly micaceous	4191
Gray to black lime, sandy in places	4257
Brown lime	4280
Black lime, shaly	4330
Gray micaceous lime	4350
White quartz and mica (arkose)	4361
Gray micaceous lime	4407
Gray arkose	4427
Dark gray to black micaceous lime	4467
Reddish shaly lime	4472
Black to gray micaceous lime	4508
Gray lime	4583
Black shaly lime and black coal	4615
Black to gray shaly lime	4690
White quartz sand with some black shaly lime	4712
Gray lime	4758
Black shaly lime, some coal	4789
Dark gray lime	4850
Light brown lime	4875
Dark gray lime, trace of coal	4878
Gray to white lime	4935
White arkose	4975
Gray micaceous lime with arkose	5026
Black mica sand	5028
Gray quartz sand	5030

Sweet gas, estimated 250,000 cubic feet at 4,680-4,780 feet; increase of gas at 4,975 feet.

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 figure 4.) The "Park," in which the apex of the structure is located, is reached by a 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 a slightly elongated upfold 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. (See figure 5.) 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 of the structure 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 northeast corner SE.1/4 sec. 25, T. 31 N., R. 18 E., and was located some 400 feet structurally down from 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 Calif. 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 at the bottom 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 hearing. However, the problem of locating a proper place to drill is left to theory, aided possibly by evidence obtained by geophysical instruments.

TURKEY MOUNTAIN DOME

Turkey Mountain, about 10 miles west of Wagon Mound in Mora County, is a conspicuous landmark of the area. Sedimentary formations are upturned on all sides forming a prominent dome. Darton[1] describes the geology of the structure in the following words.

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. Apparently the underlying rocks are not revealed.

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[1] Darton, N. H., "Red Beds" and associated formations in New Mexico: U. S. Geol. Survey Bull. 794, p. 271, 1928.

In the section (see figure 6, below) the shales a and c and the included sandstone b appear to belong to the Dock group. The sandstone d is nearly 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 e is typical Morrison shale, and the sandstone f, although in one thick body, probably represents both Purgatoire and Dakota. * * *

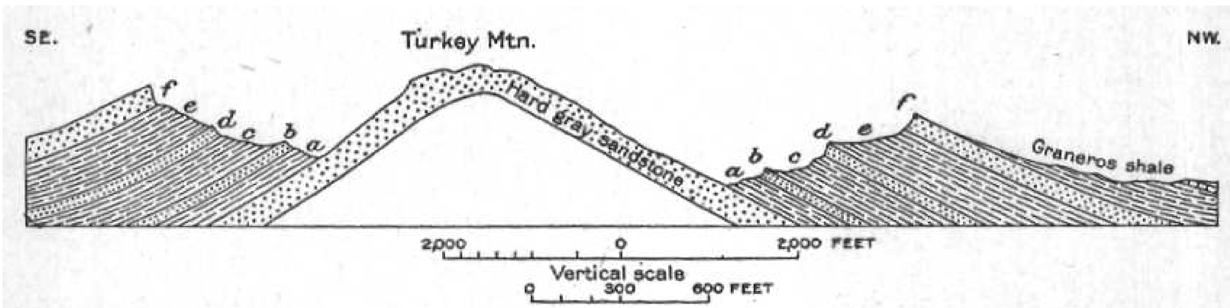


Figure 6. Section through Turkey Mountain, 10 miles west of Wagon Mound. a, Red shales grading down into gray sandy shale; b, hard gray sandstone; c, dark-red shale and red sandstone, mostly soft; d, hard light-colored massive sandstone; e, greenish-gray shale; f, hard gray massive sandstone (Cretaceous). (Courtesy of U. S. Geological Survey.)

ESTERITO DOME

The Esterito dome is an elongated domal structure in the eastern part of the Anton Chico Grant in Guadalupe County. The surface rocks are resistant sandstones and soft shales of the Chupadera formation, 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, figure 7.)

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 made by the writer of the log of the well and cuttings from the so-called granite suggests 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.

EASTERN SAN MIGUEL COUNTY AND ADJACENT AREAS

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 XXIII. 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

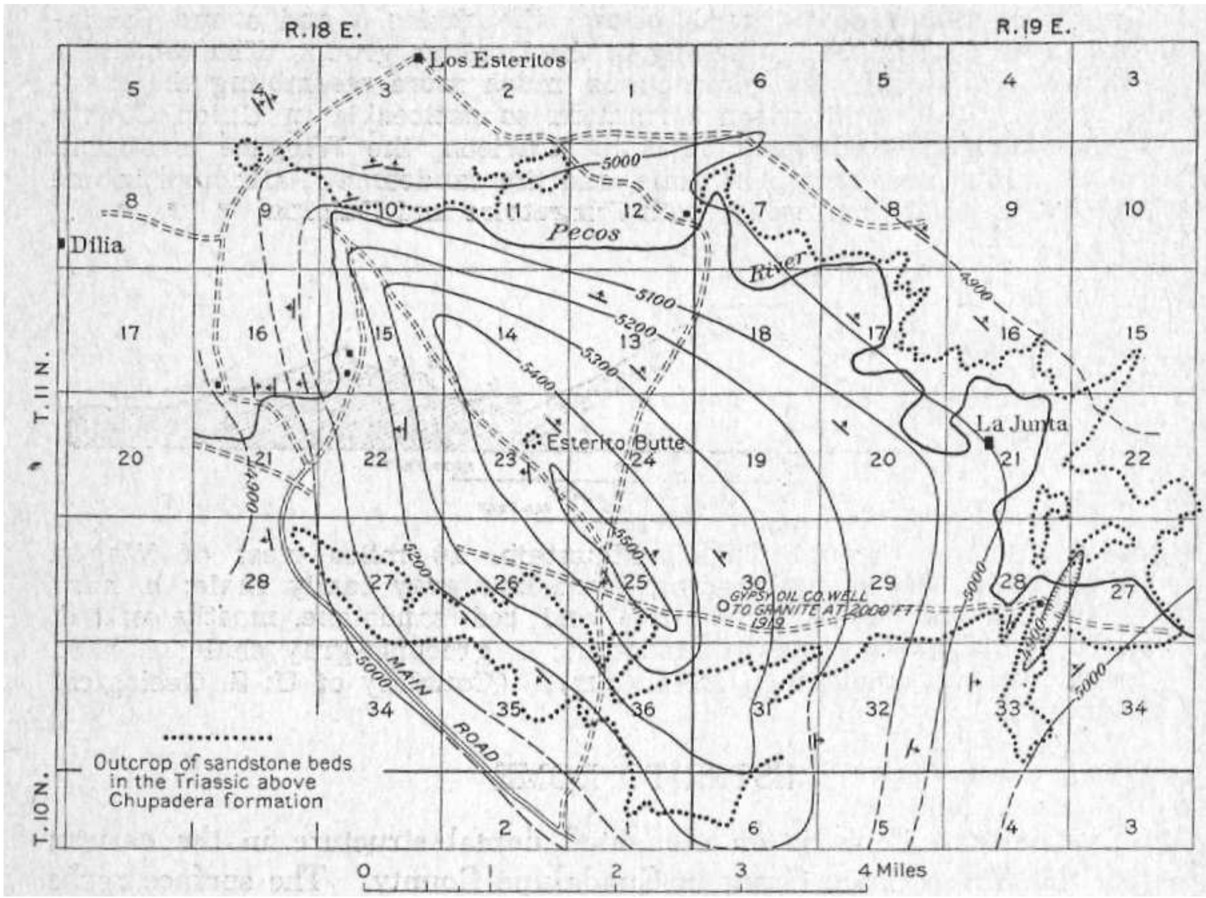


Figure 7. Map of Esterito dome. By Messrs. Newby, Garrett, Crabtree and Wright for the Gypsy Oil Co. (Courtesy of U. S. Geological Survey.)

part of the area, while a branch line of the Southern Pacific railway extends northward from Tucumcari to Mosquero and the coal mining town of Dawson, in the Raton Basin.

GEOLOGY

This general area is located east of the Rocky Mountain uplift, south of the Sierra Grande uplift, and in the general synclinal area between these major structures and the Amarillo uplift (in Texas) to the east. A careful study of the structures in this area 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 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 208.) 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 a zone of red shales, thin red sandstones and dolomite beds having a total thickness of 520 feet. Above the Eingate 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.

The formations from the top of the Wingate sandstone to a depth of 4,990 feet have been explored by a test well drilled by the Marland Oil Co. of Colo. on the Rattlesnake anticline in sec. 3, T. 13 N., R. 29 E. This well, which was completed in 1926, stopped in granite wash or arkose, and the log shows only one thin limestone stratum near the bottom of the hole.

Log of Marland Oil Co. of Colo., *Bell Ranch No.* 1 *Well*
NW ¼ SW.¼ Sec. 3, *T.* 13 *N., R.* 29 *E.*
Drilled, 1925-26

	Bottom, feet.		Bottom, feet.
Surface mud	13	Red rock and shale	2210
Red sand	180	Salt and sand	2420
Sand	240	Sand and salt	2490
Red sand	320	Hard gray lime	2602
Red mud	400	Pink sandstone	2612
Red rock	785	White sandstone	2630
Red sand; fresh water	820	Pink sand	2660
Sandy green shale	840	White sand	2720
Sandy gray shale	860	Sand and lime	2725
Sandy red shale	880	Hard lime	2770
Red rock	960	Hard red lime	2790
Gray and red streaked sandstone	975	Red lime and shale	2830
White sandy lime	1020	Red lime	2880
Red sandy shale	1170	Red sandstone and lime	2960
Gray sand; hole full of salt water	1205	Sand; water	3080
Hard lime	1245	Red lime and shale	3100
Red shale, very cavey	1360	Red sandy shale	3180
Red and green shale	1390	Red shale, pink sand; water	3230
Gray sand; hole full of water	1400	Hard lime	3255
White sand	1430	Pink sand	3470
White sand and red and green shale	1440	Red lime	3495
Gray sand	1460	Red sand	3510
Red and gray sand	1520	Red sandy lime; show of *gas* 3,545 feet	3554
White sand	1540	Red shale	3600
Blue and gray shale and sand	1600	Sandy arkose; water at 3,603 feet	3615
Gray and red sand	1640	Red sandy shale	3660
Red rock	1710	Red shale	3695
Red shale	1850	Sandy arkose	3715
Red sandy shale-	1880	Red shale	3730
Red rock and shale	1900	Sandy arkose	3745
Gypsum and red rock	1940	Red shale	3755
Broken lime	1955	Red sandy shale	3795
Brown shale	1970	Red sandy arkose	3885
Lime and shells	1975	Red shale	3965
Gray lime	2106	Sand; water	3970
Gray sand; good flow of salt water	2118	White sand	3988
Mixed lime and shale	2173	Shale	4002
		Sandy shale	4012
		White sand	4019

	Bottom, feet.
Brown shale	4021
White sand	4052
Brown shale	4056
Brown sand	4076
Brown shale	4080
Brown sand	4095
Brown shale	4100
Brown sand; hot water up 2,500 feet	4126
Shale	4175
Lime	4179
Brown shale	4182
Hard shell	4186
Brown shale	4202
White sand; 2 barrels water per hour	4209
Brown shale	4235
Sand, white	4360
Brown sandy shale	4380
White sand	4460
Dark brown sand	4480
Black shale	4482
Brown sand	4525
White sand	4610
Brown sand	4690
Black lime	4692
Brown sandstone	4756
Brown lime	4770
Brown sandy lime; total depth	4990

Note.—From 3,540 to 4,990 feet the major portion of the material was granite wash.

STRUCTURE S

A brief description of the principal anticlinal structures so far mapped in eastern San Miguel County and adjacent areas follows. (See the State map, Plate XXIII.)

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 FARM ANTICLINE

A horseshoe-shaped structure known as the Bell Farm 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 approximately 5,100 acres.

CANADIAN ANTICLINE

A small, irregular-shaped 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.

CARPENTER 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 2$^1/2$ square miles.

DIVIDE ANTICLINE

A very prominent anticline trending north and south 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.

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-southeast, with the high point in the N.1/2 sec. 25, T. 13 N., R. 31 E. The anticline has a closure of nearly 100 feet and an area of approximately 6 square miles within the lowest closing 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.

HUDSON ANTICLINE

This is a relatively low irregular domelike structure, the high point being located in the SE.1/4 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.

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, and the Wingate, Morrison and Dakota formations are exposed in the immediate vicinity. The crest of the dome is in secs. 15 and 28, T. 12 N., R. 28 E. The fold has a closure of 250 feet.

MEDIA ANTICLINE

The Media anticline is a long north-south 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 3 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 the southern part of T. 12 N., Rs. 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 closure located in secs. 27, 34 and 35, T. 14 N., R. 29 E.

PINO MESA ANTICLINE

This elongated east-west fold, known as the Pino Mesa anticline, is located in T. 12 N., R. 22 E. (See map, Plate XXI.) 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. Pino Mesa, rising 300 feet or more above the general level of surrounding country, occupies the heart of the structure. In 1930 the Hershfield Drilling Co. began a well in the NE.% sec. 21, T. 12 N., R. 22 E., and on July 1, 1931, it had reached a depth of 1,415 feet.

RATTLESNAKE ANTICLINE

This structure is located on a general northward-trending plunging anticline and has its high point near the southwest corner sec. 3, T. 13 N., R. 29 E. The local closure amounts to about 75 feet. The Wingate sandstone and Upper Dockum group shales are the surface rocks.

The Marland Oil Co. of Colo. 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. The well started a few feet above the Wingate sandstone. (See log, pages 129 and 130.)

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 NE. 1/4 sec. 19. The closure amounts to between 75 and 100 feet and the closed area is about 2,000 acres.

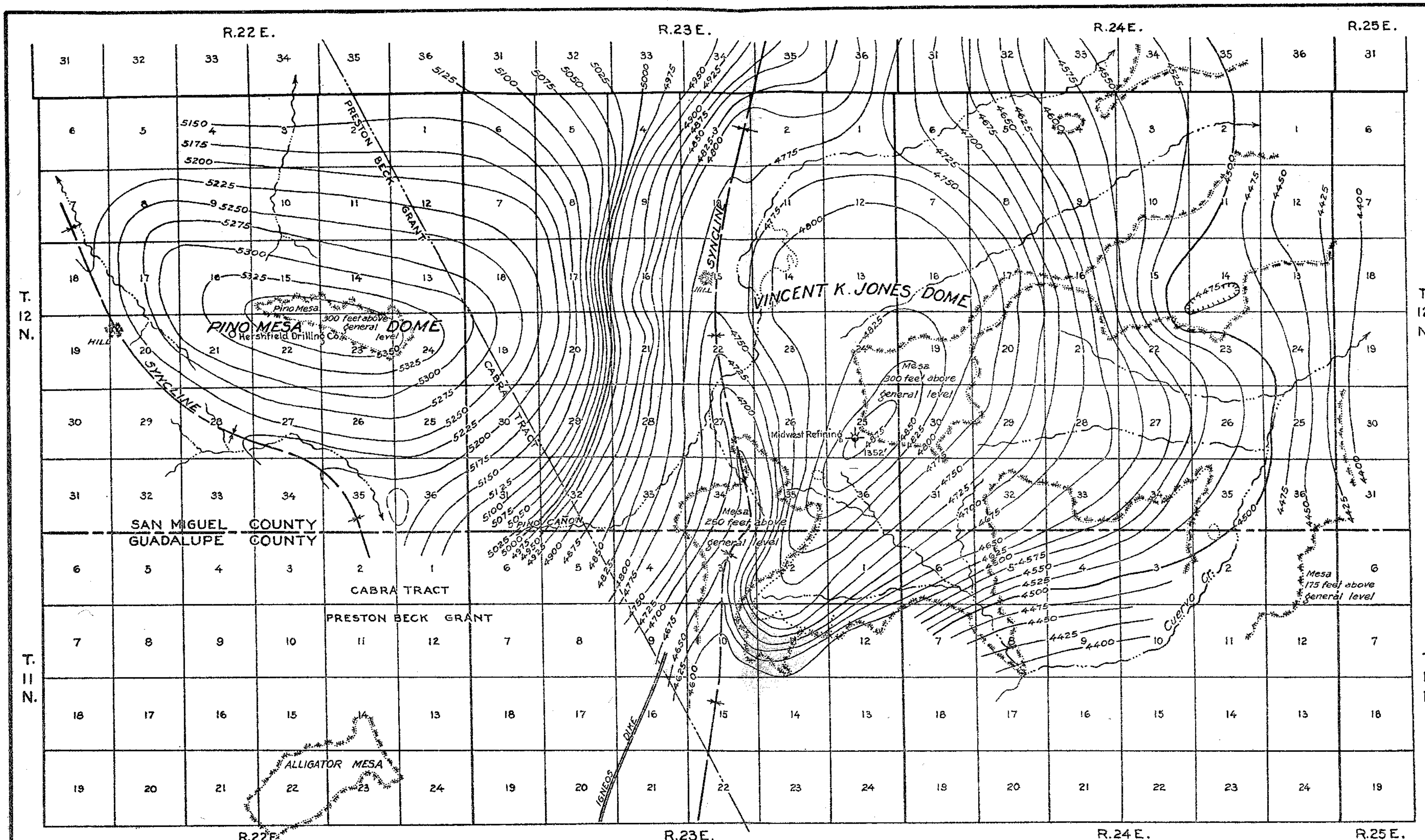
V. K. JONES DOME

This structure is pear shaped in outline. Its axis trends northeast-southwest, and the crest is in sec. 25, T. 12 N., R. 23 E. (See map, Plate XXI.) The structural closure amounts to approximately 100 feet and the enclosed area about 14 square miles. The dome is separated from the Pino Mesa anticline to the west by a syncline located in secs.].0, 15, 22, 27 and 34, T. 12 N., R. 23 E. On the synclinal axis in sec. 15, T. 12 N., R. 23 E., 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 SW.',4 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.

STRUCTURES IN SOUTHERN QUAY COUNTY

GENERAL FEATURES

The sedimentary rocks in southern Quay County have been considerably folded and somewhat faulted (see map, Plate XXII, by E. M. Parks), and structural conditions have given rise to the hope that oil or gas might be present in commercial quantities. Several deep wells have been drilled, but up to this time no commercial production has been



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

4725 4700 STRUCTURE CONTOURS, INTERVAL 25 FEET

CONTOURS ON CONGLOMERATE 500 FT. ABOVE SANTA ROSA SANDSTONE

MAP OF

VINCENT K. JONES & PINO 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

found. Additional detailed investigations may find more promising areas than those already drilled, and deeper exploration is probably warranted on some of the structures that have been drilled.

The north rim of the Llano Estacado is located about 20 miles south of Tucumcari. To the south of the rim all underlying sedimentary beds are obscured by surface deposits of caliche and soil (Ogallala formation). North of the rim, however, older rocks are fairly well exposed, and geologic structure can be studied to advantage. In this area the Purgatoire formation and underlying Wingate sandstone form steep cliffs bordering high mesas, with the underlying red shales and thin sands forming the surface of the lower lands.

The correlation of subsurface formations in this area with formations in other areas of eastern New Mexico is unsettled. Conditions of deposition were evidently quite different here from conditions prevailing during the same period in the great Permian salt basin to the south. Evidence furnished by the logs of deep wells of this area show that quite different rocks were laid down in areas only a few miles apart. Salt appears to have been deposited at numerous horizons, but in no place is there a great thickness of salt at any one horizon. To the north in San Miguel County, as shown by the log of the Marland Oil Co. Bell ranch well, great thicknesses of arkose (granite wash) were laid down at apparently the same time that limestones, shales and sandstones were being deposited to the south.

The following correlations of key horizons in five wells of the area are suggested.

Tentative Correlations of Sub-surface Formations in Quay and San Miguel Counties

Horizon.	Well A. Depth, feet.	Well B. Depth, feet.	Well C. Depth, feet.	Well D. Depth, feet.	Well E. Depth, feet.
Wingate sandstone.	0-80		0-190		0-320
Santa Rosa sandstone.	405-550	380-895	1,330-1,615	470-600	785-975
San Andres limestone.	2,455-2,750	2,330-2,580	3,055-3,310	3,200-3,575	2,490-2,880
Glorieta sandstone.	2,750-2,825	2,720-2,800	3,500-3,570	3,685-3,855	2,960-3,080
Total depth of well.	3,502	3,650	5,204	4,014	4,990

A. Gibson Oil Co. Parks No. 1 Well, sec. 25, T. 8 N., R. 32 E.
B. Midwest Refining Co. Rhodes No. 1 Well, sec. 30, T. 8 N.. R. 31 E.
C. Ohio Oil Co. Wells No. 1 Well, sec. 24, T. 7 N., R. 29 E. (See pp. 134-137).
D. Tucumcari Oil & Gas Co. McGee No. 1 Well, sec. 27, T. 10 N., R. 31 E.
E. Marland Oil Co. Bell Ranch No. 1 Well, sec. 3, T. 13 N., R. 29 E. (See pp. 129, 130.)

BENITA ANTICLINE

One of the conspicuous structural features of the area shown on the map, Plate XXII, is the great Benita fault, in the eastern part of the area. This fault has a downthrow on the north of some 500 feet and trends in a general northeast-southwest direction, passing beneath recent caliche deposits of the high plain near the north line of T. 7 N., R. 32 E. South of the fault the strata are domed against it. 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 production was found and the well was abandoned without reaching the base of the sedimentary series.

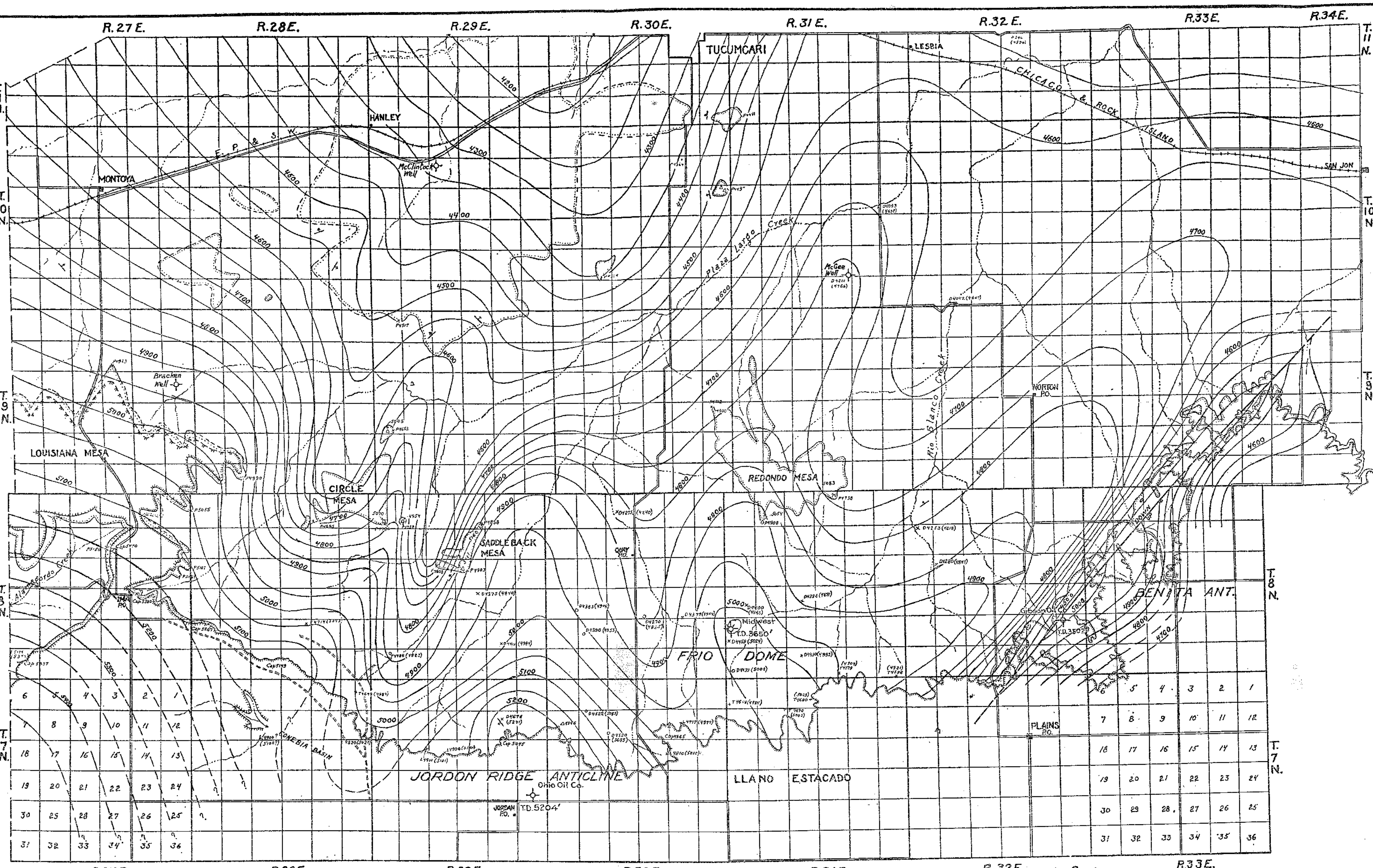
JORDAN RIDGE ANTICLINE

The Jordan Ridge anticline (see map, Plate XXII) 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 (caliche and sand).

About the same time that the test was made at the Benita anticline, 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.

Log of Ohio Oil Co. *Samuel A. Wells No.* 1 *Well*
SW. Cor. SE.¼ Sec. 24, *T. 7 N., R.* 29 *E.*
Drilled, 1926-28

	Bottom, feet.
Soil and white lime	20
Brown sand	190
Gravel	205
Red beds	400
Red shale	440
Red rock	470
Hard red rock	500
Sandy red rock; one barrel water per hour at 525 feet	550
Hard red shale	590
Red sandy shale	635
Red sand rock	650
Red shale	660
Red sandy hard shale	705
Brown shale	715
Red rock	725
Gray sand; 5 barrels water per hour at 733 feet.	743
Red rock	755
Red rock and sand	790
Red rock	795
Brown shale	805
Brown sandy shale; one bailer salt water at 845 feet	845
Blue shale	860
Red beds	1005
Red rock	1030
Blue sandy shale	1060
Brown sandy shale	1095
Sand	1100
Red sandy shale	1140
Red beds	1330
Gfay sand and lime shells (Top of "Santa Rosa")	1340
Gray sand and lime	1360
Light gray sand	1385
Gray sand and hard lime	1390
Gray sand and lime	1415
Light gray sand and lime	1430
Light gray sand and hard lime	1432
Soft blue shale	1434
Light gray sandstone and hard lime	1438
Gray shale	1440
Hard gray sand	1455
Soft gray sand	1465
Gray sand and lime; show of salt water at 1,478 feet	1478
Gray sand; show of salt water at 1,483 feet	1483
Light gray sand	1486
Gray sand	1527
Blue shale	1540
Rusty fine sand	1550
Sand; 1500 feet water in hole.	1590
Sandy shale	1600
Sand	1615
Breaks	1635
Red beds	1655
Hard sandy red beds	1690
Soft red beds; water at 1,700 feet	1700
Red beds	1740
Red beds and gypsum	1758
Gray shale and gypsum	1766
Salt	1782
Sandy red beds	1788
Gray shale and gypsum	1795
Gray shale and salt	1798



EXPLANATION

TERTIARY CAPROCK — BASE OF PURGATOIRE

Δ5470 TRIANGULATION ELEVATION — 5050/5000 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

0 1/4 1/2 1 MILE 2 3 4 5 6 7 MILES 8

E. M. Parks
Denver, Colo.
June 4-20, 1925.
April 23-May 17, 1926

MINOR ADDITIONS
BY
DEAN E. WINCHESTER
JUNE 1, 1931

	Bottom, feet.
Salt	1820
Gypsum	1830
Salt	1858
Red beds	1865
Sandy red beds	1905
Soft sandy red beds	1916
Salt	1951
Salt and gray shale	1963
Red beds	2006
Red beds, sandy	2010
Soft red beds	2020
Red beds	2030
Red beds, sandy and hard	2044
Red beds and broken salt	2070
Sandy red beds	2110
Red beds	2150
Salt	2200
Red beds	2250
Hard sand	2168
Salt	2260
Salt and red shale	2280
Salt and anhydrite	2290
Salt and red shale	2295
Salt	2300
Anhydrite	2370
Broken shale	2378
Salt	2400
Brown shale	2409
Anhydrite	2413
Salt	2418
Anhydrite	2420
Red beds	2429
Red beds and anhydrite	2442
Anhydrite and salt	2449
Salt	2475
Anhydrite	2490
Gray anhydrite	2500
Anhydrite and lime	2510
Hard lime	2515
Salt	2525
Blue shale and anhydrite	2535
Gray shale	2542
Gray shale and anhydrite	2580
Gray anhydrite	2600
Shale	2605
Gray lime	2615
White sand	2627
Anhydrite	2640
Anhydrite and gray shale	2665
Anhydrite and gray lime	2675
Anhydrite and shale	2681
Salt	2742
Gray lime	2742
White sand	2765
Gray lime, sand and anhydrite	2775
Anhydrite and hard sand,,	2805
Brown lime	2820

	Bottom, feet.
Brown lime and anhydrite	2824
Gray sandy lime	2831
White sand	2837
Brown lime	2855
Brown lime, gray shale, salt	2863
Salt	2870
Salt and black shale	3054
Gray sandy lime	3068
Hard brown lime	3092
Brown lime and anhydrite	3113
Gray lime	3130
Gray sandy lime	3136
Brown lime	3150
Brown lime, hard	3165
Water	3170
Brown lime	3181
Brown lime and anhydrite	3193
Brown lime	3206
Brown lime, lighter	3225
Brown lime	3235
Dark brown lime and anhydrite	3242
Light brown lime and anhydrite	3252
Brown lime	3260
Sandy lime	3280
Lime and sand	3300
Sandy lime	3310
Anhydrite and gray shale	3325
Gray shale	3330
Shale, anhydrite and salt	3335
Salt	3400
Red sand	3410
Salt, anhydrite, shale and sand	3435
Brown shale	3445
Salt	3450
Salt and anhydrite	3460
Sandy lime	3465
Salt, shale, sand and anhydrite	3500
Sandy brown shale	3520
Red beds, hole caving	3530
Brown shale	3543
Brown sand	3549
Brown sandy shale	3570
Brown shale	3580
Brown shale, some salt	3600
Brown sandy shale and salt	3628
Brown shale	3678
Brown shale and salt.	3688
Brown salt	3690
Salt, anhydrite and gypsum	3698
Brown shale, gypsum and salt	3827
Salt and brown shale	3847
Salt, brown shale, gypsum shells	3862

	Bottom, feet.
Anhydrite and gypsum	3870
Anhydrite, gypsum and salt	3875
Anhydrite, gypsum salt and brown shale	3883
Anhydrite and gypsum	3900
Gypsum	3905
Gypsum, anhydrite and sand	3925
Sand	3940
Anhydrite	3960
Fine hard sand	3975
Anhydrite and gypsum	3980
Anhydrite and gypsum shells	3990
Red hard sand	4003
Red sand and shale	4010
Broken red sand	4020
Broken sands	4030
Red sand	4049
Sand	4051
Shale	4060
Hard red sand	4062
Red shale	4065
Hard red sand	4076
Broken sandy shale	4085
Sand and shells	4092
Shale	4105
Sandy shale	4113
Broken sand	4123
Sandy shale	4126
Broken sand	4135
Sandy shale and gypsum	4145
Red shale and shells	4149
Red shale	4160
Shale, shells and anhydrite	4170
Shale and shells	4178
Hard red sandy lime	4184
Sandy shale and lime shells	4203
Red shale	4238
Shale and shells, red	4256
Red shale	4270
Red sandy shale	4273
Shale and lime shells	4293
Red sandy shale	4300
Shale and lime shells	4310
Sandy shale and gypsum	4319
Anhydrite, gypsum shells and brown shale	4324
Sand, brown shale and shells	4336
Brown shale and gypsum	4344
Brown sandy shale	4349
Brown sandy shale and gypsum	4361
Sandy red shale	4366
Red shale and lime shells	4373
Red shale	4388
Red shale and gypsum	4406
Red shale	4434

	Bottom, feet.
Red sandy shale	4448
Red shale	4468
Red shale and shells	4473
Red shale	4487
Red shale and shells	4492
Red shale and gypsum	4502
Gypsum and sandy shells	4511
Red shale	4560
Red shale, sand, shells	4569
Red shale	4574
Red shale and shells	4581
Red shale	4641
Red shale and salt	4654
Red shale and shells	4658
Gray lime	4668
Blue shale	4672
Gray lime	4675
Gray lime and anhydrite	4678
Blue shale	4681
Gray lime	4684
Blue shale	4686
Gray lime	4688
Blue shale and lime shells	4693
Gray lime	4696
Shale	4698
Blue shale and lime shells	4715
Hard gray lime	4726
Shale	4738
Hard gray sandy lime	4764
Lime	4766
Shale and broken lime	4772
Brown lime	4783
Sandy shale and broken lime	4795
Broken lime	4803
Lime	4806
Sandy shale and lime shells	4813
Sandy shale	4819
Hard red sand	4828
Fine sand	4843
Brown sand	4852
Shale and broken shells	4856
Sandy lime	4860
Broken sand	4865
Gray lime	4868
Sandy shale	4876
Red shale and shells	4884
Red shale	4896
Red and blue shale	4928
Red shale and broken lime	4936
Shale	4990
Broken shale and lime	5015
Shale and salt	5040
Broken shale	5065
Sandy shale	5070
Fine sand	5080
Salt, anhydrite and shale	5100

	Bottom, feet.		Bottom, feet.
Gray shale and salt	5105	Brown shale	5185
Salt	5111	Brown sand; water	5190
Anhydrite	5117	Dark brown sand; more water; total depth	5204
Gray shale and anhydrite	5132		
Blue shale	5176		

FRIO DOME

The Frio dome (see map, Plate XXII) is more completely exposed than the Jordan Ridge anticline, and more detailed study since the work of Parks shows this dome to have a closure of approximately 125 feet and a closed area of perhaps 11,500 acres.

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 this structure deserves a complete test and that the 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.

The area is traversed by good roads and is easily reached from Tucumcari, 20 miles north of the Frio dome, on the Chicago, Rock Island & Pacific railroad.

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 XXIII. Detailed data for most of these structures is not available, and they are therefore listed in the table, page 138, together with such information as is at hand regarding their size, shape, surface formations and results of drilling.

Miscellaneous Structures in the Northeast Area

Name.	Location.			Surface Formation.	Remarks.
	T.-N.	R.-E.	County.		
Baca anticline.	21	30	Harding.	Dockum.	Broad, low anticline; 3,654,000 cubic feet carbon dioxide gas in Santa Rosa sand, found by one well drilled.
Cimarron Valley anticline.	31	36	Union.	Jurassic.	Very small anticline; 30 feet of closure.
Clapham anticline.	22	34	Union.	Dakota.	
Graham anticline.	17	16	San Miguel.	Benton sh.	Very small domal uplift; Starr Oil Co. drilling at 5,093 feet July 1, 1932. See log, pp. 124, 125.
Guadalupe anticline.	9-10	19	Guadalupe.	Dockum.	100 feet of closure.
Las Vegas dome.	17	17	San Miguel.	Dakota.	
Logan anticline.	13	34	Quay.	Triassic.	Well drilled to 3,380 feet in 1926; dry.
Mesa Leon anticline.	5-6	16-17	Guadalupe.	Triassic.	300 feet of closure, large structure; well drilling at 4507 feet, July 1, 1932.
Nuevo anticline.	12	14-15	San Miguel.	Permian.	Plunging anticline, no closure.
Pasamonte anticline.	23-25	30	Union.	Dakota.	100 feet or less of closure; well 2,761 feet reported granite.
Perico anticline.	26	33	Union.	Dakota.	Small domal uplift; 50 feet of closure.
Ribera anticline.	13	14	San Miguel.	Permian.	Small elongated structure; less than 100 feet of closure.
Romero anticline.	15	16	San Miguel.	Dakota.	
Salado anticline.	4-5	20	DeBaca.	Permian.	Irregular domal structure; possibly 200 feet of closure; well drilling at 4662 feet, July 1, 1932.
Santa Rosa anticline.	8	22	Guadalupe.	Triassic.	
Sierra Negra anticline.	19-20	31	Harding.	Triassic.	
Spalding dome.	6-7	25	DeBaca.	Triassic.	Well drilled to 3,820 feet; dry.
Tate anticline.	23-24	33	Union.	Dakota.	70 feet of closure.

SOUTHEAST AREA

GEOGRAPHY AND GENERAL GEOLOGY

Geographically and geologically the southeastern part of the State, south of the Belen "cut-off" of the Atchison, Topeka & Santa Fe railway and east of the Sierra Blanca and Sacramento Mountains may be considered as a unit. The area includes the broad Pecos Valley and the Llano Estacado to the east. It is drained by the Pecos River and its tributaries.

In most of the area west of the Pecos River the surface rocks belong to the Chupadera formation. The structure is monoclinal and the beds dip eastward at small angles. The Sacramento Mountains, which are part of this monocline, are capped by the Chupadera formation, but in the steep westward-facing escarpment are exposures of the Magdalena (Pennsylvanian) and older Paleozoic formations. These formations dip eastward and some of them may underlie a considerable part of the Southeast Area. The Guadalupe Mountains are a southeastward extension of the Sacramento Mountains and have the same monoclinal structure.

East of the Pecos River the surface rises gradually in more or less broken forms to the foot of the "Caprock," which forms the westward rim of the Llano Estacado. In this area the outcropping Chupadera formation and overlying Triassic "Red Beds" dip eastward at low angles and continue to the east under the Llano Estacado. The Chupadera formation is chiefly limestone, but the "Red Beds" consist of sandstone, shale and gypsum. Much of the surface is covered with windblown sand.

The Llano Estacado is an essentially flat plain sloping gently to the east. The surface rocks consist of gravel and sand of the Ogallala formation (Tertiary) and recent sands and caliche deposits. The "Caprock" rim, which bounds it on the west, enters the Southeast Area near the west line of Roosevelt County and continues as a conspicuous cliff to the southeast corner of Chaves County, from which point it turns southeastward. Beyond the Lea pool in the northeast corner T. 21 S., R. 33 E., it becomes less conspicuous, almost disappearing as a topographic feature at the southeast corner of the State.

The Southeast Area is a part of the great Permian Basin which extends far eastward and southward into Texas. In the deepest part of the basin near the southeast corner of Eddy County, N. Mex., there is an enormous thickness (more than 2,000 feet) of salt, and in places considerable thickness of rich potash salts are found in the salt ("Evaporite") series of the upper Permian. Sediments older than the salt series are brought to the surface along the east side of the mountains which form the western border of the basin. Salt deposition in Permian time appears to have been limited essentially to that part of-the basin east of the Pecos River. In the northern part of the area salt occurs in relatively thin beds separated by sand, lime and anhydrite.

Because of the inclusion of considerable thicknesses of valuable potash salts in the "Evaporite Series," careful attention has been paid to the thickness and composition of the series during the past few years. The most comprehensive report published on this phase of the stratigraphy of the Permian Basin is that by Hoots. [1] His report gives numerous correlated well sections and two highly interesting maps. One map shows, by contours on the top of the salt, the general structure of the Permian Basin, and the other by contours the thickness of the salt in various parts of the basin. Since the publication of this report a vast amount of information in the form of well logs has been accumulated, but the general conclusions remain with but little change.

Geologists involved in the search for oil and gas in the Permian Basin have found the stratigraphy of the area to be complicated by more problems than perhaps in any other area. One of the most frequented spots in the area is in the Guadalupe Mountains near the south line of the State, where the formations are well exposed, yet few geologists agree upon the meaning of evidences there exposed. One will find nearly as many opinions regarding the meaning of certain evidences as there are geologists who have studied the problems. Furthermore, in that part of the area east of the Pecos River particularly, the student of geologic structure is severely hampered by lack of surface exposures. A great amount of wildcat drilling has taken place in this area within the past few years, and it is now more nearly possible to answer many of the questions of structure than before.

Because of the limited time available for studies in this area the writer has been forced to depend upon the views of geologists who have spent long periods in studying the area, published reports and the data supplied by the drillers' logs of wells put down. Actual cuttings from the rocks penetrated by the drill in many of the wells are available, but it was not possible to study this line of evidence, although it was realized that its use would have made possible the painting of a much more accurate picture.

The geologic formations of the Southeast Area are summarized in the table, page 142.

Drilling in Lea County has not explored the formations below the upper part of the San Andres limestone. In the Artesia field a few holes have penetrated 1,000 to 1,500 feet of the San Andres. Eest of the Pecos on structures near the mountains two or three holes have explored the Yeso, Abo and Magdalena formations.

The detailed character of the lower part of the Triassic and the underlying Permian beds down to the top of the San Andres limestone as determined in the Hobbs field in eastern Lea County are shown on Plate XXV, page 146, and discussed in connection with the description of the Hobbs field, pages 154-168. The underlying San Andres limestone is discussed by Blanchard and Davis [2] as follows:

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[1] Hoots, H. W., Geology of a part of western Texas and southeastern New Mexico with special reference to salt and potash: U. S. Geol. Survey Bull. 780, pp. 33-126, 1925.

[2] Blanchard, W. G., and Davis, M. J., Permian stratigraphy and structure of parts of southeastern New Mexico and southwestern Texas: Am. Assoc. Petroleum Geologists Bull. vol. 13, No. 8, p. 971, 1929.

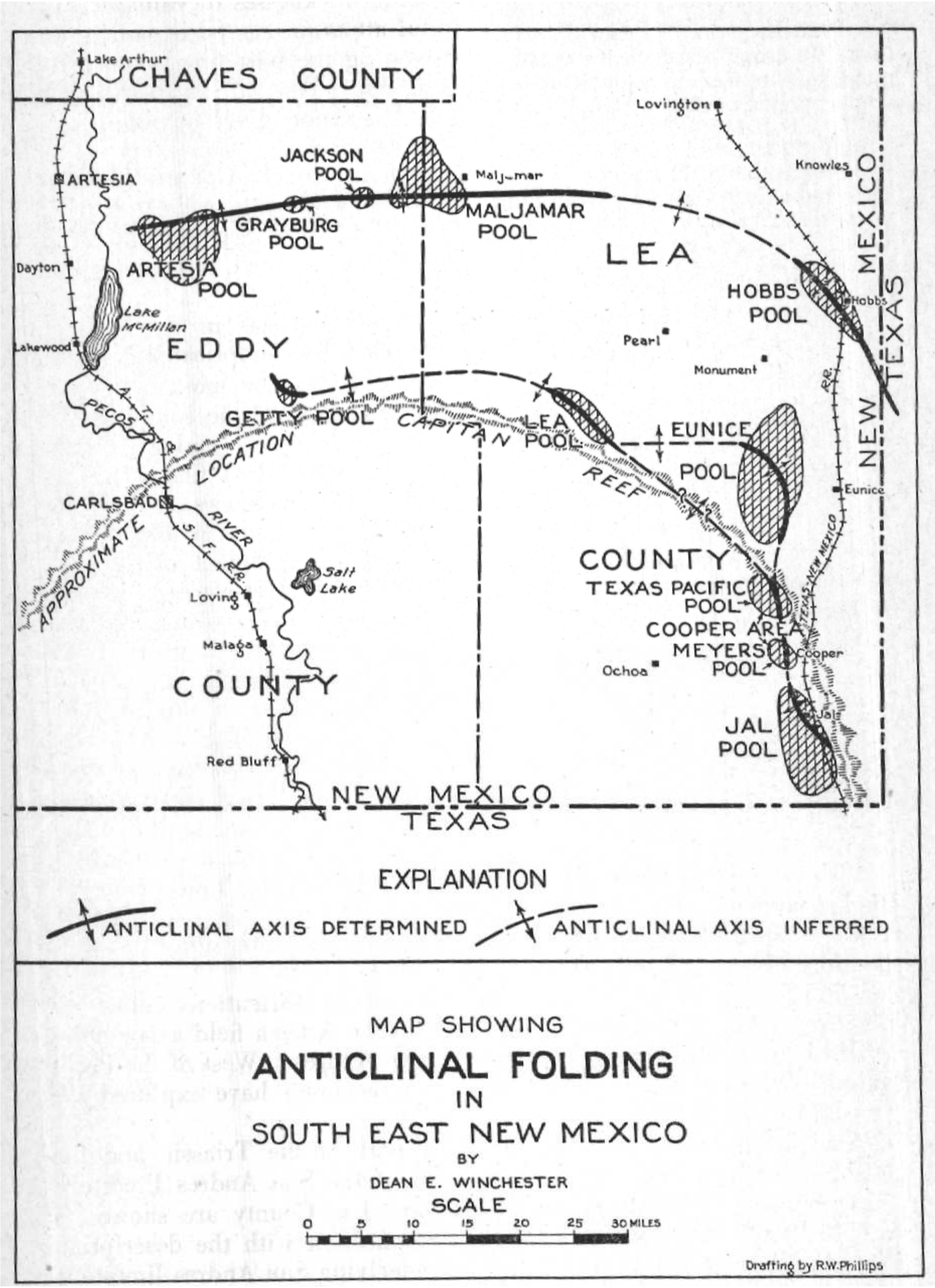

CHAVES COUNTY
Lake Arthur
ARTESIA
Dayton
Lakewood
Lake McMillan
JACKSON POOL
GRAYBURG POOL
ARTESIA POOL
Maljamar
MALJAMAR POOL
Lovington
Knowles
LEA
HOBBS POOL
Hobbs
Pearl
Monument
EDDY
GETTY POOL
LEA POOL
EUNICE POOL
Eunice
APPROXIMATE LOCATION CAPITAN REEF
PECOS RIVER
CARLSBAD
Salt Lake
Loving
Malaga
COUNTY
TEXAS PACIFIC POOL
COOPER AREA
MEYERS POOL
Cooper
Ochoa
JAL POOL
Jal
Red Bluff
NEW MEXICO
TEXAS
EXPLANATION
ANTICLINAL AXIS DETERMINED
ANTICLINAL AXIS INFERRED
MAP SHOWING
ANTICLINAL FOLDING
IN
SOUTH EAST NEW MEXICO
BY
DEAN E. WINCHESTER
SCALE
0 5 10 15 20 25 30 MILES
Drafting by R.W.Phillips

Figure 8.

In the vicinity of Roswell, New Mexico, the maximum thickness of the San Andres is known in subsurface where it attains a thickness of 1,200 feet. It crops out 6 miles west of Roswell. The division is composed of massive, dark gray or dark brown limestones, with a few shale and sandstone partings. The San Andres thins at a uniform rate north of Roswell until in San Miguel County and in wells near Tucumcari, New Mexico, it is only 50-100 feet thick.

Northeast of Roswell, toward Clovis, New Mexico, subsurface exploration shows that although the San Andres maintains its thickness of 1,000-1,200 feet, the upper part grades laterally into anhydrite and salt until, in a well 6 miles north of Clovis, only 235 feet of the basal part of the member remains solid limestone.

Geologic Formations in Southeast Area

Age.	Formation.	Character and Economic Value.
Tertiary.		Surface sands and limestone (Caliche.)
Triassic.	Dockum group.	Red shales and sands with the thick "Santa Rosa sandstone" at the base.
	Post Rustler red beds.	
	Rustler formation.	Principally anhydrite.
	Castile formation.	Salt, potash bearing at the top, with anhydrite and red shale at base.
Permian.	Carlsbad formation.	"Brown Lime" marker at top, with anhydrite, sandy zones and some shale below. Within this formation occur the productive zones of the Hobbs and other fields.—"Upper Gas Horizon," "Bowers Sand," "Big Gas Pay" and the "Main Pay," just below the White or "Crystalline Lime."
	San Andres limestone.	Principally dark limestone but including at the top the "Queen sand" and other sandy zones below.
	Yeso formation.	"Glorieta Sand" at the top with light red and yellow shales, gypsum and limestones below.
	Abo formation.	Dark red sandstones, in places arkosic, dark red shales and thin limestones.
Pennsylvanian.	Magdalena limestone.	Fossiliferous limestones, organic shales and sandstones.

The log of the Texas Production Co. State Wilson No. 1 well on the Dunken dome in sec. 29, T. 17 S., R. 18 E., Chaves County, furnishes a record of formations encountered below the San Andres limestone and is therefore given in detail on pages 143, 144. The sandstone between 705 and 765 feet is correlated with the Glorieta sandstone at the top of the Yeso formation. The Abo formation includes that part of the beds recorded between 3,150 and 4,250 feet and the beds below 4,255 feet to the bottom of the hole, 4,900 feet, are probably of the Magdalena formation.

The stratigraphy of the area is further complicated by the existence of a thick mass of limestone at Guadalupe Point (in Texas) and to the northeast in New Mexico, which has only recently been proven to have been formed as an extensive reef deposit. Lloyd [1] was one of the first to call attention to the fact that the so-called "Capitan limestone" (see Plate IV, B) was of reef origin and formed contemporaneously with parts of the bedded deposits of the Carlsbad and San Andres formations. The reef can be followed in a northeast direction from Guadalupe Point to near Carlsbad where it dips beneath younger formations. East of the

[1] Lloyd, E- R., Capitan limestone and associated formations in New Mexico and Texas: Am. Assoc. Petroleum Geologists Bull. vol. 13, No. 6, pp. 645-658, 1929.

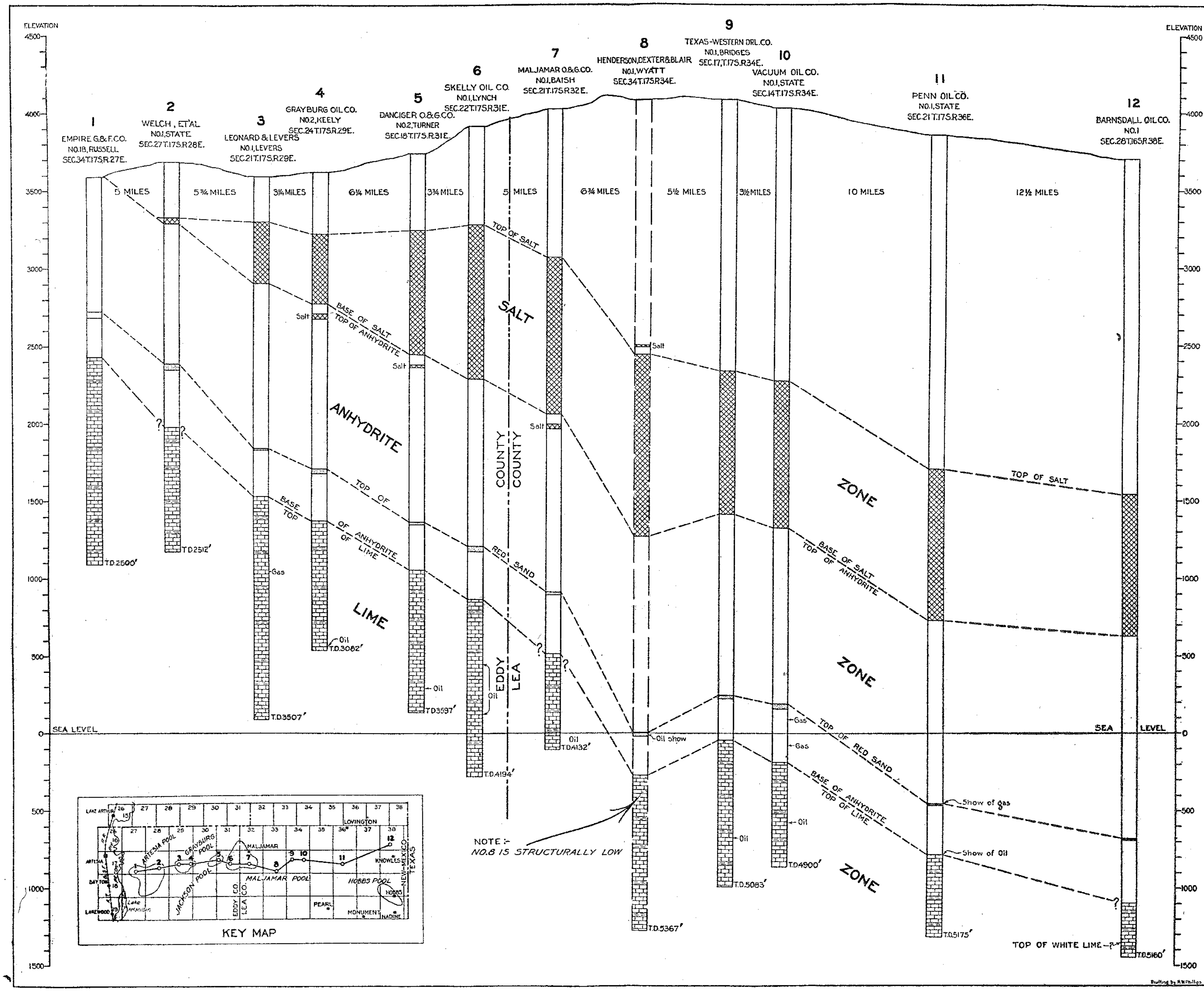
Log of Texas Production Co. *State Wilson No.* 1 *Well*
SW. COT. *of Sec.* 29, *T.* 17 *S., R.* 18 *E.*
Drilled, 1926-27

	Bottom, feet.
Soft yellow limestone	210
Hard gray lime	430
Hard brown lime	505
Gray and brown limestone	520
Hard brown lime	600
Hard gray lime	620
Hard brown lime	705
Gravel	710
Yellow sand	740
Yellow and gray sand	765
Hard sandy lime	790
Gravel and red salt	815
Soft yellow sand	845
Hard brown lime	855
Soft red gravel; 4 barrels water per hour at 855-860 feet.	860
Soft red shale	970
Soft black sand	975
Soft red shale	980
Gray sandy lime	985
Blue shale	995
Hard brown lime	1015
Hard blue lime	1020
Blue shale	1030
Black lime	1050
Shale, blue and gray lime	1060
Hard brown lime	1070
Blue shale	1080
Gray lime and shale	1095
Gray lime	1120
Soft gray shale	1130
Hard gray lime	1135
Soft gray shale	1140
Gray lime; fresh water at 1,165 feet	1170
Blue shale	1240
Soft red shale	1280
Hard blue shale	1300
Gray lime shells	1310
Lime and blue shells	1320
Soft gray shale	1350
Hard blue lime	1355
Hard gray lime	1400
Gray lime and shale	1415
Hard blue lime	1450
Hard gray lime	1560
Hard brown lime	1570
Hard gray lime	1574
Black lime	1590
Hard gray lime	1610
Brown sandy shale	1620
Gypsum	1640
Hard black lime	1680
Gray lime	1700
Hard gray lime	1795
Hard black lime	1805
Hard brown lime	1820
Hard gray lime	1830
Hard brown lime	1960
Hard gray lime	2000
Shale	2085
Hard gray sandy lime	2105
Hard gray lime	2185
Brown lime	2200
Hard white sand	2233
Lime and sand	2250
Soft red sand	2330
Red sand	2365
Gray sand	2375
Lime	2430
Red sand	2440
Red shale	2450
Hard gray lime	2468
Hard gray lime	2478
Red sandy lime	-2482
Lime	2510
White sand; water at 2,510-2,515 feet	2550
Red shale	2555
Lime	2560
Sand	2562
Red shale	2565
Lime	2580
Blue shale	2590
Lime	2595
Shale	2597
Lime	2610
Shale	2612
Lime	2615
Red sand	2620
Shale	2623
Lime	2633
Lime and salt	2640
Lime	2685
Black sand	2710
Sandy lime	2735
Shale	2737
Lime and shale	2755
Shale	2790
Green shale	2797
Red and green shale	2805
Red shale	2809
Red and green shale	2812
Red shale; 1,000,000 cubic feet *gas*	2872
Hard red shale	2985
Green shale	2995
Green lime	3030

	Bottom, feet.
Black lime	3115
Black and sandy lime	3120
Black lime	3150
Sandy shale	3155
Red shale	3160
Red sandy shale	3300
Red shale	3350
Red sandy shale	3355
Hard red shale	3370
Red sandy shale	3501
Red shale and shells	3512
Red shale	3650
Hard red lime and shale	3655
Hard red shale	3705
Gray and red lime and shale	3735
Gray lime shale	3760
Red sandy shale	3820
Red shale and shells	4030
Red sandy shale	4080
Red shale	4093
Lime shells	4120
Red sandy shale	4130
Sandy shale	4145
Red shale	4155
Gray sand	4165
Hard black shale	4170
Gray lime	4175
Black shale	4220
Gray sand	4228
Pink shale	4245
Soft shale	4250
Hard shells	4255
Gray lime	4275
Red and gray lime	4280
Red shale	4300
Gray shale	4310
Red shale	4320
Gray lime	4335
Red lime	4340
Black sandy lime	4355
Blue lime	4360
Gray sandy lime	4363
Sandy shale	4370
Gray lime	4373
Brown sandy lime; 3 barrel's water per hour at 4,373-4,385 feet	4385
Gray sandy lime, sulphur gas at 4,390 feet	4395
Brown sandy lime	4410
Gray lime	4425
Black lime and shale	4432
Black sandy lime	4435
Black lime	4446
Gray lime	4450
Black lime	4470
Black sandy shale	4506
Black lime and shale	4510
Black sandy shale	4517
Gray sand	4528
Gray sandy lime	4555
Black sandy shale	4575
Black lime shells	4580
Hard sandy shale	4610
Black lime and shale	4620
Gray sand	4700
White lime	4720
Black lime	4738?
Gray lime	4735
Gray sandy lime	4742
Gray lime	4747
Gray shale	4753
Gray lime	4800
White lime shells	4810
Gray lime	4822
Hard brown sand	4835
Black sandy lime	4870
Hard gray lime	4885
Dark limy sand	4890
Hard white sand	4894
White floating sand; 1,200 feet of water in hole from 4,900 feet; total depth	4900

Pecos River evidences of reef formation have been found in wells south of the Getty and Lea pools and near Jal, as well as over the line south in Texas. It has been assumed that these findings in reality define the trend of the "Capitan Reef." The present writer's interpretation of the general trend of the reef is shown on the map, figure 8, page 141.

Radical changes in the character and thickness of the sedimentary beds occur from place to place in the area, and the two cross sections (Plates XXIV and XXV) have been prepared from the drillers' logs of wells to show some of these variations. The east-west section, Plate XXIV, is across Eddy and Lea counties just north of the Artesia and



East-west section across Eddy and northern Lea Counties, based on well logs.

Hobbs fields and shows the sudden thinning of the salt series near the west end of the section. At the same time it shows how nearly parallel the base of the salt is to underlying key horizons. The north-south section, Plate XXV, traverses eastern Lea County through the productive areas of Hobbs, Eunice, Cooper and Jal. Along this line there is a more gradual change in the salt thickness but a more rapid change in the thickness of the Carlsbad formation (essentially the interval between the "Brown Lime" and the White or "Crystalline Lime").

OIL AND GAS

The general structure of the Southeast Area is that of a broad basin, in places interrupted by minor folds. The deepest part of the basin, on the basis of the lowest salt beds, is in Texas a short distance south of the southeast corner of Eddy County, N. Mex. This great Permian Basin, which extends far to the east and south into Texas, is divided by the Capitan Reef into the deep-sea portion (Delaware Basin) to the south and the shallow lagunal area bordered by the "Central Basin Platform" to the north and east. So far no commercial oil or gas has been found west of the Pecos River in New Mexico, and in the area to the east of the river surface exposures are so scarce and unreliable that subsurface structural conditions must be worked out by the interpretation of well logs. To date, drilling has shown the presence of a number of closed folds in the lagunal area but none in the deep-sea area. Two fields, Jal and Cooper, in the deep-sea area owe their location to erratic porosity of the formations.

All of the oil and gas produced in southeastern New Mexico is found in the series of rocks immediately underlying the salt series (Castile). The upper part of this series is composed of limestone, anhydrite and shale and in places sandstones, and is correlated with the Carlsbad formation by DeFord and Wahlstrom[1], and the lower part is referred to the San Andres. The exact correlation of the producing beds is in question, various geologists having used other names—Chupadera,[2] San Andres,[3] Queen sand zone of the White Horse[4], Double Mountain,[5] and the Big Lime.[6] In the present bulletin the writer has followed the correlations of DeFord and Wahlstrom in the discussion of the sediments of the Southeast Area.

Study of the detailed subsurface structure maps given in connection with the discussion of the productive areas on the following pages shows

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[1] DeFord. R- K., and Wahlstrom. E. A., Hobbs field: Am- Assoc. Petroleum Geologists Bull. vol. 15, No- 9, p. 58. 1932.

[2] Darton. N. H., "Red Beds" and associated formations in New Mexico: U. S. Geol. Survey Bull. 794, p- 248. 1928.

[3] Lloyd, E. R., Capitan limestone and associated formations in New Mexico and Texas: Am- Assoc. Petroleum Geologists Bull. vol- 13, No. 6. p. 652, 1929.

Willis, Robin, Correlation of Texas and New Mexico Permian: Am. Assoc. Petroleum Geologists Bull. vol. 13. No. 8, p, 1014, 1929.

[4] Bybee, H. P., Boehms, E. F., Butcher. C. P., Hemphill, H. A., and Green, G. E.. Detailed cross section from Yates Area. Pecos Co.. Texas, into southeastern New Mexico: Am. Assoc. Petroleum Geologists Bull. vol. 15. No. 9 p- 1088. 1931-

[5] Davis, Morgan, J.. Artesia field. Eddy County', New Mexico: in Structure of typical American oil fields, vol. 1, pp. 114-116. Am- Assoc. Petroleum Geologists, 1929.

[6] Edwards, E. C. Stratigraphic position of the Big Lime of West Texas: Am. Assoc. Pe- troleum Geologists C., vol. 11, No. 7, pp. 727-728, 1927.

that there are two general lines of folding in the lagunal area north of the Capitan Reef. (See figure 8.) The Artesia, Grayburg, Jackson, Maljamar and Hobbs pools are to be found along the northern axis while the Getty, Lea and Eunice pools are along the more or less parallel southern axis. The Texas Pacific and Meyers pools of the Cooper area and the Jal pool to the south are on the deep-sea side of the Capitan Reef. In each of these latter areas subsurface dips are relatively steep into the basin, and no structural closure is evident. The structure is quite different in type from that present in the fields on the lagunal side of the reef where dips are very moderate.

Future studies in southeastern New Mexico will doubtless lead to the drilling of many additional wells in the hope of finding additional productive areas. Such studies may well include a careful examination of the cuttings of wells already drilled and careful geophysical surveys particularly with seismic equipment. It is suggested that additional productive areas similar to Jal and Cooper on the deep-sea side of the Capitan Reef may be expected, but the finding of such areas of actual production where accumulation is explained by lenticular porosity of beds will be accidental or attended by large money expenditures. On the lagunal side of the reef it is logical to expect additional closed structures like Hobbs and Eunice. It should be possible to outline these by seismic surveys.

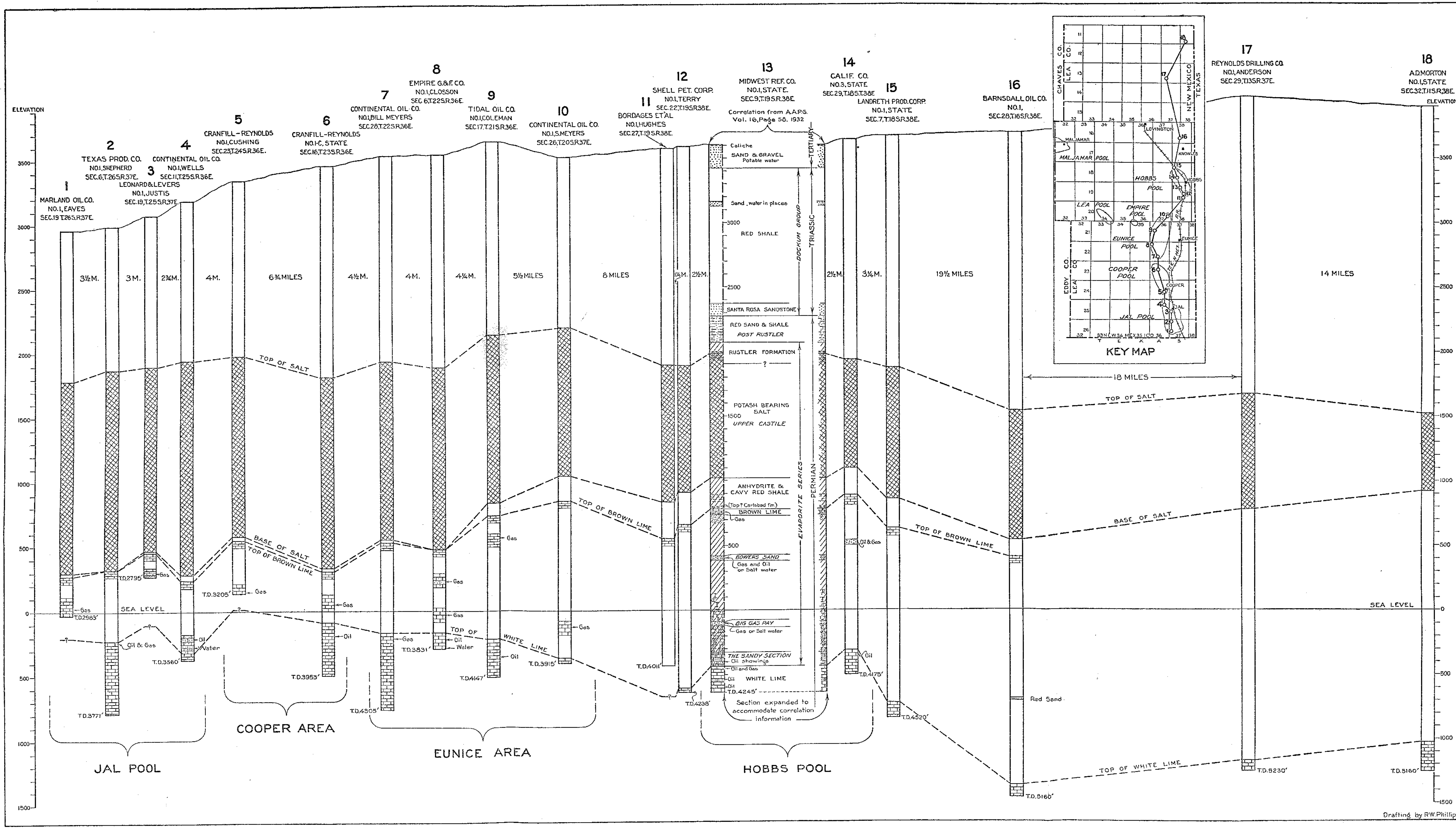
Up to this time very few wells have been drilled below the top of the San Andres formation in the Southeast Area, yet where the lower formations are exposed their character suggests that they are well worth testing. The Glorieta sandstone at the base of the San Andres appears as a good prospect for production. By still deeper drilling, the Magdalena limestone series (Pennsylvanian) may be tested, and under good structural conditions, such as at Hobbs, may be found productive.

ARTESIA FIELD

The Artesia field is located in Eddy County southeast of the town of Artesia and east of the Pecos River. In this report the field includes the main pool, which is about 14 miles by auto highway from Artesia, and several small areas of production in Tps. 16-19 S., Rs. 27-29 E. The map, Plate XXVI (in pocket), published originally by the United States Geological Survey in 1928, has been revised by the addition of wells drilled since May 1, 1928, and is reproduced by permission of the Survey.

The Artesia field is located in an area of low relief, the altitude ranging from 3,550 to 3,660 feet. No well-defined drainage channels are present, and most of the rain water disappears in sink holes.

The principal productive area is in the west half of T. 18 S., R. 28 E., as shown by the map. The lands are largely owned by the State of New Mexico. Production in the main field comes from a zone of irregular porosity some 300 feet in thickness in the upper part of the lime series, which occurs at from 2,000 to 2,400 feet below the surface. In the Grayburg area in sec. 24, T. 17 S., R. 29 E., and adjoining sections in the township to the east, production is obtained at depths of around



North-south section across eastern Lea County, based on well logs.

3,000 feet, some 650 feet below the top of the lime series. Several isolated wells throughout the area shown on the map produce small amounts of gas and oil from higher horizons.

HISTORY AND PRODUCTION

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.

Up to the present time, over 325 wells have been drilled within the area shown on the map. The field reached its peak of production in 1926, the production for the year amounting to a little over 1,000,000 barrels of oil. On December 31, 1931, the field was producing at the rate of approximately 530 barrels of oil per day. The yearly production of the Artesia field is as follows:

Oil Production from the Artesia Field, in Barrels

1925	748,000
1926	1,016,000
1927	572,200
1928	403,606
1929	321,280
1930	255,336

Considerable gas with good gasoline content is found with the oil, and this led the Phillips Petroleum Co. to install a casing-head plant in the field for the extraction of gasoline from the gas. A 2-inch welded gasoline line carries the product from the plant to the railroad at Artesia. The New Mexico Pipe Line Co., a subsidiary of the Continental Oil Co., operates a 4-inch oil pipe line to the refinery at Artesia, and the Illinois

Pipe Line Co., has a 6-inch line to Dayton. The Illinois Pipe Line Co. also has a 4-inch oil line, which collects oil from the small fields of Gray-burg, Jackson and Maljamar to the east of the main field. ,

In 1925 gas was discovered in the Vandergriff area in sec. 5, T. 17 S., R. 28 E., and gas from this area and from the Texas Robinson well in the Maljamar area was piped to Roswell, Carlsbad and other Pecos Valley towns through the lines of the Pecos Valley Gas Co. The Leonard and Levers gas area in secs. 20, 21, 28 and 29, T. 17 S., R. 29 E., was discovered in 1929 and now supplies about 90 per cent of the gas used in the valley. The average consumption is about 2,000,000 cubic feet per day.

STRATIGRAPHY

The surface rocks of the Artesia field are chiefly red shales, soft sands, and gypsum of the Permian "Red Beds." In much of the area these rocks have a thin covering of caliche and loose sand. Surface slumping has occurred widely, making the determination of geologic structure very difficult.

Drilling has revealed the section to a depth of 4,035 feet at the Ohio Oil Co. New State No. 9 well in sec. 4, T. 18 S., R. 28 E., and to 3,633 feet in the Texas Production Co. Levers No. 4 well in sec. 5, T. 18 S., R. 28 E. These logs give the subsurface section of the field so far as known.

Log of Ohio Oil Co. New State No. 9 Well
SE. Cor. SW. ¼ SE.¼, T. 18 S., R. 28 E.

	Bottom, feet.
Lime	30
Gypsum	40
Lime	55
Red sand	180
Gypsum	200
Red sand	240
Gypsum	250
Red rock	265
Gypsum	280
Sand; water	295
Red rock	310
Gypsum	335
Red rock	355
Gypsum	380
Red rock	410
Gypsum	440
Blue slate	445
Lime shell; water, 3 bailers per hour	450
Red rock	455
Lime	480
Salt	485
Lime	600
Broken lime	620
Pink lime	690
Red rock	695
Pink lime	920
Lime; rainbow of *oil* at 990 feet	1295
Red rock	1300
Lime	1430
Red rock	1440
Lime	1530
Red sand	1565
Lime	2080
Shale	2085
Lime; show of *oil*	2320
Sand and pink shale	2340
Lime; *oil* show	2376
Sandy shale	2385
Lime	3220
Sandy lime	3320
Black sandy lime	3360
Sandy lime	3380
Black sandy lime	3415
Sandy lime	3460
Lime	3475
Sandy lime	3520
Gray lime	3535
Lime	3550
Gray lime	3630
Gray sandy lime	3640
Gray lime	3690
Lime; total depth	4035

Note.—Plugged back to 2,500 feet and shot with 160 quarts nitro- glycerin.

Log of Texas Production Co. *Levers No.* 4 *Well*
Cen. SE. $1/_4$ *SE.* 1/4 *Sec.* 5, *T.* 18 *S., R.* 28 *E.*
Drilled, 1925-26

	Bottom, feet.
Surface gypsum	20
White mud	40
Red mud	60
Red sand	115
Red mud	170
Yellow sand	192
Red mud	229
Red gypsum	240
Red mud	330
Red mud	375
Red gypsum	408
White gypsum	482
Blue shale	487
Red gypsum	507
Red mud	527
White gypsum	535
Red sandy shale	550
Red gypsum	584
Sand, water	600
Red shale	612
White gypsum	620
Red shale	628
Red mud	632
White gypsum	657
Red gypsum	693
Red mud	699
Gray gypsum	719
Red mud	728
Red gypsum	738
Gray gypsum	750
White gypsum	758
Red mud	765
Red gypsum	794
White gypsum	800
Red gypsum	852
White gypsum	1102
White lime	1114
White gypsum	1130
Red gypsum	1153
White gypsum	1160
Pink gypsum	1245
Red gypsum	1271
Pink gypsum	1283
White gypsum	1300
Pink gypsum	1425
Red sand	1445
Pink gypsum	1466
White gypsum	1473
Pink gypsum	1523
White lime	1535
White gypsum	1541
Pink gypsum	1561
White gypsum	1578
Pink gypsum	1596

	Bottom, feet.
White lime	1608
Pink gypsum	1680
White gypsum	1710
Red sandy gypsum	1720
Pink gypsum	1749
White gypsum	1766
Pink gypsum	1816
White lime	1828
Pink gypsum	1856
White lime	1870
Pink gypsum	1882
White lime	1942
Gray lime	2027
Gray sandy lime	2052
Gray lime	2126
White lime	2175
Gray lime; steel line measurement shows 2,196 feet	2200
White sand	2215
White sandy lime; show of *oil.*	2230
Gray sand	2239
Gray lime	2248
Light sand; *oil*	2262
White lime	2312
White gypsum	2318
White lime	2328
Gray gypsum	2340
Gray lime	2342
Gray gypsum	2361
White lime	2367
Gray lime	2392
Gray sand	2398
Sand; show of *gas* and oil.	2411
Gray lime	2526
Brown lime	2534
Gray lime	2543
Brown lime	2554
Gray lime	2558
Sand; gray sandy lime	2572
Gray lime; 150 feet of *oil* in hole after standing 3 days.	2713
Sand	2720
Gray lime	2763
Black lime	2779
Lime	2793
Gray lime	2800
Black lime	2815
Sandy lime; no oil; steel line measurement	2827
Black lime	2859
Brown lime	2878
Black lime	2898
Brown lime	2920
Gray lime	2961

	Bottom, feet.
Gray sandy lime	2972
Gray lime	3009
Gray sandy lime	3031
Gray lime	3087
Gray sandy lime	3099
Gray lime	3149
Black lime	3187
Hard gray lime	3200
Gray lime	3247
Black lime	3295
Black sandy lime	3311
Black lime	3337
Gray lime	3567
White sand; one bailer water per hour	3572
White sandy lime	3584
Gray lime; steel line measurement 3,633 feet	3636

As shown by the above logs the lime-dolomite section is approximately 2,Q00 feet thick from the top down to the point at which the drill stopped. The upper 300 feet of the dolomite appears to be more sandy than the lower part of the series, and it contains at its base the principal pay horizon of the north part of the field, locally known as the New State pay. In the central and southern parts of the field, the principal oil-bearing horizon, called the Maljamar pay, is in the top 100 feet of the sandy dolomite section. In the Grayburg pool to the east, the pay zone is about 650 feet below the top of the lime-dolomite series, and in the Leonard and Levers area the gas occurs in a thin sandy lime bed about 180 feet from the top of this series.

Above the top of the lime-dolomite series is an anhydrite series approximately 1,100 feet thick, broken here and there by beds of red sandstone and red shales. The hard red sandstone, which occurs approximately 400 feet above the base of the anhydrite series, has been extensively used as a key bed for subsurface contouring. In some wells this bed carries showings of both oil and gas. Salt is found in wells to the east of the main producing field.

According to Lloyd,[1] the productive horizons of the Artesia field are in the upper part of the San Andres formation, which is of Permian age.

STRUCTURE

The beds already described as outcropping in the Artesia field have been used as key beds in the mapping of surface structure in T. 18 S., R. 27 E. Although a great amount of slumping is present, it has been found in general, when sufficient care is used, that surface structural highs indicate subsurface conditions. The discovery well of the Empire Gas & Fuel Company's "pool," drilled in sec. 35, T. 17 S., R. 27 E., was located on a small surface dome. This surface structure has been found to check satisfactorily with subsurface information disclosed by drilling. The key beds used in the surface work were thin dolomitic limestones interbedded with red shales and gypsum.

The subsurface structure of the Artesia area, based on the prominent marker (the "Red Sand") 400 feet above the top of the dolomite, is shown on the accompanying contour map, Plate XXVI. It consists of a large

[1]Lloyd, E. R., Capitan limestone and associated formations in New Mexico and Texas: Am. Assoc. Petroleum Geologists Bull, vol. 13, No. 6, p. 652, 1929.

northeastward-trending anticlinal fold, with subsidiary nosing or terracing on which the main part of the Artesia field in T. 18 S., R. 28 E., is located. The Empire pool in sec. 35, T. 17 S., R. 27 E., is located at or near the apex of the main fold.

RESERVOIR ROCKS

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. Eith rare exceptions sand does not constitute more than 15 per cent 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 disappearad 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.

OIL AND GAS ACCUMULATION

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, located at the top of a subsurface anticlinal uplift, has only a few wells and these are relatively small.

As indicated by the contours of the map, 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. Eells that yield gas and very little oil are irregularly distributed among the oil-producing wells, and Davis [1] has suggested that this is explainable by varying degrees of porosity in the dolomite.

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[1] Davis, Morgan J., Artesia field, Eddy County, New Mexico: in Structure of typical American oil fields, vol. 1, p. 120, Am. Assoc. Petroleum Geologists, 1929.

THE OIL

Oil from the Artesia pool has a gravity of 32° to 37° A. P. I., and a sulphur content of 0.85 to 1.02 per cent, 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.	
Sulphur (per cent).	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., K. 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.

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 average gasoline content of gas put through this plant during its operation from July, 1926, to January, 1931, was approximately 2 gallons per thousand cubic feet of gas.

The gas from the Leonard and Levers area is a sweet gas with a heating value of 1,050 B. t. u.

Wells Drilled in Maljamar Area.

Company.	Well.	Location, Sec., T.-S., R.-E.	Total depth, feet.	Date completed.	Remarks.
Grayburg Oil Co.	No. 2 Keely.	24 - 17 - 29	3,082	Nov. 5, 1929.	Initial production, 400 barrels oil.
Grayburg Oil Co.	No. 2 Burch.	19 - 17 - 30	3,142	June 27, 1929.	Initial production, 60 barrels oil.
Wooley et al.	No. 1 Beeson.	33 - 17 - 30	3,505	May 16, 1927.	Dry and abandoned.
Wooley et al.	No. 2 Beeson.	28 - 17 - 30	3,565	Mar. 24, 1930.	Initial production, 17 barrels oil.
Wooley et al.	No. 1 McIntyre.	21 - 17 - 30	3,470	July 21, 1927.	4,000,000 cubic feet gas at 1,806 feet, 2,000,000 cubic feet gas at 2,006 feet.
Harry Leonard.	No. 1 Haggerty.	18 - 16 - 30	3,752	July 18, 1929.	Dry and abandoned.
Ohio Oil Co.	No. 2 A. M. Sellery.	22 - 16 - 30	2,308	July 27, 1929.	Dry and abandoned.
Etz Bros.	No. 2 Etz.	13 - 16 - 30	3,850	Jan. , 1930.	Abandoned.
Lockhart & Co.	No. 1 Parks.	10 - 17 - 30	3,578	Jan. 16, 1930	Abandoned.
Lockhart & Co.	No. 2X Parks.	23 - 17 - 30	3,419	Oct. 7, 1930.	Abandoned.
Henderson, Dexter & Blair.	No. 1 Arnold.	23 - 17 - 30	3,629	Mar. 15, 1930.	Initial production, 80 barrels oil.
Flynn, Welch & Yates.	No. 1 Stevens.	13 - 17 - 30	3,464	Jan. 31, 1931.	507 barrels oil.
Flynn, Welch & Yates.	No. 1 Jackson.	13 - 17 - 30	3,560	Mar. 21, 1929.	500,000 cubic feet gas (estimated) at 2,905 feet, 30 barrels oil, 37° A. P. I., at 3.057 feet, initial production, 225 barrels oil, 36° A. P. I.
Flynn, Welch & Yates.	No. 2 Gissler.	12 - 17 - 30	3,615	Aug. 9, 1929.	Initial production, 80 barrels oil.
Prairie Oil & Gas Co.	No. 2 Keel.	7 - 17 - 31	3,600	Aug. 26, 1929.	Initial production, 120 barrels oil.
Pueblo Oil Co.	No. 4 Russell.	18 - 17 - 31	3,485	Aug. 9, 1929.	Initial production, 150 barrels oil.
Pueblo Oil Co.	No. 5 Russell.	18 - 17 - 31	3,445	June 20, 1930.	Initial production, 50 barrels oil.
Danciger et al.	No. 2 Turner.	18 - 17 - 31	3,597	Mar. 1, 1930.	Initial production, 100 barrels oil.
Skelly Oil Co.	No. 1 Lynch.	22 - 17 - 31	4,194	1927.	Initial production, small oil well.
Prairie Oil & Gas Co.	No. 1 Keel.	10 - 17 - 31	3,872	1927.	Initial production, 15 barrels oil.
Henderson, Dexter & Blair.	No. 1 Grier.	21 - 16 - 31	3.806	May 29, 1930.	Dry and abandoned.
Texas Production Co.	No. 1 Compton.	9 - 16 - 31	4,381	Sept. 21, 1928.	Dry and abandoned.
Texas Production Co.	No. 1 Robinson.	25 - 16 - 31	3,885	Aug. 4, 1927	16,000,000 cubic feet gas with tools in hole.
Texas Production Co.	No. 2 Robinson.	25 - 16 - 31	4,103	Jan. 9, 1928.	Initial production, 125 barrels oil.
Pueblo Oil Co.	No. 2 Gessert.	1 - 17 - 31	3.704		Dry and abandoned.
Pueblo Oil Co.	No. 3 Gessert.	1 - 17 - 31	4.412	Oct. 12, 1927.	Dry and abandoned.
Apache Oil Co. (Bruce Sullivan).	No. 1 Lodewick.	1 - 18 - 31	2,685	1926	Dry and abandoned.
Maljamar Oil & Gas Co.	No. 2 Pearsall.	33 - 17 - 32	4,218	Feb. 21, 1929.	Dry and abandoned.
Maljamar Oil & Gas Co.	No. 1 Baish.	21 - 17 - 32	4.132	July 3, 1926	Initial production, 200 barrels oil.
Maljamar Oil & Gas Co.	No. 2 Baish.	21 - 17 - 32	4.121	Nov. 14, 1929	Initial production, 160 barrels oil.
Maljamar Oil & Gas Co.	No. 3 Baish.	21 - 17 - 32	4.169	July 10, 1930	Initial production, 200 barrels oil, 3,000,000 cubic feet gas.
Maljamar Oil & Gas Co.	No. 1 State.	16 - 17 - 32	4.115	Jan. 17, 1927	Initial production, 50 barrels oil.
Maljamar Oil & Gas Co.	No. 2 Beardsley.	15 - 17 - 32	4.319	Feb. 10, 1928.	Initial production, 12 barrels oil; abandoned.
Ohio Oil Co.	No. 1 Wm. Mitchell.	18 - 17 - 32	4.385	Jan. 1, 1927	Initial production, 38 barrels oil; abandoned.
Maljamar Oil & Gas Co.	No. 1 G. Mitchell.	5 - 17 - 32	4,233	Mar. 15, 1927.	Initial production, 150 barrels oil.
Caprock Oil & Gas Co.	No. 1 State.	11 - 16 - 32	4 880	Sept. 16, 1927.	Dry and abandoned.
Henderson, Dexter & Blair.	No. 1 Wyatt.	34 - 17 - 33	5,367	Jan. 18, 1928.	Dry and abandoned.
Inglefield-Bridges.	No. 1 State.	4 - 17 - 34	5.329	Jan. 28, 1928.	12 barrels oil at 4,725 feet; abandoned.
Texas Co.-Western Drilling Co.	No. 1 State (Bridges).	17 - 17 - 34	5 083	Apr. 30, 1931.	Good oil show; non-commercial, abandoned.
Vacuum Oil Co.	No. 1 State.	14 - 17 - 34	4,900	Sept. 6, 1929.	100 barrels oil, non-commercial, abandoned.

MALJAMAR AREA

The term, Maljamar area, has been used to apply to an area 18 miles wide, north and south, by 30 miles long, east and west, including Tps. 16-18 S., Rs., 30-34 E., inclusive. In addition to the Maljamar pool proper, it included the Jackson pool, as shown on the Oil and Gas Map of New Mexico, Plate XXIII. The town of Maljamar is located near the center of the area and a short distance west of the "Caprock" escarpment. (See map, Plate XXVII.) State Automobile Highway 83 traverses the area from east to west through Maljamar and connects with Lovington to the east and Artesia to the west.

The surface west of the "Caprock" escarpment is rolling and covered with soft, loose sand. The westward-facing escarpment of the "Caprock" rises some 150 feet above the surface of the area immediately to the west. East of the escarpment the surface is essentially level, sloping to the eastward at only about 15 feet per mile. The "Caprock" area is covered by caliche. Surface evidence of subsurface structure is entirely lacking in the whole Maljamar area, as the sand and caliche effectually conceal all rock formations.

The Maljamar Oil & Gas Co. in 1926 completed the first well of the area in sec. 21, T. 17 S., R. 32 E. This well, Baish No. 1, was drilled to a total depth of 4,132 feet and developed 200 barrels of oil per day. Up to July 1, 1931, a total of 40 test wells had been completed (exclusive of shallow wells which failed to reach important depths) of which 19 were made into commercial oil wells, the largest having an initial production of 507 barrels of oil per day. Two were gas wells and 19 were abandoned as non-commercial.

The table facing page 153 shows the record of drilling in the Maljamar area.

A study of the logs of wells drilled in the area, shows the "Red Sand" to be the one bed which can be identified in all of the wells. The "Red Sand" occurs in the anhydrite zone some 300 feet above the main lime zone, which is probably the equivalent of the basal Carlsbad (Ehite Lime) - Upper San Andres lime series of the Hobbs field. On the basis of elevation of the "Red Sand" the structure of the Maljamar area (see Plate XXVII) appears to be a general long eastward-plunging anticlinal ridge showing no westward closure. Oil and gas accumulation most commonly, though not always, occurs along this structural ridge, and is limited to relatively small local areas where porosity is greatest. To date all commercial production has been found in the upper 600 feet of the lime zone.

The oil from the Maljamar area has a gravity ranging from 30.0° to 37.4° A. P. I., and has a sulphur content of less than one per cent. The following analyses were made by the United States Geological Survey of oils from wells as indicated.

Analyses of Oil from the Maljamar Area

Sample No.	29-026		29-038		29-031	
The Crude Oil.						
Specific gravity (°A. P. I.).	36.7		30.0		31.4	
Centrifuge; B. S., mud and water (per cent).	0.1		Trace		Trace	
Sulphur (per cent).	0.79		1.34		1.14	
Universal Saybolt viscosity at 100° F., seconds.	40		51		50	
Distillation (Air)						
First drop.	120° F.		136° F.		122° F.	
	Per cent	Gravity (°A. P. I.)	Per cent	Gravity (°A. P. I.)	Per cent	Gravity (°A. P. I.)
Up to 392° F.	37.3	53.9	26.7	48.1	26.7	47.8
392° F. to 482° F.	9.7	40.0	16.0	38.2	11.2	39.9
482° F. to 527° F.	5.3	36.3	7.0	33.3	8.5	35.4
Vacuum Distillation (40 mm.).						
Up to 392° F.	5.2		4.3		4.7	
392° F. to 482° F.	8.7		8.0		11.5	
482° F. to 527° F.	5.7		5.2		5.7	
527° F. to 572° F.	4.5		6.0		4.3	
Residuum.	13.6		26.8		27.4	
Base.	Intermediate		Intermediate B		Intermediate	

Sample No. 29-026; Prairie Oil & Gas Co. No. 2 Keel Well; sec. 7, T. 17 S.,R.31E.

Sample No. 29-038; Maljamar Oil & Gas Co. No. 2 Baish Well; sec. 21, T. 17 S., R. 32 E. (upper Maljamar pay).

Sample No. 29-031; Vacuum Oil Co. No. 1 State Well, sec. 14, T. 17 S., R. 34 E. (Inglefield pay).

Oil from the Maljamar area is taken westward to Artesia and Roswell through the New Mexico Pipe Line Company's 4-inch line, whereas gas from the area is taken by the Pecos Valley Gas Co. through a 3½-inch welded line.

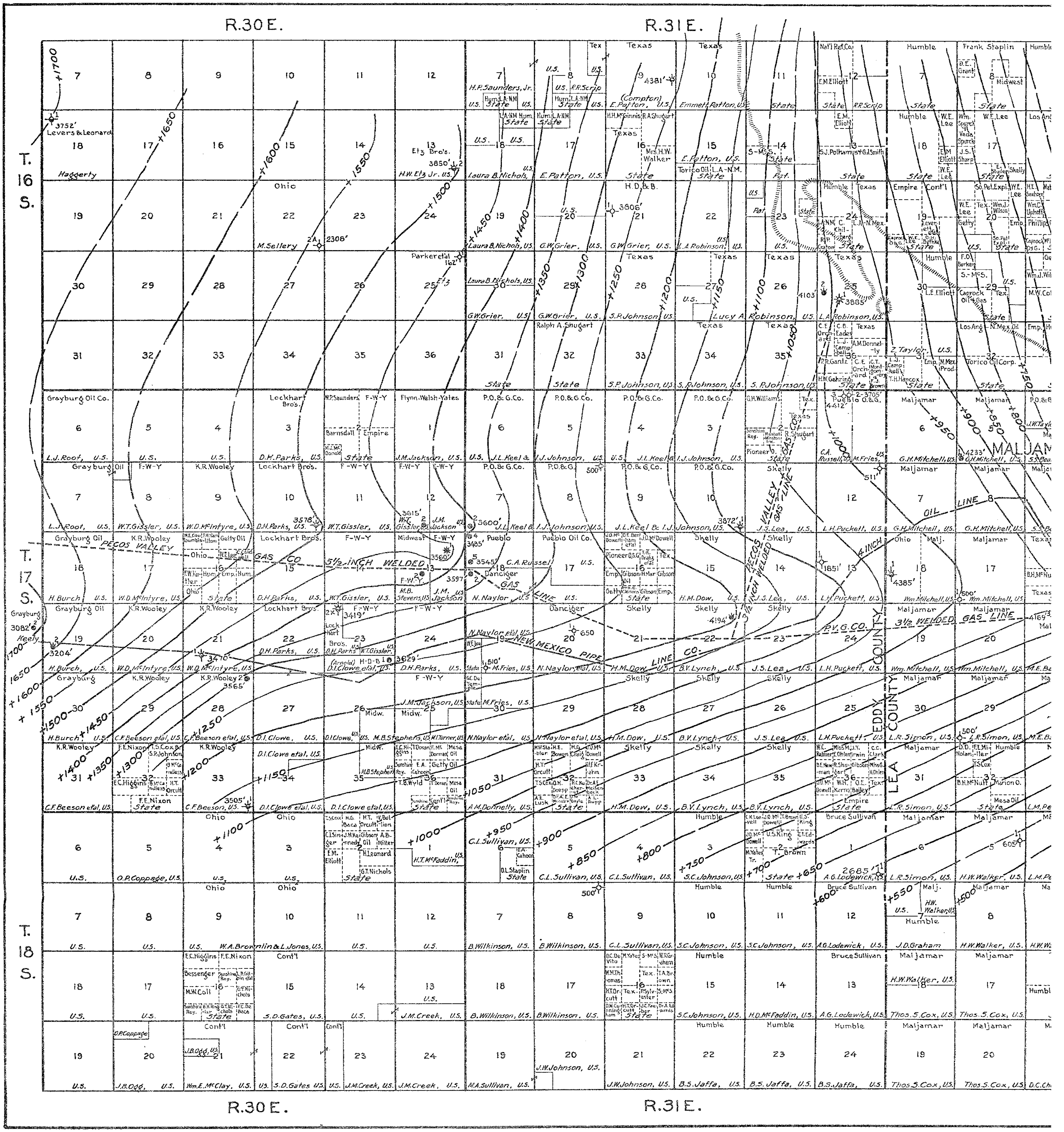
HOBBS FIELD

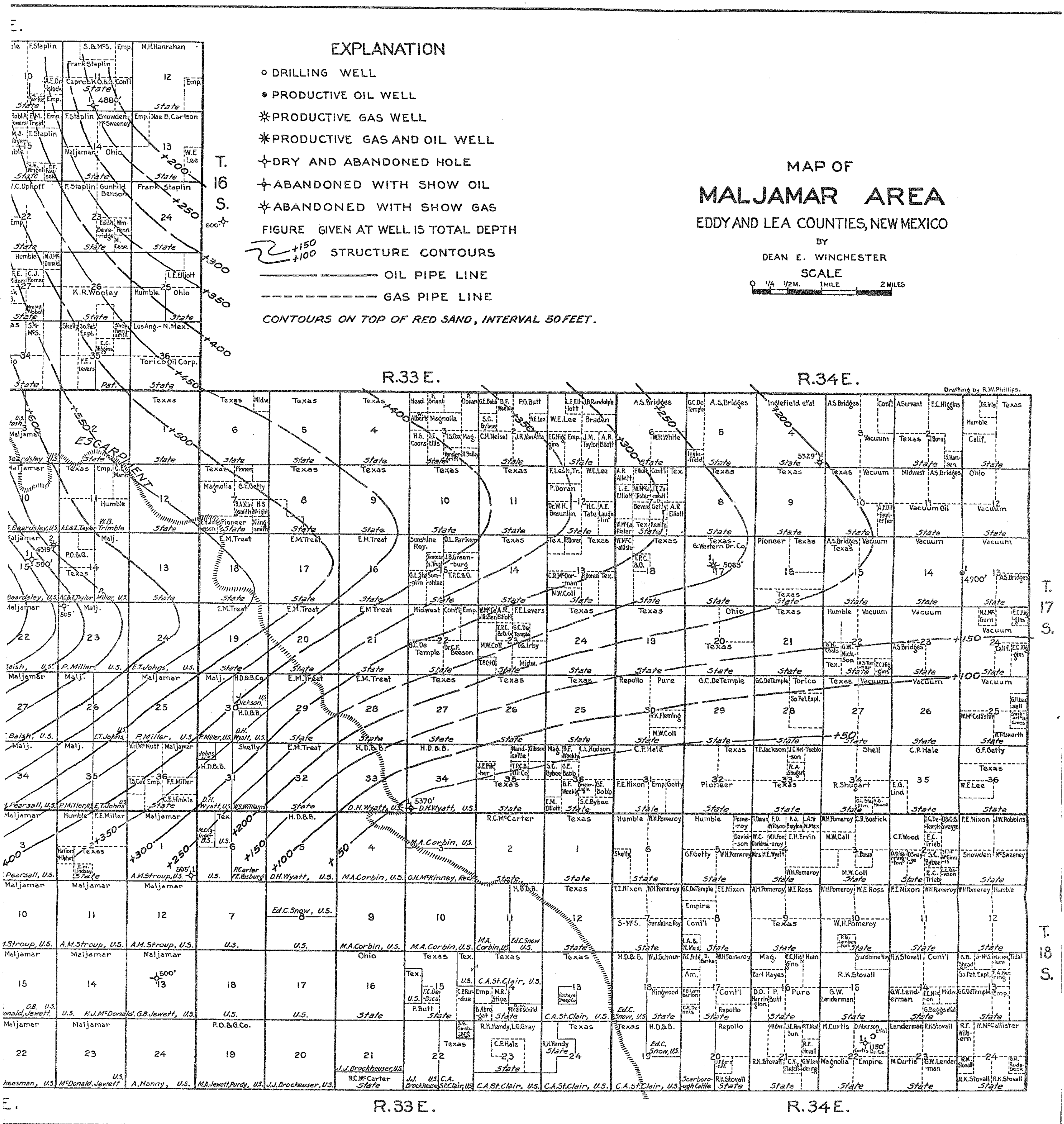
LOCATION AND TOPOGRAPHY

The Hobbs field is located in eastern Lea County only a few miles from the eastern line of the State on the great Llano Estacado, which covers a vast area in eastern New Mexico and western Texas. The surface of the field is relatively "as flat as a floor," there being less than 100 feet difference in elevation of the more than 150 wells so far drilled in an area 7 miles long by 3 miles wide.

HISTORY

The extreme southeastern corner of New Mexico was not regarded as a particularly promising area by oil men until the development of large oil fields in Winkler County, Tex., in 1925. Following their discovery, intensive studies were undertaken to determine whether or not the general north-south trend evident in these Texas fields extended into Lea County, N. Mex. Drilling which followed resulted first in the discovery in 1927 of 90,000,000 cubic feet of gas by the Texas Production Co. in its No. 1 Rhodes well in the Jal area in southern Lea County. A magnetometer survey by W. H. Denning and C. A. Weintz for the Midwest Refining Co. in 1926 caused that company to purchase leases in the vicinity of the Hobbs store and led to further studies with torsion balances. On October 12, 1927, the Midwest spudded in what was to be the discovery well of


R.30 E.
R.31 E.
T. 16 S.
T. 17 S.
T. 18 S.
PECOS VALLEY GAS CO.
5½ INCH WELDED
NEW MEXICO PIPE LINE CO.
PECOS VALLEY GAS LINE
4 INCH WELDED
OIL LINE
P.V.G.CO.
3½ WELDED GAS LINE
EDDY COUNTY
LEA COUNTY
MALJAMAR


EXPLANATION
DRILLING WELL
PRODUCTIVE OIL WELL
PRODUCTIVE GAS WELL
PRODUCTIVE GAS AND OIL WELL
DRY AND ABANDONED HOLE
ABANDONED WITH SHOW OIL
ABANDONED WITH SHOW GAS
FIGURE GIVEN AT WELL IS TOTAL DEPTH
+150 +100 STRUCTURE CONTOURS
OIL PIPE LINE
GAS PIPE LINE
CONTOURS ON TOP OF RED SAND, INTERVAL 50 FEET.
MAP OF
MALJAMAR AREA
EDDY AND LEA COUNTIES, NEW MEXICO
BY
DEAN E. WINCHESTER
SCALE
0 1/4 1/2M. 1MILE 2MILES
Drafting by R.W. Phillips.
R.33 E.
R.34 E.
T. 16 S.
T. 17 S.
T. 18 S.
ESCARPMENT

the Hobbs field in the NE. cor. sec. 9, T. 19 S., R. 38 E. The drill, on June 13, 1928, disclosed oil in the "Ehite Lime" at a depth of 4,065 feet. On November 8, 1928, the well was 4,220 feet deep when, having penetrated the oil bearing zone it encountered bottom water which threatened to ruin the well. Eith this shut off, however, the well flowed by heads and during a six-weeks test an average of 700 barrels of oil per day was produced.

At the time of the completion of the discovery well the town of Hobbs consisted of two buildings, a schoolhouse and a store facing each other across a country road. The nearest railroad was at Carlsbad, 90 miles to the west, with not even a reasonably good road connecting.

Before any more wells were completed the Humble Oil & Refining Co. on June 10, 1929, spudded in its No. 1 Bowers well 3 miles northwest of the discovery. This well, which was located and drilled at the time for apparently no other reason than to satisfy an expiring land agreement, was completed eight months later at a total depth of 4,106 feet for the first well in the area of large production on the top of the structure. This well is reported to have had 12,000,000 cubic feet of gas at 2,820 feet, 438 barrels of oil at 3,368 feet ("Bowers Sand"), 50,000,000 cubic feet of gas in the "Big Gas Pay" at 3,684 feet and 9,720 barrels of oil in the "Ehite Lime" at 4,106 feet.

A well of this character naturally started an active campaign of development, and 21 companies, most of which are major companies, have taken part in the development of the field. Starting without rail or pipeline connections the field is now served by both. The Texas-New Mexico railroad, a branch of the Texas and Pacific railroad, reached Hobbs in April, 1930. The Humble pipe line carried the first oil from the field in May, 1930, and in July, 1930, the Atlantic and Shell pipe lines began to take oil. On Jan. 1, 1931, there were 141 producing wells in the field. Out of the plains has grown the town of Hobbs, which in the summer of 1930 had a population of perhaps 12,000 people, making it at that time, next to Albuquerque, the largest town in the State. By February, 1931, however, the population at Hobbs had settled to about 1,500 inhabitants. The field today presents an orderly alignment of steel derricks and permanent field camps.

On July 10, 1930, the production of the field was placed on a restricted basis under the provisions of a proration agreement. Two gasoline plants for the extraction of natural gasoline from the gas of the field were constructed in the summer of 1930, and they began to operate in October of that year. In December, 1930, a 4-inch gas pipe line was completed to Lovington.

STRATIGRAPHY

No rock outcrops occur in the vicinity of Hobbs except recently formed caliche, which in places is covered by a thin mantle of soil and wind-blown sand. The underground sequence of beds (see log No. 13, Plate XXV) has been ably described by DeFord and Wahlstrom,[1] and the following description is largely a brief from their report.

[1] DeFord, Roland K., and Wahlstrom, Edwin A., Hobbs field, Lea County, New Mexico: Am. Assoc. Petroleum Geologists Bull, vol. 16, No. 1, pp. 51-90, January, 1932.

TERTIARY SYSTEM

At Hobbs the Tertiary rocks consist of buff to pinkish sand having a thickness of approximately 170 feet. The upper 50 feet increases in calcium carbonate toward the surface, finally grading upward into a flaggy surface limestone (caliche). At approximately 60 feet it contains excellent potable water in large quantities, supplying the field and town.

TRIASSIC SYSTEM (DOCKUM GROUP)

Shale.—Dark red shale and clay, having a total thickness of 1,060 feet, is found below the Tertiary in the discovery well. This series is somewhat sandy near the top and base. The gummy Dockum shale is difficult to drill with cable tools but easily drilled with rotary equipment.

Santa Rosa Sandstone.—At the base of the Dockum group is the Santa Rosa sandstone 110 feet thick. This sand consists mainly of calcareous micaceous red sandstone with some interbedded red shale, and is water bearing.

PERMIAN SYSTEM

Post-Rustler Red Beds.—Between the Santa Rosa and the top of the "Evaporite Series" (anhydrite, salt, etc.) is about 200 feet of sandy red-beds, which are classified as Permian on the basis of general character.

"Evaporite Series."—DeFord and Wahlstrom have described the entire 2,500 feet of beds between the Post-Rustler red beds and the "White Lime" under the name of "Evaporite Series." This interval is occupied by a series of light-colored evaporites and gray elastics. In general the more soluble evaporites are found near the top of the series and the less soluble toward the base; that is, salt predominates at the top, anhydrite in the middle, limestone at the base. The elastics have a random distribution. At the top of the series is about 100 feet of anhydrite with about 50 feet of saliferous red sandstones and sandy red beds below, which are correlated with the Rustler formation of southern Eddy County.

Below the Rustler is the main potash-bearing series of the area, which is correlated with the Upper Castile. This salt body has a thickness of 950-1,000 feet. Thin anhydrite beds and very thin layers of red shale and gray shale are interbedded in the salt. Potash in the form of poly-halite is plentiful. Pockets of non-inflammable gas are common in the salt series, but are quickly exhausted. Beneath the main salt body is about 150 feet of anhydrite and red shale and a few stringers of salt. This series gives trouble in drilling, as the shale is cavey.

Almost midway in the "Evaporite Series" is the "Brown Lime" key bed. This bed, which is essentially solid limestone and 25-30 feet thick, is easily recognized in drilling. The top of the "Brown Lime" is correlated with the top of the Carlsbad formation. The "Brown Lime" usually yields a small flow of inflammable gas in a porous zone about 10 feet below the top. Just beneath the "Brown Lime" occurs a gray sand, which has yielded a showing of gas in a few wells.

Beneath the "Brown Lime" and down to the "Bowers Sand" the Carlsbad formation consists chiefly of anhydrite with little or no limestone, but some red and gray clastics.

The "Bowers Sand," which occurs about 350 feet below the top of the "Brown Lime" has a total thickness of about 50 feet. The sand, however, consists of interbedded sand, sandy shale, and anhydrite. Humble Bowers No. 1 well near the top of the structure produced oil at the rate of 413 barrels per day from this zone on a two-day test. The oil has a gravity of 37°-40 A. P. I., and has a paraffin base. Several wells have shown several million cubic feet of gas at this horizon.

Beneath the "Bowers Sand" the beds are predominantly anhydrite with red and gray clastics and thin stringers of salt in the discovery well.

Humble Bowers No. 1 disclosed the "Big Gas Pay" at a depth of 3,684 feet corresponding to a depth of 3,700 feet in the discovery well. The well after blowing open for several days gauged 50,290,000 cubic feet of gas. The well blew open for nearly a month before the gas was killed, and the flow showed no signs of exhausting itself. The total volume of gas in the "Big Gas Pay" in the Hobbs field is undoubtedly great, but to date practically none of this gas has been utilized. Rock pressure in the "Big Gas Pay" is estimated at 1,500 pounds per square inch.

Beneath the "Big Gas Pay" occur anhydrite and limestone in nearly equal amounts interbedded with gray limy sandstone, having a thickness of about 200 feet.

The basal member of the "Evaporite Series" is locally known as "The Sandy Section." This 100 feet of beds is composed of limy sandstone, limy shaley sandstone, limy shale, sandy limestone and limestone variously interbedded. Chemically "The Sandy Section" is predominantly calcium-magnesium carbonate, but sand is the characteristic material. The sandstone members are non-porous. The shaly and sandy beds in the basal part of "The Sandy Section" contain angular fragments derived from the slight erosion of the highest member of the underlying "White Lime."

"White Lime."—Beneath "The Sandy Section" in the Hobbs field is a dense, gray, pyritic limestone with a bluish tinge which forms the caprock of the main oil-producing horizon of the field. At from 10 to 30 feet below the top of this "White Lime" most wells find oil and gas in soft, very porous limestone or in caverns. Most of the members of the "White Lime," which has a total thickness of about 200 feet, contain no sand, although thin persistent sandstone beds do occur near the middle of that formation. Very black carbonaceous shale is also a minor constituent of the "White Lime."

Dark Anhydride Limestone.—The only well at Hobbs to penetrate through the "White Lime" is Midwest No. 6 Wright in sec. 14, T. 19 S., R. 38 E., outside the productive area. This well, after penetrating 190 feet of "White Lime," drilled 100 feet of dark anhydritic magnesian limestone, which is correlated with the San Andres limestone to the north on the basis of lithology as revealed by microscopic study of cuttings.

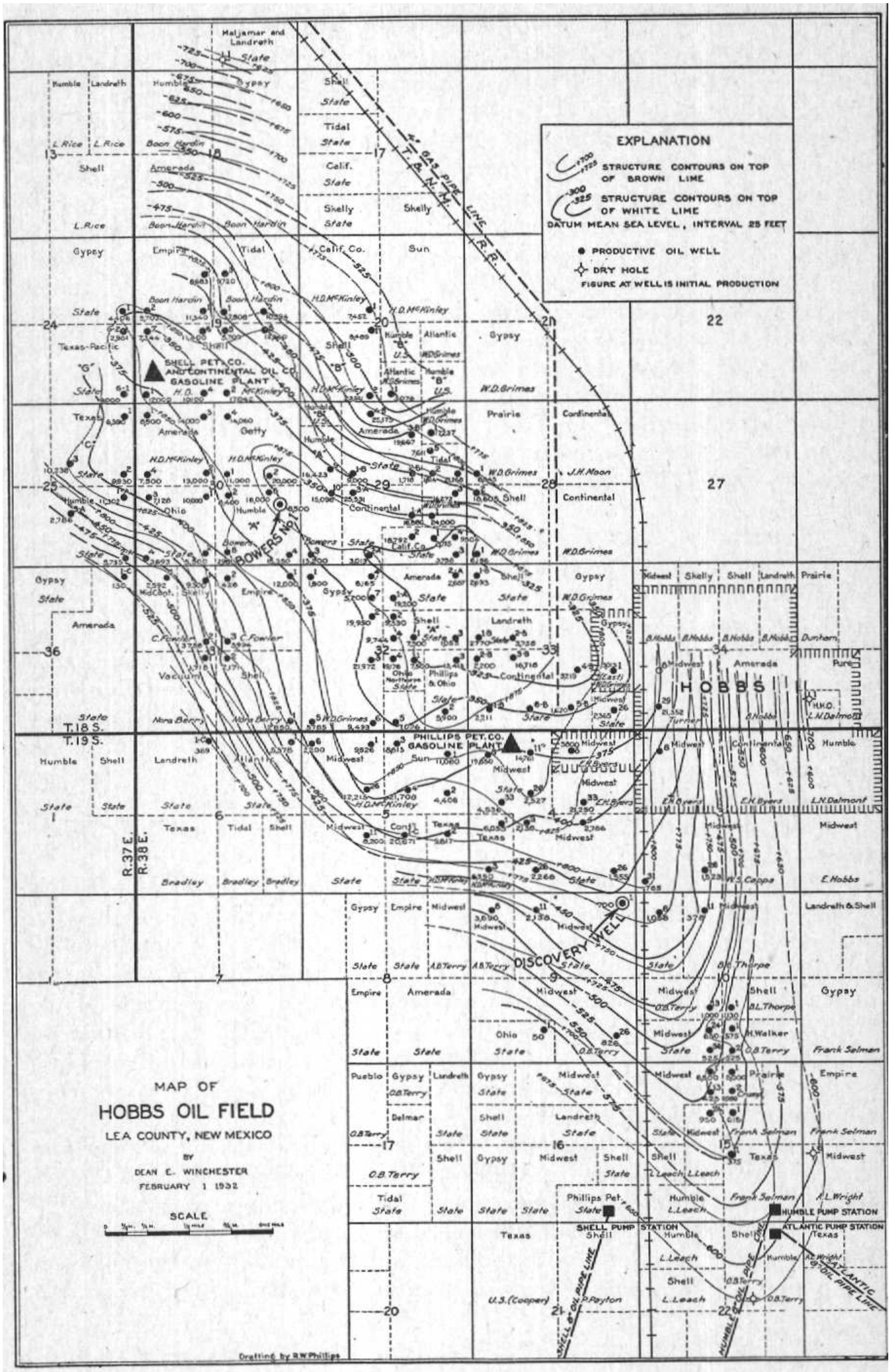

EXPLANATION
STRUCTURE CONTOURS ON TOP OF BROWN LIME
STRUCTURE CONTOURS ON TOP OF WHITE LIME
DATUM MEAN SEA LEVEL, INTERVAL 25 FEET
PRODUCTIVE OIL WELL
DRY HOLE
FIGURE AT WELL IS INITIAL PRODUCTION
MAP OF
HOBBS OIL FIELD
LEA COUNTY, NEW MEXICO
BY
DEAN E. WINCHESTER
FEBRUARY 1 1932
SCALE
HOBBS
DISCOVERY WELL
BOWERS No. 1
SHELL PET. CO. AND CONTINENTAL OIL CO. GASOLINE PLANT
PHILLIPS PET. CO. GASOLINE PLANT
SHELL PUMP STATION
HUMBLE PUMP STATION
ATLANTIC PUMP STATION
T. 18 S.
T. 19 S.
R. 37 E.
R. 38 E.
Drafting by R.W. Phillips

Figure 9.

STRUCTURE

The surface beds in the Hobbs field give no indication of the anticlinal structure which exists in the Permian formations below. Geophysical instruments were used to locate the structural high before drilling commenced, but now with 155 wells completed it is possible to map the subsurface structure with considerable certainty. The structure is a more or less regular anticlinal fold, having a general northwest-southeast trend. (See map, figure 9.) Contours drawn on successively deeper key horizons show slight difference in detail and slightly greater closure in the lower beds. The structure on the top anhydrite above the salt is slightly less accurate than the underlying "Brown Lime," and the "White Lime" shows most accurately the structure of the present producing horizon.

To July 1, 1932, only four wells have been drilled outside the area of production, two at the southeast extremity of the field, one on the east and one on the north. Four others have proven small-producer edge wells—Amerada No. 1 C, NE. cor. sec. 36, T. 17 S., R. 37 E.; Landreth No. 1 C, NE. cor. NW.1/4 sec. 6, T. 19 S., R. 38 E.; Ohio No. 1 State, SE.1/4 SW.1/4 sec. 9, T. 19 S., R. 38 E.; and Texas Production Co. Selman No. 1, NW. cor. SE.1/4 sec. 15, T. 19 S., R. 38 E. Because of this the total amount of structural closure as well as the configuration and actual limit of productivity are not known except at a few points. Wells outside the productive area show a maximum closure to the east and north of at least 300 feet and edge wells indicate a productive closure of 175 to 200 feet. The highest portion of the anticline is located west of the town of Hobbs near the northeast corner of sec. 32, T. 18 S., R. 38 E. Drilling has not yet shown the structural conditions in that part of the field immediately northwest of the town of Hobbs nor at the extreme northwest end of the field along the axis in sec. 24, T. 18 S., R. 37 E.

DeFord and Wahlstrom have suggested that the limits of production for the different proven horizons in the Hobbs field will be approximately as follows, based on the structure as shown by contours on the "White Lime."

Productive Limits of Proven Horizons in Hobbs Field

"Bowers Sand"	—400 feet "White Lime" contour.
"Big Gas Pay"	—400 feet "White Lime" contour.
Main "White Lime Pay"	—550 feet "White Lime" contour.

LAND OWNERSHIP

Present development in the Hobbs field indicates a total productive area of 9,700 acres for the "Ehite Lime" productive zone. Of this area nearly 39 per cent is owned by the State, about 4 per cent belongs to the Federal Government, and approximately 57 per cent is deeded land. Operating leases are distributed among 21 operators.

PRODUCTION

The total oil production of the Hobbs field to July 1, 1932, was 25,071,609 barrels. The following table, in addition to showing the production, gives an interesting comparison between the month by month rated potential of the field and the actual production as shown by total pipe-line runs.

Rated Potential and Actual Production of Oil in the Hobbs Field from Discovery to June 30, 1932

	Rated potential at beginning of month, barrels per day.	Average production, barrels per day.	Total production for period, pipe line runs, barrels.
Up to July 10, 1930			1,019,865
1930			
July 10-31	126,797	35,142	737,993
August	167,765	31,267	969,273
September	415,535	34,078	1,022,354
October	678,406	32,395	1,004,237
November	901,255	31,420	942,593
December	1,010,356	31,503	976,509
1931			
January	1,081,578	31,465	975,430
February	1,116,820	31,259	875,255
March	1,122,963	31,950	990,437
April		32,570	977,094
May	1,148,920	36,979	1,146,353
June		36,910	1,107,286
July	1,156,834	35,598	1,114,710
August		36,596	1,134,383
September	1,176,234	36,246	1,087,389
October	1,176,234	36,552	1,133,102
November	1,128,590	37,188	1,115,651
December	1,134,822	35,958	1,114,698
1932			
January	1,152,837	31,617	979,139
February		32,140	899,909
March	1,168,515	30,553	947,150
April	1,144,435	31,572	947,150
May	1,160,679	29,609	917,890
June	1,152,825	31,192	935,759
Total production			25,071,609

Present production of oil and gas in the Hobbs field is coming entirely from the "White Lime," which has a total thickness of about 200 feet. The gas and oil proven in the "Bowers Sand" zone and the gas in the "Big Gas Pay" are completely shut in, but undoubtedly future demands will make the development of these productive zones advisable. All but three of the productive wells in the field flow naturally.

Since July 10, 1930, all wells in the field have been operated under a proration agreement, and the production of each restricted to approximately 3 per cent of its rated potential. There is, therefore, little information regarding the possible behavior of wells under unrestricted production. Humble Bowers No. 1 was produced unrestricted from May 9 to June 30, 1930, and its daily record is, therefore, given below.

Production of Humble Bowers No. 1 *Well,*
May 9, 1930 - *June* 30, 1930, *in Barrels*

May 97,476	May 27	6,979	June 147,335
107,277	28	6,913	157,345
117,262	29	7,043	167,428
127,271	30	7,323	177,565
137,271	31	7,392	187,371
147,603	June 1	7,442	197,351
157,558	2	7,638	207,318
167,647	3	7,335	217,264
177,235	4	7,341	227,278
187,598	5	7,438	237,562
197,272	6	7,200	247,216
207,364	7	7,292	257,292
217,067	8	7,432	267,185
227,374	9	?	276,976
237,610	10	7,490	287,219
247,286	11	7,360	297,289
257,346	12	7,402	
267,425	13	7,329	307,210

This record shows exceptionally uniform production throughout a period of 53 days, but it must be borne in mind that at the time this record was made there were no other wells in the immediate vicinity and consequently no interfering effects.

The initial production for wells in the field varies greatly. (See map, figure 9.) These differences have caused considerable speculation among operators. Production comes primarily from porous and cavernous zones in limestone. The distribution of porosity is erratic and not altogether related to structure. Some of the largest wells are found well down on the sides of the structure, others on top. Some large wells are offset by small wells. Some of these differences may be due to methods of completion, but certainly relative porosity is responsible for most of the differences in initial production.

DeFord and Wahlstrom[1] make the following statement in discussion of the relation of porosity to structure.

That the porosity of the "White lime" at Hobbs is related to *its* structure is obvious. In general, the limestone is most porous on the crest of the anticline, less porous on the flanks, least porous beyond the limits of the oil pool.

Determinations of the actual porosities of limestone reservoirs are not practicable because the really productive openings are so large (ranging, in size from "mouse holes" to caverns) that core recovery is almost impossible. As previously stated, core loss is a better indication of a limestone "pay" than the recovery of porous material that bleeds oil. The only index of porosity in the Hobbs field is initial production of oil. * * *

Some of the possible reasons why initial production does not everywhere correspond with porosity follow. 1. The greater amount of gas in the top of the structure may there cause a more rapid outflow of oil from the same space than the less amount of gas on the flanks. 2. On the contrary, certain high wells may have a great excess of gas and correspondingly less oil. This was true of some of the wells high on structure which gauged less than 5,000 barrels a day. The production of oil has recently

[1] Op. cit., p. 76.

caused local "gas caps" to form and spread, thus introducing more wells into this category. 3. A well may fortuitously drill into a channel, crevice, or other opening so connected as to drain oil rapidly from considerable distance, thus gaining a greater initial production than the average surrounding porosity indicates.

The oil in the "White Lime" at Hobbs is accompanied by gas, and a relatively constant oil-gas ratio of approximately 900 cubic feet of gas to one barrel of oil was maintained up to March, 1931. Since that time the gas-oil ratio has increased somewhat. It is estimated that up to January 1, 1932, a total of 23,278,185,000 cubic feet of gas had been drawn from the "White Lime" producing zone.

Two plants for the extraction of natural gasoline from the gas of the field have been constructed, one by the Phillips Petroleum Co. and the other by the Shell Petroleum Corp. and the Continental Oil Co. From October, 1930. when these plants began to operate, to June 30, 1931, a total of 5,845,872,000 cubic feet of gas was treated, with a gross recovery of 10,209,058 gallons of gasoline. After the gasoline is extracted the gas is burned in flares or blown into the air.

The field supplies the town of Hobbs with gas for domestic use, and a 4-inch line carries gas 20 miles north to Lovington.

RESTRICTIONS OF PRODUCTION

Early in the development of the Hobbs field it became evident that the field was capable of yielding a much greater amount of oil per day than could be marketed to advantage. With this situation in mind a proration agreement providing for restricted production was made and entered into by all the operators in the field and the Commissioner of Public Lands of the State of New Mexico and was approved by the State Geologist. This agreement became effective on July 10, 1930, and all production since that date has been on a proration basis.

Under proration only the amount of oil that the purchasing companies have agreed to take has been produced. The field has been divided into 40-acre tracts, each tract being considered as a unit for proration purposes. One-fourth of the daily market outlet for the field has been prorated among the several producing units equally. The remaining three-fourths of the market outlet has been prorated to the several producing units in the ratio that the average daily potential production of the several units bears to the average potential production of the field. The average daily potential production of a tract or unit is the total of the daily potential production of all wells on the unit divided by the number of wells, and the total average daily potential of the field is the sum of the average potential of all the tracts or units. The number of wells on each unit varies from one to three, most units having only one well. The total potential of the field is of course somewhat greater than the total average potential. The daily potential production of each well has been obtained by multiplying by 24 the amount of oil produced during an open-flow test lasting one hour, or computed from a one-hour test through tubing.

On July 10, 1930, the Hobbs pool had a rated daily potential production of 126,797 barrels. In December of that year it had increased to 1,010,356 barrels, and in June, 1932, the daily potential was 1,152,825 barrels. During the period from July 10, 1930, to June 30, 1932, the actual daily production varied from 29,609 to 37,188 barrels.

It is not expected that the rated potential would be realized for more than a single day if all wells were produced simultaneously at their maximum rate. Experience has shown that, even under the prorated restricted production calling for the production of an average of only about 3 per cent of the rated potential of each well, water encroachment is a serious problem in parts of the field and certain wells are unable to yield their allowable production without using an excessive amount of gas. These and other production problems would become much more serious with an appreciable increase in the daily output. Restricted production is undoubtedly best for the field in terms of ultimate recovery, expressed either in barrels of oil or dollars and cents.

The establishment of proration in the Hobbs field brought together the engineers and officials of all producing companies and resulted in excellent cooperation. Production problems of each operator have been discussed by all as problems of the field rather than of particular wells.

Late in 1931 a careful study of the field was commenced by committees of engineers representing the operating companies with the view of unitizing the field. Under unit operation the entire field would be handled by a single company or operator as though it were one property. Each 40-acre tract or unit would be allowed a calculated percentage of the total future output of the field, and only those wells which could produce oil most efficiently would be operated. It was hoped that by unit operation of the field overhead and production costs might be reduced, scientific and economic development and exploitation carried out, and the field made to yield not only more oil but a greater profit for both operators and royalty owners. The unitization of a field already 60 per cent developed, with leases distributed among more than 20 companies and royalties owned by hundreds of people, has proven a Herculean task, but progress is being made. Even should the Utopia never be reached, the cooperation of the various companies, the mutual understanding by each of the problems of the others, and particularly the bearing of those problems on the whole field will undoubtedly enure to the benefit of all interested parties.

THE OIL

The oils from the two different oil pay zones of the Hobbs field have somewhat different qualities as is shown by the following analyses furnished by the United States Geological Survey. Oil from the upper or "Bowers Sand" is of a paraffin base whereas the oil from the main "White Lime" pay borders on an asphalt base.

Analysis of Oil from "Bowers Sand", Hobbs Field.

Humble Bowers Well No. 4 A; SE.¼ sec. 20, T. 18 S., R. 38 E. Sample taken by T. G. Taylor.
Depth to top of sand 3.161 feet. Depth of hole 3.260 feet.
9-5/8-inch casing cemented at 2,750 feet with 650 sacks.
Initial production 235 barrels oil, 1,500,0000 cubic feet gas daily.
Analysis by J. G. Crawford, July 31, 1930.

The Crude Oil.

Gravity		39.4° A. P. I.
Centrifuge; B. S., mud and water		0.80 per cent.
Sulphur		1.07 per cent.
Gravity		39.4° A. P. I.
Universal Saybolt viscosity at 100° F.		43 seconds.

Distillation (Air).

First drop		106°
Up to 392° F.	37.3 per cent	58.4° A. P. I.
392° to 482° F.	9.3 per cent	44.0° A. P. I.
482° to 527° F.	6.0 per cent	40.4° A. P. I.

Vacuum Distillation (40 mm.).

Less than 392° F	5.7 per cent.
393° F. to 482° F.	9.3 per cent.
482° F. to 527° F.	5.7 per cent.
527° F. to 572° F.	4.7 per cent.
Residuum	23.0 per cent.
Base	Paraffine.

Analyses of Oil from "White Lime" or Main Producing Horizon, Hobbs Field.

Sample No.	I		II	
The Crude Oil.				
Specific gravity (°A. P. I.)	37.0		34.8	
Centrifuge; B. S., mud and water (per cent).	0.45		0.1	
Sulphur (per cent).	1.57		1.47	
Universal Saybolt viscosity at 100° F., seconds.	40		43	
Distillation (Air).				
First drop.	115° F.		100° F.	
	Per cent	Gravity (°A. P. I.)	Per cent	Gravity (°A. P. I.)
Up to 392° F.	39.3	58.2	34.7	56.6
392° F. to 482° F.	12.3	36.5	9.0	38.5
482° F. to 527° F.	8.2	31.0	6.0	34.3
Vacuum Distillation (40 mm.).				
Up to 392° F.	1.3		4.7	
392° F. to 482° F.	7.2		8.3	
482° F. to 527° F.	3.3		5.0	
527° F. to 572° F.	4.2		4.7	
Residuum.	24.2		27.8	
Base.	Paraffine		Intermediate	

Sample No. 1 taken by E. A. Hanson from flow line Humble Bowers No. 1 Well, SE. ¼ sec. 30, T. 18 S., R. 38 E. Total depth of well 4,106 feet; top of "White lime" 4,006 feet; 7-inch casing set at 3,962 feet. Initial production 8,500 barrels. Analysis February 1, 1930.

Sample No. II taken by Foster Morrell from lead line Midwest Refining Co. No. 1 State Well, NE. cor. sec. 9, T. 19 S., R. 38 E. Total depth of well 4,245 feet; top of "White lime" 4,045 feet; plugged back to 4,217 feet; 8-inch casing set at 4,040 feet. Initial production 700 barrels. Analysis October 15, 1929.

THE GAS

The wells of the Hobbs field encountered gas at five horizons as follows:

Gas Horizons of the Hobbs Field

	Depth, feet.	Pressure, pounds per square inch.
1. Air Pockets (non-inflammable gas)	2,300-2,400	High
2. "Brown Lime"	2,750-2,950	1,400±
3. "Bowers Sand" (associated with oil)	3,150-3,250	1,450±
4. "Big Gas Pay"	3,600-3,750	1,500±
5. "White Lime" (associated with oil)	3,950-4,175	1,500±

Air pockets are found in the "Evaporite Series" mainly high on structure. Enough pressure and volume is encountered in some wells to clean the hole of drilling fluid and damage drilling equipment. This gas is quickly exhausted. No analysis of the gas is available.

The "Brown Lime" gas is usually found in small volume, but at high pressure both on and off structure. A small amount of this gas is produced for camp use as bradenhead gas. An analysis of the "Brown Lime" gas from the Texas Pacific No. G1 State well showed neither H_2S nor CO2.

The "Bowers Sand" gas is usually found associated with oil. As much as 35,000,000 cubic feet have been encountered. Analysis of this gas from Humble Bowers No. A2 well showed both H_2S and CO_2 to be absent. A small amount of "Bowers Sand" gas is produced for camp use as a bradenhead gas.

The gas in the "Big Gas Pay" is found only high on structure, and large volumes have been reported. Humble Bowers No. A4 well gauged 85,000,000 cubic feet from this horizon. This gas is cemented off by the oil string of casing in all Hobbs wells. The following is an average analysis of a sample containing the combined gases from the "Big Gas Pay," "Bowers Sand" and "Brown Lime" horizons as given by DeFord and Wahlstrom.[1]

Analysis of Combined Gas from "Big Gas Pay," "Bowers Sand" and "Brown Lime" Horizons, Hobbs Field

	Per Cent
H_2S	nil
CO_2	0.07
O_2	0.07
CH_4	58.
C_2H_6	21.
N_2	20.

The gas occurring with the oil in the main producing horizon ("White (Lime") and produced with the oil is the only gas utilized in large amounts in the field. It contains nearly 2 gallons of gasoline per thousand cubic feet, and this gasoline is extracted at the two gasoline plants in the field. The following analysis of this gas is taken from DeFord and Wahlstrom's rep ort.[2]

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[1] 0p. cit., p. 89.
[2] Idem.

Analyses of Gas from "White Lime," Hobbs Field

	I. Per Cent	II. Per Cent
H_2S	2.27	1.05
CO_2	4.00	5.25
O_2	1.06	0.81
CH_4	52.19	63.30
C_2H_6	7.16	3.34
Propane	13.31	9.09
Isobutane	2.49	1.32
Normal butane	6.99	5.29
Pentanes and Heavier	4.55	4.18
N_2	5.98	6.37
	100.00	100.00
Observed gravity	1.050	0.933
Caiculated gravity	1.044	0.938

I. Sample taken from meter station No. 13 (Phillips gas plant); gas from discovery well and the Midwest's State No. 8, NW.¼ sec. 10, T. 19 S., R. 38 E.

II. Sample from the Midwest's Byers No. 33, NE. ¼ sec. 4, T. 19 S., R. 38 E.

WATER

The various subterranean waters encountered in the Hobbs field are readily distinguished by chemical analysis. The following table of analyses is compiled from data given by DeFord and Wahlstrom.[1] Analyses were made in the laboratory of the Midwest Refining Co. gas plant, Salt Creek field, Wyo.

Analyses of Waters of the Hobbs Field

(Parts per million)

	I	II[a]	III	IV[c]	V[b]
Sodium (Na) (Calculated)	29	2,363	730	84,292	2,733
Calcium (Ca)	72	200	6	14,200	280
Magnesium (Mg)	22	70	Trace	10,500	262
Sulphate radical (SO_4)	82	1,010	716	682	41
Chloride radical (Cl)	42	3,370	143	185,000	0
Carbonate radical (CO_3)	0	0	51	0	4,107
Bicarbonate radical (HCO_3)	226	134	685	279	2,240
Total parts per million	473	7,147	2,331	294,953	9,663
Total solids by evaporation	420	6,740	1,660	284,700	7,960
Specific gravity	1.002	1.004	1.005		1.010

I. Water from Tertiary rocks, depth 50-62 feet.
II. Water from Upper Dockum sand, depth 455-462 feet.
III. Water from Santa Rosa sandstone, depth 1,235-1,250 feet.
IV. Water from "Bowers Sand," depth 3,720-3,725 feet.
V. Water from "White Lime" (bottom water), depth 4,220 feet.
a. Organic matter present.
b. Hydrogen sulphide (H=S) present.
c. No correction made for specific gravity, hence actual salinity is approximately 50,000 parts per million less than reported above.

Several wells in the field encountered water while drilling or were producing water on July 15, 1931. The following table taken from the report (unpublished) of a committee composed of engineers of the various companies to the chairman of the Hobbs proration committee shows the status of water in wells showing water on that date.

[1] Op. cit., pp. 86-88.

Water Conditions in the Hobbs Pool, July 15, 1931

Company.	Well No.	Elev.	T. D. Top water.	Datum of water.	Date of water.	Per cent water 7-1-31.	Remarks.
Amerada.	State C1.	3,655	4,236 T. D.	-581	1-30-31	21	Drilled into water 56 feet in "White Lime."
Landreth.	State C1.	3,642	4,221 T. D.	-579	1-22-31	6	Drilled into water 51 feet in "White Lime."
Midwest.	State 1 NE.¼-9	3,606	4,220	-614	12-20-28		Drilled into water 175 feet in "White Lime." P. B. to 4,213 feet. Shut off.
Midwest.	State 11 SW. ¼-5	3,619	4,193 T. D.		6-12-31	50.	Production, 3315 barrels.
Ohio.	State 1 sec. 9	3,602	4,207	-605	11-6-29		P. B. to 4,202 feet. 20 feet in "White Lime" for shut off.
Texas.	Selman 1	3,593	4,181	-586	9-17-30		Drilled into water 36 feet in "White Lime." P. B. to 4,175 feet for shut off.

Of the wells listed above all are edge wells except the two of the Midwest Refining Co.

Midwest State No. 1 discovery well in section 9 successfully shut off the bottom water. Midwest State No. 11 in the SW.¼ sec. 5, T. 19 S., R. 38 E., was completed January 28, 1931, for 8,200 barrels of oil. The well penetrated the "White Lime" 163 feet and according to the other wells should not be making water. It is suggested by the engineers that "the prolific zone in this well and Continental 1-C (initial production 20,671 barrels, on the next location east) is highly permeable down structure to water and that drainage is largely from down structure through this zone. This may prove to be a local point of water entry in the southwest portion of the field."

DRILLING AND PRODUCTION METHODS

The discovery well of the Hobbs field was drilled with cable tools. Practically all wells drilled since the discovery have used rotary equipment, although a few have used combination outfits. On most wells 122-foot steel derricks are used, and strict attention is paid to straight-hole drilling. A recent survey of the field showed but four crooked holes or 2.8 per cent of the total.

The casing program calls for three strings of casing. The surface pipe is set and cemented in the red-bed section at 200-250 feet. The second string, usually 9 5/8 inch, is set and cemented just above the "Brown Lime" at about 2,750 feet. This is required by the State and the Government to protect the salt and potash beds above and to prevent the caving of the red beds. The third or oil string, usually 7-inch, is set just above the "White Lime" at about 3,950 feet. Three-inch tubing is run in most wells to within a few feet of the bottom of the hole.

Three troublesome gas zones are encountered in most wells. The first ("Brown Lime") is at about 2,800 feet with a volume of 500,000 to

2,000,000 cubic feet but with heavy rock pressure. The second ("Bowers Sand") is encountered with oil at about 3,200 feet and has volumes varying from 4,000,000 to 50,000,000 cubic feet with rock pressure of 1,450 pounds per square inch. The third and last ("Big Gas Pay") occurs at about 3,700 feet with volumes up to 85,000,000 cubic feet and rock pressure of 1,500 pounds per square inch.

Eells are usually drilled with water to the 3,200 foot ("Bowers Sand") gas beyond which depth mud of sufficient weight is used to prevent blowing out. The weight of mud used varies from 13 ½ pounds to 15 pounds per gallon. Heavy mud is carried until the oil string of casing is cemented. The most satisfactory drilling mud for this field has been found to be made of barytes and a suspensoid of sufficient proportion to prevent settling. Due to the great expense of this mud, a mixture of barytes, clay and suspensoid is more commonly used. Mud costs are dependent upon the location of the well. In the high-pressure gas areas mud costs range from $3,000.00 to $25,000.00 whereas outside that area they are as low as $300.00.

Total drilling costs in the high-pressure gas area have varied from $60,000.00 to $110,000.00, the normal cost being from $60,000.00 to $75,000.00. Eells outside the high-pressure gas area cost from $45,000.00 to $65,000.00.

Oil from the field is collected through about 50 miles of gathering lines to the tank farms of the Humble, Atlantic and Shell Pipe Line companies. These companies together with the Tidal Oil Co. have tankage at the south end of the field capable of storing 328,000 barrels from which tankage it is pumped out of the State through three 8-inch pipe lines, one to Midland and the other two to Wink, Texas.

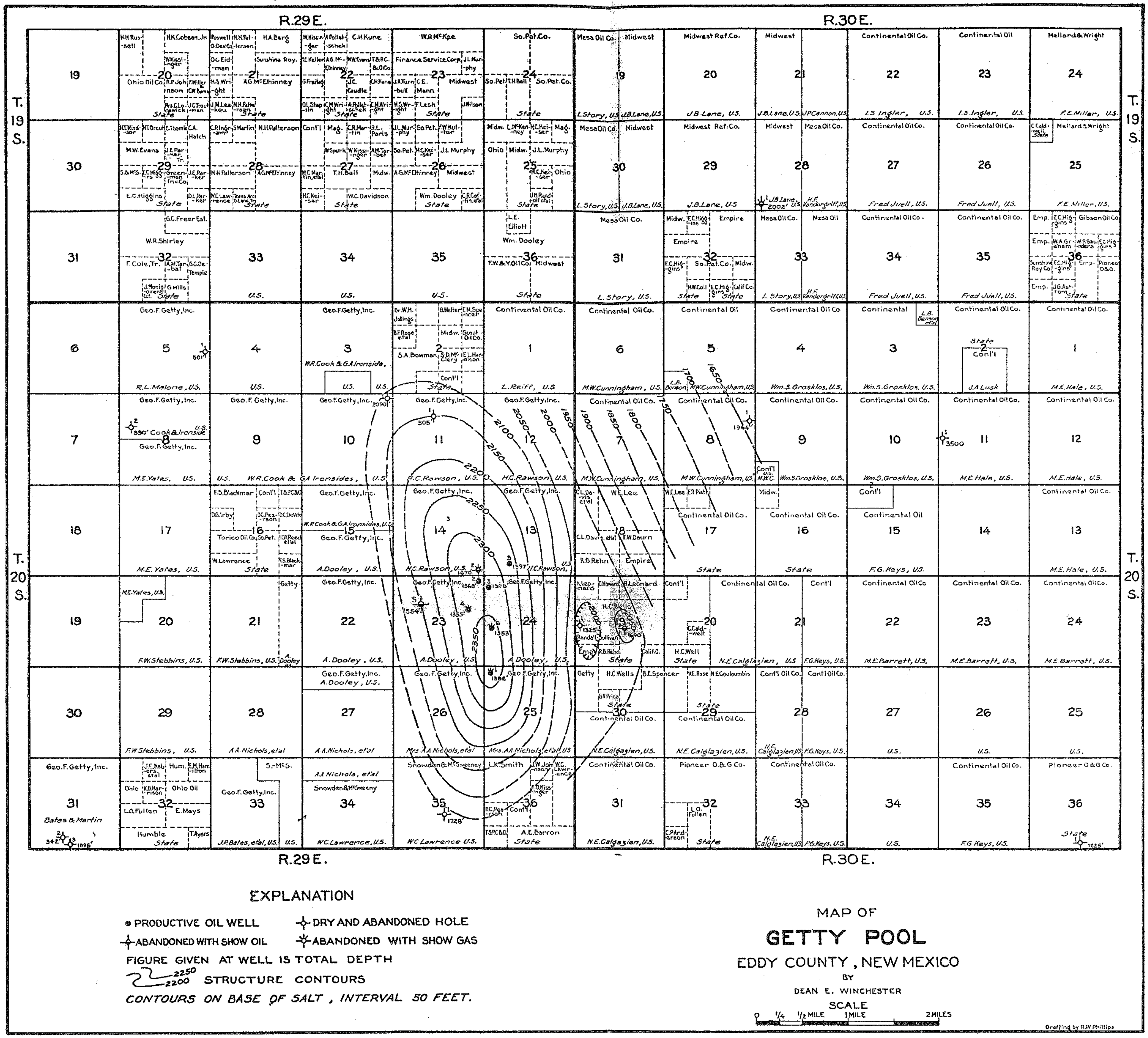
FUTURE DEVELOPMENT

Eith 155 wells completed (Feb. 1, 1932) the limits of production for the field have not been defined along the axial trend to the northwest and on the northeast side in secs. 28 and 33, T. 18 S., R. 38 E. (See map, fig. 9) Based upon the drilling of one well per 40-acre tract, it is probable that nearly 100 additional productive wells can be completed before the field is drilled up. It is conservatively estimated that the field will ultimately produce 150,000,000 barrels of oil from the present producing zone and that by proper repressuring and the development of proven oil producing sands above this zone the total may be greatly increased.

Drilling to date in the Hobbs pool has tested formations down to the top of the San Andres limestone, but not deeper. Future developments should include not only the exploitation of known productive horizons above the "Ehite Lime" zone now being produced, but also the testing of possible productive beds below.

GETTY POOL

Oil was first discovered in the Getty pool in November, 1927, when the George F. Getty Co. Dooley No. 2 well in the NE. cor. sec. 23, T. 20 S., R. 29 E., came in for 200 barrels of oil at 1,368 feet. The field


R.29E.
R.30E.
T. 19 S.
T. 20 S.
EXPLANATION
PRODUCTIVE OIL WELL
DRY AND ABANDONED HOLE
ABANDONED WITH SHOW OIL
ABANDONED WITH SHOW GAS
FIGURE GIVEN AT WELL IS TOTAL DEPTH
2250
2200
STRUCTURE CONTOURS
CONTOURS ON BASE OF SALT, INTERVAL 50 FEET.
MAP OF
GETTY POOL
EDDY COUNTY, NEW MEXICO
BY
DEAN E. WINCHESTER
SCALE
0 1/4 1/2 MILE 1 MILE 2 MILES
Drafting by R.W. Phillips

as outlined today is approximately 1½ miles long, north to south, and less than a mile wide. The field is located in a sand-covered area 15 miles northeast of Carlsbad with which it is connected by a good auto road.

Low-gravity oil is found in a lime zone which occurs only a few feet below the base of the salt series. Structure contours drawn on the base of the salt (see Plate XXVIII) show the production to be on the top of an elongated dome having a closure of more than 250 feet. Willis[1] has attributed the structure to "regional tilting and to compaction" or "differential deposition and compaction over the topographic elevation of the reef," referring to the "Capitan Reef" which is known to extend into the basin from the west. Blanchard and Davis [2] in the same bulletin make the statement that "The Getty pool in T. 20 S., R. 29 E., the producing area in the vicinity of Jal, New Mexico, the Leck area in northern Winkler County, Texas, and the main Hendricks pool in the same county are located near the margin of the reef."

The initial production of wells in the Getty pool ranges from 35 barrels per day in Nicholas No. 1 at the south end of the field to 750 barrels per day in Dooley No. 4 in the SE.¼ NE.¼ sec. 23. Nicholas No. 1, although the smallest producer in the field, is one of the highest on structure as indicated by the base of the salt. The aggregate initial production of the six producing wells in the field was 2,405 barrels per day. The entire field is owned by the George F. Getty Co.

The oil, which is of asphaltic base, has a gravity of 21° A. P. I., and on distillation yields only a small percentage of gasoline. The following analyses were furnished by the George F. Getty Co.

Analysis of Oil from Dooley Lease, Getty Field

Determinations	
Specific gravity at 60° F.	0.9270
Gravity A. P. I.	21.0°
M. & B. S.	0.1 per cent
Tops (steam distilled)	19.1 per cent
Gravity A. P. I., 60° F. of tops	39.8°
Sulphur (S) in tops	0.34 per cent
Distillation Test	
U. S. Motor gasoline	7.0 per cent
437° F. end point distillate	11.0 per cent
Gravity of 437° F. fraction	45.6° A. P. I.
Kerosene stock	7.7 per cent
Gravity of kerosene stock	36.2° A. P. I.
Light fuel oil	4.5 per cent
Gravity of light fuel oil	29.6° A. P. I.
Road oil, 60/70 per cent asphalt	80.9 per cent
Characteristics of Road Oil	
Asphalt, 100° penetration at 77° F	65.0 per cent
Flash point. Pensky Marten's c/c	270° F.
Viscosity, Engler at 122°	26°
Water and sediment	0.1 per cent
Paraffin wax or scale	0.39 per cent

[1] Willis, Robin, Structural development and oil accumulation in the Texas Permian: Am. Assoc. Petroleum Geologists Bull. vol. 13, No. 8, pp. 1036-1038, 1929.

[2] Blanchard, W. Grant, Jr., and Davis, Morgan J., Permian stratigraphy and structure of parts of southeastern New Mexico and southwestern Texas: Am. Assoc. Petroleum Geologists Bull. vol. 13, No. 8, p. 994. 1929.

Analysis of Oil from Rawson Lease, Getty Field

Determinations	
Water by distillation	Trace
Specific gravity at 60° F.	.9297=20.7° A. P. I.
Sulphur (S)	1.22 per cent
Asphalt	48.0 per cent
Paraffin	3.1 per cent
Distillation Test	
Tops over at 600° F. (gravity 39.3° A. P. I.)	23.3 per cent
U. S. motor gasoline	4.5 per cent
Gasoline stock, 437° F. end point, gravity 50.5° A. P. I.	10.3 per cent
Kerosene stock (gravity 38.2° A. P. I.)	8.6 per cent
Stove distillate	4.4 per cent
Fuel oil (gravity 17.0° A. P. I.)	76.7 per cent

The oil from the Getty pool appears to be valuable chiefly for road oil. The field is without a pipe line, and all of the oil produced and marketed has been transported by truck to the railroad at Carlsbad and Artesia. The wells at no time have been produced to capacity. The total production of the field to July 1, 1931, amounted to only 141,155 barrels.

LEA POOL

The townsite of Lea is located on the "Caprock" in sec. 2, T. 21 S., R. 33 E., Lea County. It is approximately 45 miles east of Carlsbad on the Atchison, Topeka & Santa Fe railroad and 25 miles west of Eunice on the recently constructed Texas-New Mexico railway. The Lea oil pool surrounds the townsite. Its northwest extension includes a well in sec. 34 and the one in sec. 18, T. 20 S., R. 24 E. (See map, fig. 10.)

The surface surrounding the main portion of the producing area is typical flat "Caprock" country, while to the northwest the area is more dissected and covered by soft sand. No surface evidence of geologic structure is present. Lea is approximately 3,775 feet above sea level.

The discovery well in the Lea pool was completed in April, 1929, by the Texas Co. on the Beulah Lynch permit in sec. 34, T. 20 S., R. 34 E., and was good for about 900 barrels of oil on the pump at 3,731 feet. In August, 1929, Cranfill-Reynolds Co. put down their No. 1 State in the SE.¼ sec. 2, T. 21 S., R. 33 E., which had an initial production of 1,700 barrels through 3-inch tubing. To date 11 producing wells have been completed in the field, and five dry holes have been drilled in the immediate vicinity of the productive area. Up to Dec. 31, 1930, the pool had produced about 4,500,000 barrels of pipe-line oil. All wells are pumped, there being practically no gas in the area.

Geologic structure on the top of the "Brown Lime" just above the productive zone, shows the Lea pool to be located at the end of a gently plunging but steep-sided nose, which plunges to the southeast. (See map, fig. 10.) The wells drilled fail to indicate a structural closure to the northwest.

The Continental Oil Co. drilled its No. 1 Flint along the axis of the structure in sec. 28, T. 20 S., R. 34 E., between two producing wells. This well went to a total depth of 3,890 feet, or more than 250 feet deeper than the Texas Production Company's Lynch well only three-quarters of a mile to the southeast, without finding production. It appears, there-

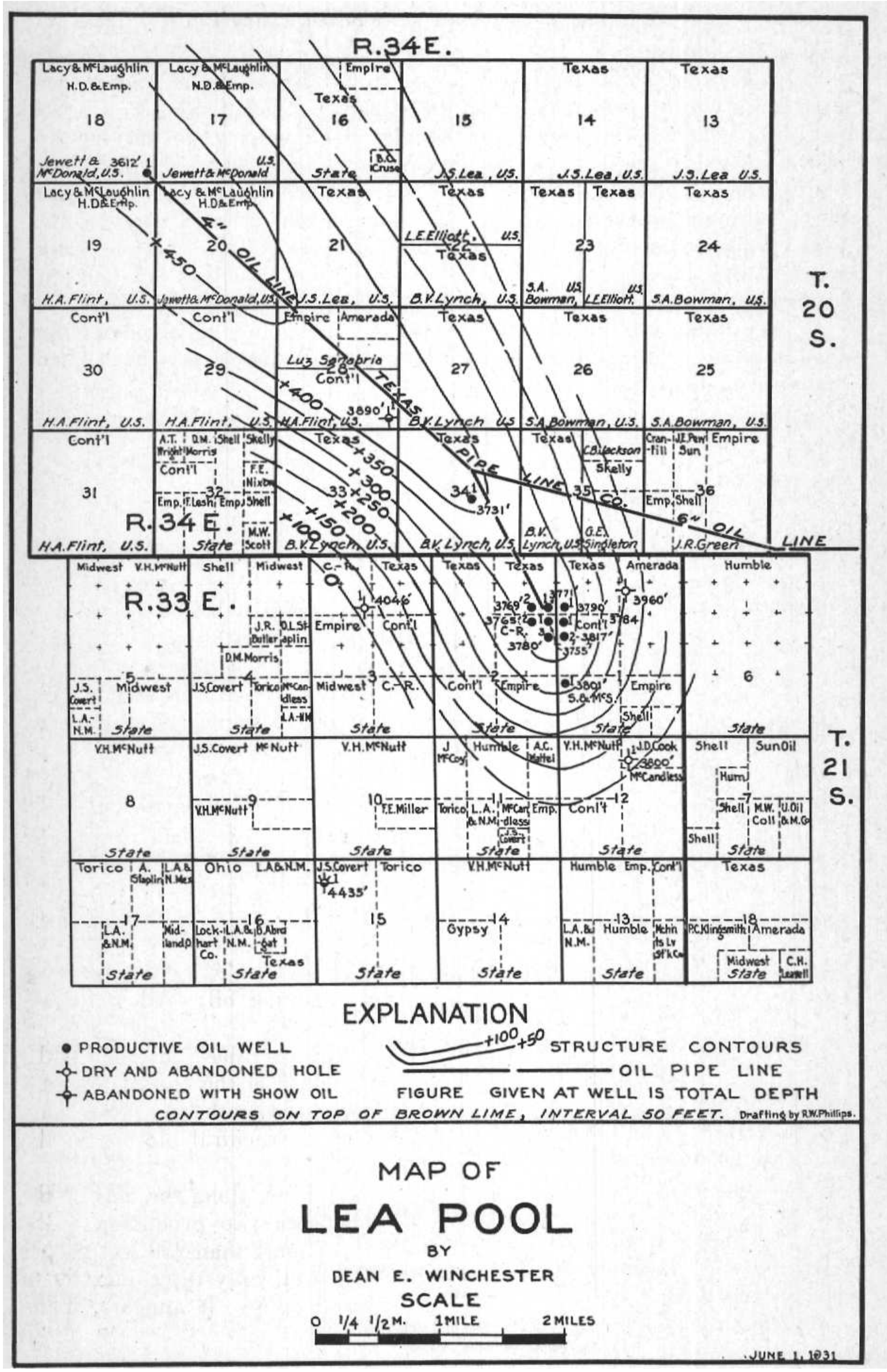

R.34E.
R.34 E.
R.33 E.
T. 20 S.
T. 21 S.
4" OIL LINE
TEXAS PIPE LINE CO.
6" OIL LINE
EXPLANATION
PRODUCTIVE OIL WELL
DRY AND ABANDONED HOLE
ABANDONED WITH SHOW OIL
+100 +50 STRUCTURE CONTOURS
OIL PIPE LINE
FIGURE GIVEN AT WELL IS TOTAL DEPTH
CONTOURS ON TOP OF BROWN LIME, INTERVAL 50 FEET.
Drafting by R.W. Phillips.
MAP OF
LEA POOL
BY
DEAN E. WINCHESTER
SCALE
0 1/4 1/2M. 1MILE 2MILES
JUNE 1, 1931

Figure 10.

fore, that oil accumulation is controlled by a combination of structure and erratic porosity.

Production in the Lea pool comes from a lime and sand zone occurring only a short distance below the salt series, and it is quite probable that the productive beds are closely related to, if not part of the Capitan reef described in the introductory description of the Southeast Area of the State, pages 139-145. The producing wells are from 3,594 to 3,817 feet deep, but some of the outside dry holes are much deeper. Most of the wells produce clean pipe-line oil at first, but after a few months water accompanies the oil. Several wells which were originally completed as producers have since been abandoned.

The oil has a gravity of 30° - 33° A. P. I., and contains about 1.5 per cent sulphur. The following analyses were furnished by the United States Geological Survey.

Analyses of Oil from Lea Pool.

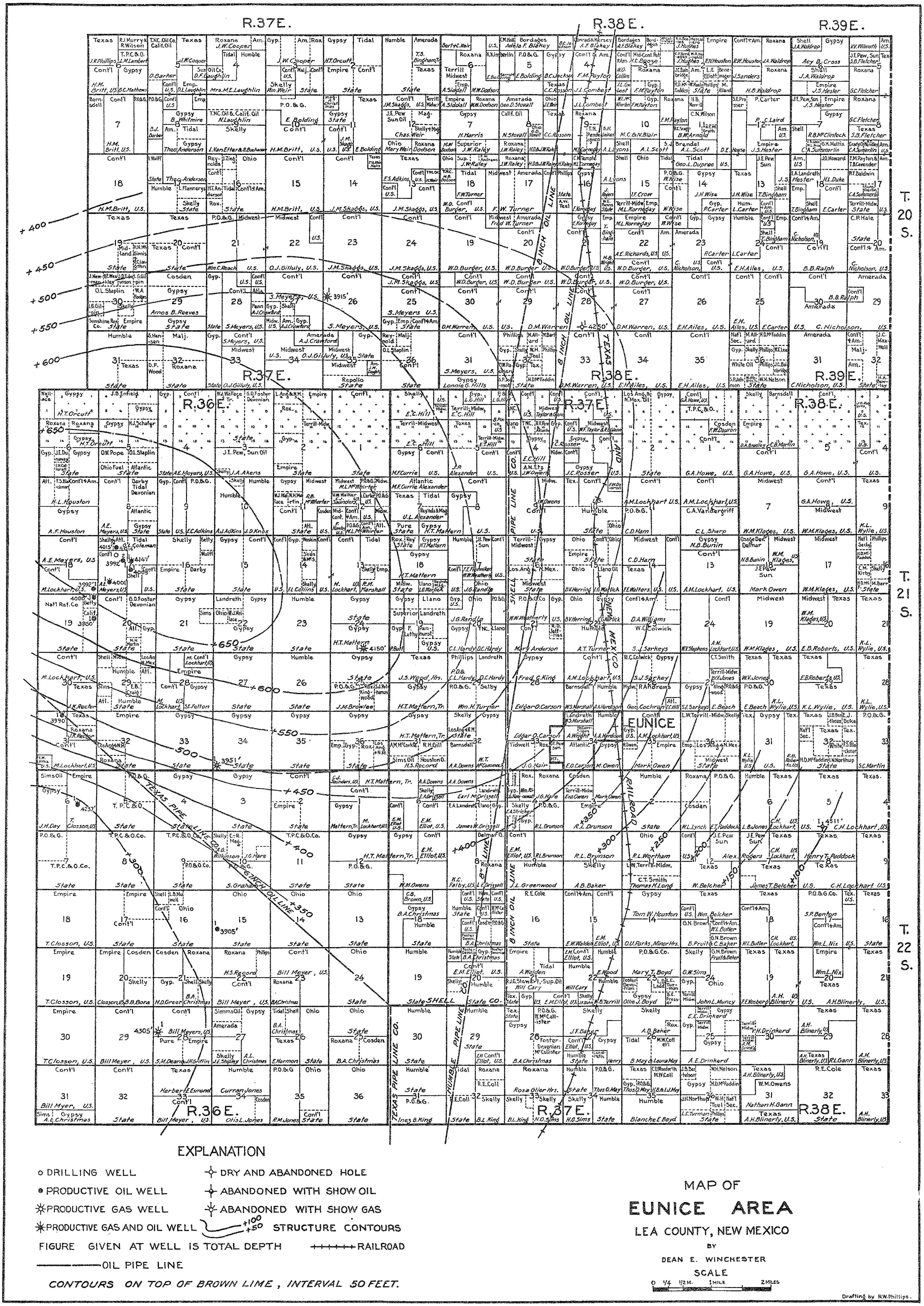
Sample No.	29-018		29-019		29-023	
The Crude Oil.						
Specific gravity (°A. P. I.).	30.7		30.7		33.2	
Centrifuge; B. S., mud and water (per cent).	1.0		0.15		4.4	
Sulphur (per cent).	1.43		1.53		0.67	
Universal Saybolt viscosity at 100° F., seconds.	66		60		49	
Distillation (Air)						
First drop.	106° F.		122° F.		134° F.	
	Per cent	**Gravity (°A. P. I.)**	**Per cent**	**Gravity (°A. P. I.)**	**Per cent**	**Gravity (°A. P. I.)**
Up to 392° F.	27.0	54.2	27.3	54.9	28.3	55.9
392° F. to 482° F.	9.3	38.9	9.0	39.3	10.3	41.8
482° F. to 527° F.	5.7	35.8	4.0	35.6	6.7	36.1
Vacuum Distillation (40 mm.).						
Up to 392° F.	6.3		5.8		3.3	
392° F. to 482° F.	7.7		11.0		8.0	
482° F. to 527° F.	6.0		5.5		4.5	
527° F. to 572° F.	5.3		6.2		4.7	
Residuum.	32.7		31.2		34.2	
Base.	Intermediate		Intermediate		Intermediate	

Sample No. 29-018; Cranfill-Reynolds Co. No. 1 State Well; sec. 2, T. 21 S., R. 33 E.
Sample No. 29-019; Texas Production Co. Beulah Lynch No. 1 Well; sec. 34, T. 20 S., R. 34 E.
Sample No. 29-023; Henderson, Dexter & Blair Jewett No. 1 Well; sec. 18, T. 20 S., R. 34 E.

EUNICE AREA

The Eunice area in Lea County, as defined in this report, includes T. 20 S., Rs. 37, 38 and 39 E., and Tps. 21 and 22 S., Rs. 36, 37, and 38 E. (See Plate XXIX.) The area is crossed from north to south by the Texas-New Mexico railroad and by the Texas, Humble and Shell oil pipe lines. The town of Eunice is located in sec. 34, T. 21 S., R. 37 E., near the center of the area. Surface evidences of geologic structure are lacking, as practically the whole area is covered by recent sands and caliche.

The first well drilled in this area, Texas Production Co. No. 1 Lockhart in sec. 5, T. 22 S., R. 38 E., was abandoned at 4,507 feet in 1927. The second well, Gypsy No. 1 State in sec. 34, T. 21 S., R. 36 E., was completed a year later as a gas well good for 20,000,000 cubic feet. The


R.37E.
R.38E.
R.39E.
R.36E.
T. 20 S.
T. 21 S.
T. 22 S.
EUNICE
8 INCH OIL LINE
TEXAS PIPE LINE CO.
HUMBLE PIPE LINE
SHELL PIPE LINE CO.
TEXAS AND NEW MEXICO RAILROAD
EXPLANATION
DRILLING WELL
PRODUCTIVE OIL WELL
PRODUCTIVE GAS WELL
PRODUCTIVE GAS AND OIL WELL
FIGURE GIVEN AT WELL IS TOTAL DEPTH
OIL PIPE LINE
DRY AND ABANDONED HOLE
ABANDONED WITH SHOW OIL
ABANDONED WITH SHOW GAS
+100
+50
STRUCTURE CONTOURS
RAILROAD
CONTOURS ON TOP OF BROWN LIME, INTERVAL 50 FEET.
MAP OF
EUNICE AREA
LEA COUNTY, NEW MEXICO
BY
DEAN E. WINCHESTER
SCALE
0 1/4 1/2 M. 1 MILE 2 MILES
Drafting by R.W. Phillips.

Wells Drilled in Eunice Area

Company.	Well.	Location Sec., T.-S., R.-E.	Total Depth, Feet.	Date Completed.	Remarks.
Texas Production Co.	No. 1 Lockhart.	5 - 22 - 38	4,507	Nov. 28, 1927.	Dry and abandoned.
Gypsy Oil Co.	No. 1 State.	34 - 21 - 36	3,951	Jan. 18, 1929.	6,000,000 cubic feet gas at 3,218-41 feet; 5,000,000 cubic feet gas at 3,477-3.532 feet; 9,000,000 cubic feet sulphur gas at 3,532-43 feet; 7,000,000 cubic feet gas at 3,548 feet; completed as 20,000,000 cubic feet gas well. 1,280 pounds rock pressure.
Continental Oil Co.[a]	No. 1 Lockhart.	31 - 21 - 36	3,990	Mar. 8, 1929.	Initial production, 278 barrels oil after shot.
Continental Oil Co.[a]	No. 1 Warren.	28 - 20 - 38	4,215	Mar. 14, 1929.	Dry and abandoned.
Continental Oil Co.[a]	No. 1 Meyers Per.	26 - 20 - 37	3,915	Mar. 28, 1929.	Estimated 150 barrels oil and 4,000,000 cubic feet gas; completed for 1,500,000 cubic feet gas, 1,200 pounds rock pressure.
Gypsy Oil Co.	No. 1 Mattern.	24 - 21 - 36	4,150	Nov. 1, 1929.	Completed 4,000,000 cubic feet gas and 10 barrels oil.
Continental Oil Co.[a]	No. 1 A. E. Meyers.	17 - 21 - 36	4,001	Feb. 6, 1930.	40,000,000 cubic feet gas (estimated) at 3,255-78 feet; 77,000,000 cubic feet gas (tested) at 3,850 feet; completed as 1,300 barrel oil well.
Empire Gas & Fuel Co.	No. 1 Closson.	6 - 22 - 36	4,237	May 30, 1930.	80,000,000 cubic feet gas at 3,540 feet; 110,000,000 cubic feet gas at 3,650 feet; completed as 140 barrel oil well.
Geo. F. Getty.	No. 1 State.	19 - 21 - 36	4,000	Sept. 20, 1930	Initial production, 1,142 barrels oil after shot.
Ohio Oil Co.	No. 1 State (McDonald).	15 - 22 - 36	3,904	Dec. 18, 1930.	24,000,000 cubic feet gas and 10 barrels oil.
Tidal Oil Co.	No. 1 Coleman.	17 - 21 - 36	4,147	Oct. 30, 1930.	2,000.000 cubic feet gas at 2,990 feet; 8,000,000 cubic feet gas at 3,139 feet. Initial production, 950 barrels oil and 4,000,000 cubic feet gas.
Continental Oil Co.[a]	No. 1 Bill Meyers.	28 - 22 - 36	4,304	Jan. 4, 1931.	23,000,000 cubic feet gas (estimated) at 3,280 feet; 30,000,000 cubic feet gas (estimated) at 3,750 feet; plugged back to 3,772 feet for gas well.
Continental Oil Co.	No. 2 A. E. Meyers.	17 - 21 - 36	3,992	Jan. 10, 1931.	Initial production after shot, 260 barrels oil.
Shell Petroleum Co.	No. 1 Coleman.	17 - 21 - 36	4,005	Jan. 20, 1931.	Initial production, 214 barrels oil after shot, 47,000,000 cubic feet gas at 3,555 feet.
Continental Oil Co.	No. 1 A. Lockhart.	18 - 21 - 36	3,992	Feb. 10, 1931.	422 barrels oil plus some water.
Atlantic Prod. Co.	No. 1 Coleman.	17 - 21 - 36	4,015	Mar. 20, 1931.	Initial production, 1,194 barrels oil.
California Co.	No. 1 Meredith.	19 - 21 - 36	3,950	Apr. 2, 1931.	Initial production, 225 barrels oil and 667,000 cubic feet gas.

[a]Drilled by the Marland Oil Co. of Colo., and later acquired by the Continental Oil Co.

gas had a rock pressure of 1,280 pounds and tested 0.7 gallons of gasoline per 1,000 cubic feet of gas. Late in 1929 the Continental Oil Co. (Marland Oil Co. of Colo.) in its A. E. Meyers No. 1 well in sec. 17, T. 21 S., R. 36 E., went through several big gas flows, one of which tested 77,000,000 cubic feet. The well was finally completed as a 1,220-barrel oil well at a total depth of 4,001 feet, and was the first oil well in the area. Seventeen wells have been drilled, of which four were completed as gas wells, 11 as oil wells and only two were dry.

The table, page 173, gives the record of drilling up to July 1, 1931.

All of the wells in the Eunice area appear to have reached the "Crystalline" or "White Lime" below the Carlsbad lime series. At least three of the wells were drilled 500 feet below the top of the "Crystalline Lime" but each was plugged back to just below the top after finding nothing of commercial interest. Drillers' logs of these wells do not record dark lime which can be correlated with the San Andres. All of the important gas production of the area comes from horizons above the "Crystalline Lime" in the zone which is correlated with the Carlsbad lime. In some of the wells much gas was found at horizons which may well correlate with both the "Bowers Sand" and the "Big Gas Pay" of the Hobbs field. Practically all of the oil production of the field comes from either just above or just below the top of the "Crystalline Lime."

Tentative correlations of the "Brown Lime" and the "Crystalline Lime" horizons over the area show that the interval between these two horizons gradually thins from north to south as indicated on the cross section, Plate XXV, page 146.

The subsurface structure on the top of the brown lime, as indicated by the scattered wells so far drilled in the area, is a broad dome-shaped uplift with its highest part in secs. 16 and 17, T. 21 S., R. 36 E. It is, however, quite probable that additional drilling will entirely change the conception of the structure as indicated by the contours on the map of the area, Plate XXIX.

The oil produced in the Eunice area has a gravity of 30° to 32° A. P. I., as shown by the following analyses furnished by the United States Geological Survey. The sulphur content is from 1.49 to 1.63 per cent.

Analyses of Oil from Eunice Area.

Sample No.	29-027		30-08	
The Crude Oil.				
Specific gravity (°A. P. I.).	30.6		32.8	
Centrifuge; B. S., mud and water (per cent).	0.15		Trace	
Sulphur (per cent).	1.65		1.49	
Universal Saybolt viscosity at 100° F., seconds.	56		47	
Distillation (Air).				
First drop.	151° F.		114° F.	
	Per cent	Gravity (°A. P. I.)	Per cent	Gravity (°A. P. I.)
Up to 392° F.	22.7	49.5	32.0	52.8
392° F. to 482° F.	12.2	40.2	12.0	38.2
482° F. to 527° F.	7.7	35.5	5.7	33.7
Vacuum Distillation (40 mm.).				
Up to 392° F.	4.3		5.0	
392° F. to 482° F.	11.8		8.3	
482° F. to 527° F.	5.8		5.5	
527° F. to 572° F.	6.2		6.0	
Residuum.	29.3		25.5	
Base.	Intermediate		Intermediate B	

Sample No. 29-027; Continental Oil Co. (Marland) Lockhart No. 1 Well; sec. 31, T. 21 S. R. 36 E.
Sample No. 30-08; Empire Gas & Fuel Co. Closson No. 1 Well; sec. 6, T. 22 S., R. 36 E.

COOPER AREA

The Cooper area is described as including Tps. 23 and 24 S., Rs. 36, 37 and 38 E., Lea County, and lies between the Jal area on the south and the Eunice area on the north. It is served by the oil pipe lines of the Humble Pipe Line Co. and Texas Pipe Line Co., and by the Texas-New Mexico railway.

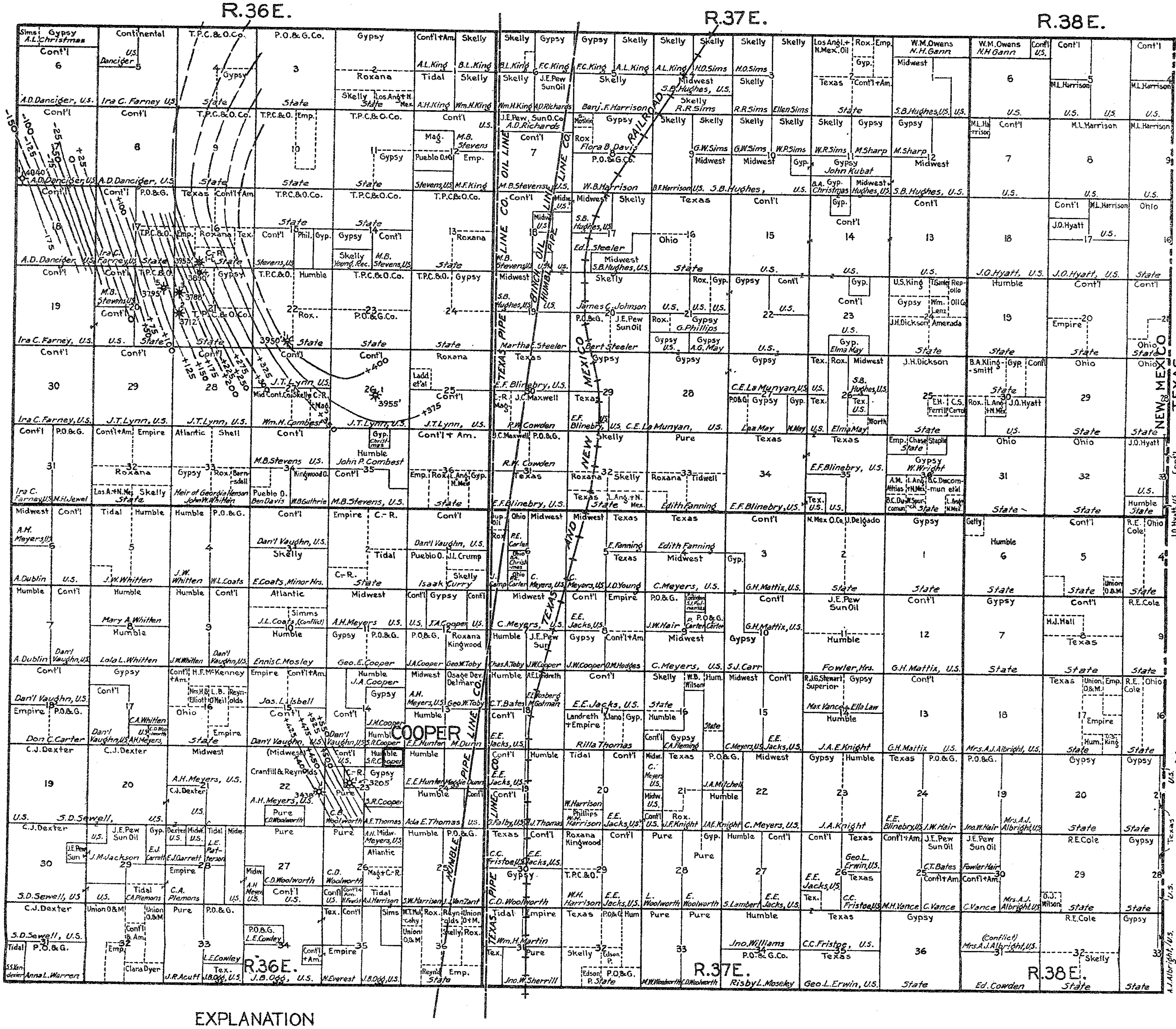
The surface of the area is covered by caliche and soft sand, with the result that prior to the completion of the wells in the area, there was no evidence of geologic structure. Even now the completed wells are confined to so small a percentage of the area that the knowledge of subsurface structure is very incomplete. The contours shown on the accompanying map, Plate XXX, give some suggestions of the structural conditions as portrayed by the position of "Brown Lime," which occurs only a short distance above the productive zone in the lime series. The "Brown Lime" is shown to have a relatively steep westerly dip, but minor undulations are suggested.

Drilling started in the Cooper area in 1928. Ten wells have been completed to date, of which eight obtained gas or oil or both and two were dry. In future drilling, large gas wells and moderately large oil wells can be expected.

The history of drilling in the Cooper area is shown on the following table.

Wells Drilled in Cooper Area

Company.	Well.	Location Sec., T.-S., R.-E.	Total Depth, feet.	Date Completed.	Remarks.
Marland Oil Co.	No. 1 Danciger.	7 - 23 - 36	4,040	Dec. 13, 1928.	Dry and abandoned.
Marland Oil Co.	No. 1 Lynn.	26 - 23 - 36	3,930	Mar. 1, 1929.	15,000,000 cubic feet sulphur gas at 3,091 feet; 25,000,000 cubic feet gas at 3,208 feet; 50,000,000 cubic feet gas at 3,779 feet. Plugged back to 3,650 feet and completed for 30,000,000 cubic feet gas.
Texas Pacific Coal & Oil Co.	No. 1 State.	22 - 23 - 36	3,995	June 5, 1929.	Initial production, 12,000,000 cubic feet gas.
Cranfill-Reynolds Co.	No. 1 Myers.	22 - 24 - 36	3,438	July 18, 1929.	Estimated 90,000,000 cubic feet gas.
Texas Pacific Coal & Oil Co.	No. 2 State.	21 - 23 - 36	3,712	Oct. 12, 1929.	Tested 14,000,000 cubic feet gas at 3,637 feet; estimated 30,000,000 cubic feet gas at 3,682 feet; initial production, 350 barrels oil, 28.9° Baume.
Cranfill-Reynolds Co.	No. 1 Cushing.	23 - 24 - 36	3,205	Nov. 24, 1929.	30.000.000 cubic feet gas at 3,146 feet. Initial production, 40,-000,000 cubic feet gas.
Texas Pacific Coal & Oil Co.	No. 3 State.	21 - 23 - 36	3,717	Mar. 2, 1930.	Estimated 15,000,000 cubic feet gas at 3,467-95 feet. Initial production, 1,687 barrels oil, flowing.
Cranfill-Reynolds Co.	No. 1C State.	16 - 23 - 36	3,953	May 6, 1930.	2,000.000 cubic feet gas at 3,325 feet; 11,000,000 cubic feet gas at 3,357-64 feet; 10,000,000 cubic feet gas at 3,440 feet. Initial production, 220 barrels fluid, 68 per cent oil.
Texas Pacific Coal & Oil Co.	No. 4A State.	21 - 23 - 36	3,790	June 4, 1930.	Initial production, 40 barrels oil.
Texas Pacific Coal & Oil Co.	No. 5A State.	20 - 23 - 36	3,795	Aug. 8, 1930.	Abandoned.



EXPLANATION

○ DRILLING WELL
● PRODUCTIVE OIL WELL
✻ PRODUCTIVE GAS WELL
✻ PRODUCTIVE GAS AND OIL WELL
FIGURES GIVEN AT WELL IS TOTAL DEPTH
——— OIL PIPE LINE
DRY AND ABANDONED HOLE
ABANDONED WITH SHOW OIL
ABANDONED WITH SHOW GAS
+100 +75 +50 STRUCTURE CONTOURS
+++++++ RAILROAD

CONTOURS ON TOP OF BROWN LIME, INTERVAL 25 FEET.

MAP OF

COOPER AREA

LEA COUNTY, NEW MEXICO

BY

DEAN E. WINCHESTER

SCALE

0 1/4 1/2M. 1MILE 2MILES

Drafting by R.W.Phillips.

JAL AREA

The Jal area as here defined includes approximately five townships in the extreme southeast corner of the State, these being Tps. 25 and 26 S., Rs. 36, 37 and 38 (fractional) E. (See map, Plate XXXI.) It is raversed by the Texas-New Mexico railway.

This area was one of the first in Lea County to receive the attention of the major oil companies. The discovery of commercially important I ools to the south in Winkler County, Texas, suggested that similar geologic conditions extended northward into New Mexico along the general rend established in Texas. With this thought in mind, the Texas Production Co. on April 3, 1927, spudded in its No. 1 Rhodes well in sec. 22, T. 26 S., R. 37 E., and on November 1 of the same year completed he well at a total depth of 3,213 feet. Three important gas horizons -ere encountered, the largest at 3,160 to 3,180 feet being rated at 50,000,00 cubic feet. (See table, page 178.) The well was finally completed or 22,500,000 cubic feet of gas and 300 barrels of oil at a total depth f 3,212 feet. In June, 1928, the Marland Oil Co. completed its No. 1 ayes in sec. 19, T. 26 S., R. 37 E., as a 90,000,000-cubic-foot gas well t 2,983 feet. Subsequent drilling proved an immense area within which ommercial gas wells may be expected and has resulted in a number of oil ells.

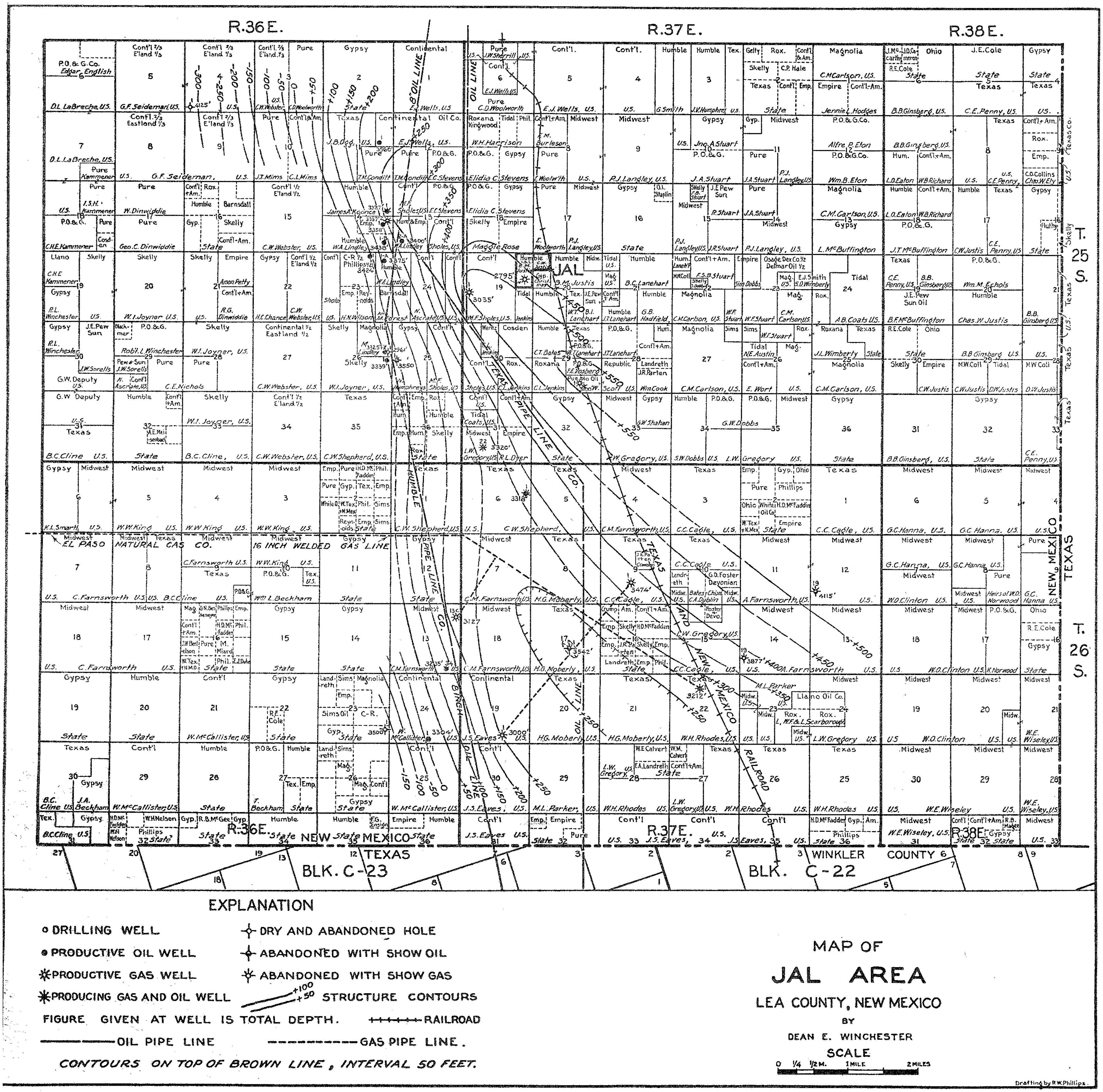
In 1929 the El Paso Natural Gas Co. completed a 16-inch welded gas pipe line from the Jal field to El Paso, and in 1931 this line was extended t o towns in southwestern New Mexico, southeastern Arizona and to Cananea, Sonora, Mexico. On January 1, 1932, twelve gas wells were connected with the line and were supplying approximately 20,000,000 cubic feet of gas per day. Up to December 31, 1930, the Jal area had produced approximately 1,000,000 barrels of oil in addition to the gas. The area is served by oil pipe lines of the Humble Pipe Line Co. and the Texas Pipe Line Co., and by the Texas-New Mexico railway.

The table, page 178, gives the story of drilling in the Jal area.

Surface geology of the Jal area is valueless in determining the sub-surface structure. Both the gas and oil in the area are found in a series of sands and lime beds beneath the "Brown Lime" and above the "White Lime," but few of the wells have reached the latter horizon. The interval between the "Brown Lime" and the "White Lime" is only 500 to 600 feet in this area as compared with twice that thickness at Hobbs. (See section, Plate XXIV, page 141.) This is taken by many geologists to indicate that the Jal field is located on top of the Capitan reef. Two deep wells were drilled by the Midwest Refining Co. east of the productive area without finding production. On the "Brown Lime" both of these wells (Arthur Farnsworth No. 19 in sec. 12, T. 26 S., R. 37 E., and No. 19 in sec. 14 of the same township) were structurally high. (See Plate XXXI.) The well in sec. 12 topped the "Brown Lime" at 2,470 feet and Was drilled to a total depth of 4,115 feet, finding no sandy beds, but considerable anhydrite. The 1,645 feet of beds below the "Brown Lime" was principally hard limestone. The well in sec. 14 reached the "Brown

Wells Drilled in Jal Area

Company.	Well.	Location Sec., T.-S., R.-E.	Total Depth, feet.	Date Completed.	Remarks.
Texas Production Co.	No. 1 Rhodes.	22 - 26 - 37	3,213	Nov. 1, 1927.	10,000,000 cubic feet gas at 3,105 feet, 30,000,000 cubic feet gas at 3,130 feet, 50,000,000 cubic feet gas at 3,160-80 feet. Initial production, 22,500,000 cubic feet gas and 300 barrels oil.
Continental Oil Co.[a]	No. 1 Eaves.	19 - 26 - 37	2,983	June 1, 1928.	8,000,000 cubic feet gas at 2,908 feet, 62,000,000 cubic feet gas at 2 927 feet, 90,000,000 cubic feet gas at 2,968 feet.
Continental Oil Co.[a]	No. 1 Seidman.	4 - 25 - 36	4,125	June 8, 1928.	Dry and abandoned.
Continental Oil Co.[a]	No. 1 Sholes.	19 - 25 - 37	3,035	Jan. 8, 1929.	14,000,000 cubic feet gas at 2,719 feet, 15,000,000 cubic feet gas at 2,790-95 feet, 60,000,000 cubic feet gas at 3,025-35 feet. Initial production, 60,000,000 cubic feet gas.
Cranfill-Reynolds Co.	No. 1 State.	23 - 26 - 36	3,500	Dec. 13, 1928.	Dry and abandoned.
Texas Production Co.	No. 1 Cagle.	9 - 26 - 37	3,474	Jan. 10, 1929.	Initial production, 75,000,000 cubic feet gas.
Midwest Refining Co.	No. 13 C. Farnsworth.	13 - 26 - 36	3,127	Apr. 4, 1929.	Initial production, 35,000,000 cubic feet gas.
Midwest Refining Co.	No. 19 A. Farnsworth.	12 - 26 - 37	4,115	Apr. 25, 1929.	Dry and abandoned.
Skelly Oil Co.	No. 1 Joyner.	26 - 25 - 36	3,339	May 23, 1929.	Initial production, 438 barrels oil.
Cranfill-Reynolds Co.	No. 1 Wilson.	23 - 25 - 36	3,424	June 5, 1929.	Initial production, 115 barrels oil.
Pueblo Oil Co.	No. 1 Crosby.	29 - 25 - 37	3,100	July 2, 1929.	Initial production, (estimated) 20,000,000 cubic feet gas.
Texas Production Co.	No. 1 Sheppard.	6 - 26 - 37	3,318	July 19, 1929.	Initial production, 1,680 barrels oil and 20,000,000 cubic feet gas.
Humble Oil & Refining Co.	No. 1 Lindley.	23 - 25 - 36	3,375	Aug. 9, 1929.	Initial production, 785 barrels oil.
Gypsy Oil Co.	No. 1 Humphreys.	25 - 25 - 36	3,550	Aug. 22, 1929.	4,000 barrels water. Abandoned.
Humble Oil & Refining Co.	No. 1B. Lindley.	14 - 25 - 36	3,438	Sept. 22, 1929.	Initial production, 693 barrels oil.
Midwest Refining Co.	No. 22 Gregory.	31 - 25 - 37	3,320	Sept. 18, 1929.	25,000,000 cubic feet gas at 3,055-70 feet, 70,000,000 cubic feet gas at 3,070-71 feet. Initial production, 100 barrels oil.
Continental Oil Co.[a]	No. 1 McAllister.	24 - 26 - 36	3,304	Oct. 3, 1929.	Initial production, 45 barrels oil on swab.
Continental Oil Co.[a]	No. 1 Wells.	11 - 25 - 36	3,560	Sept. 5, 1929.	Initial production, 90 barrels oil.
Humble Oil & Refining Co.	No. 2 A. Lindley.	13 - 25 - 36	3,400	Dec. 27, 1929.	Initial production, 80 barrels oil.
Empire Gas & Fuel Co.	No. 1 Lindley.	14 - 25 - 36	3,358	Jan. 10, 1930.	Initial production, 1,800 barrels oil.
Texas Production Co.	No. 1 Moberly.	17 - 26 - 37	3,542	May 24, 1929.	Abandoned, mechanical troubles.
Magnolia Petroleum Co.	No. 1 Lindley.	26 - 25 - 36	2,961	Nov. 26, 1929.	Abandoned, rig skidded to No. 1X.
Magnolia Petroleum Co.	No. 1X Lindley.	26 - 25 - 36	3,325	Mar. 7, 1930.	Initial production, 160 barrels oil.
Empire Gas & Fuel Co.	No. 2 Lindley.	14 - 25 - 36	3,337	Mar. 20, 1930.	34,000,000 cubic feet gas at 3,313-35 feet; shut in for gas well.
Humble Oil & Refining Co.	No. 1 Koonce.	14 - 25 - 36	3,323	Mar. 7, 1930.	5,800,000 cubic feet gas at 3,292 feet. Initial production, 175 barrels oil.
Midwest Refining Co.	No. 34 C. Farnsworth.	13 - 26 - 36	3,235	Apr. 27, 1930.	Initial production, 675 barrels oil.
Midwest Refining Co.	No. 19 A.	14 - 26 - 37	3,877	Sept. 30, 1930.	Dry and abandoned.


R.36E.
R.37E.
R.38E.
T. 25 S.
T. 26 S.
JAL
NEW MEXICO
TEXAS
BLK. C-23
BLK. C-22
WINKLER COUNTY
EL PASO NATURAL GAS CO.
16 INCH WELDED GAS LINE
8" OIL LINE
HUMBLE PIPE LINE CO.
TEXAS PIPE LINE CO.
TEXAS AND NEW MEXICO RAILROAD
EXPLANATION
DRILLING WELL
PRODUCTIVE OIL WELL
PRODUCTIVE GAS WELL
PRODUCING GAS AND OIL WELL
DRY AND ABANDONED HOLE
ABANDONED WITH SHOW OIL
ABANDONED WITH SHOW GAS
+100
+50
STRUCTURE CONTOURS
FIGURE GIVEN AT WELL IS TOTAL DEPTH.
RAILROAD
OIL PIPE LINE
GAS PIPE LINE.
CONTOURS ON TOP OF BROWN LINE, INTERVAL 50 FEET.
MAP OF
JAL AREA
LEA COUNTY, NEW MEXICO
BY
DEAN E. WINCHESTER
SCALE
0
1/4
1/2 M.
1 MILE
2 MILES
Drafting by R.W.Phillips.

Lime" at 2,600 feet, and found practically nothing but hard lime to the bottom at 3,877 feet. These wells both found the section below the "Brown Lime" to be radically different from the section found in the productive area. Based upon the evidence of the drillers' logs of the area the writer suggests that the two Midwest wells just described were in fact located on top of the reef and that the lime section drilled below the "Brown Lime" is the reef limestone itself. If this be a true diagnosis of the evidence, then the Jal pool is on the west side of the reef proper and, therefore, on the open sea side of the reef as described by Lloyd.[1]

The writer's conception of the approximate course of the Capitan reef in southern New Mexico is given on the map, fig. 8, page 141. By reference to this map it will be seen that the productive area of both the Jal and Cooper areas are on the west or open sea side of the reef, whereas the rest of the production in southeastern New Mexico is on the opposite side.

The geologic structure in the Jal area is very incompletely defined by present drilling. However, the "Brown Lime" structure is evidently essentially monoclinal with slight east reversal indicated by the Leonard & Levers Justis well in sec. 19, T. 25 S., R. 37 E. Dips within the productive area are relatively steep as is shown by the contours on the map, Plate XXXI.

The oil produced has an asphaltic base, a gravity of 24.5° to 29.9° A. P. I., and a sulphur content of 1.71 per cent to 1.97 per cent as shown by the following analyses furnished by the United States Geological Survey.

Analyses of Oil from Jal Area.

Sample No.	29-036		29-037	
The Crude Oil.				
Specific gravity (°A. P. I.).	29.9		24.5	
Centrifuge; B. S., mud and water (per cent).	0.3		7.6	
Sulphur (per cent).	1.97		1.71	
Universal Saybolt viscosity at 100° F., seconds.	63		92	
Distillation (Air).				
First drop.	124° F.		176° F.	
	Per cent	**Gravity (°A. P. I.)**	**Per cent**	**Gravity (°A. P. I.)**
Up to 392° F.	27.3	53.5	17.5	46.5
392° F. to 482° F.	11.8	35.7	11.2	35.7
482° F. to 527° F.	9.0	29.5	10.0	30.4
Vacuum Distillation (40 mm.).				
Up to 392° F.	3.0		4.0	
392° F. to 482° F.	8.3		10.3	
482° F. to 527° F.	4.3		6.0	
527° F. to 572° F.	5.0		6.5	
Residuum.	31.3		34.5	
Base.	Asphaltum		Asphaltum	

Sample No. 29-036; Skelly Oil Co. Joyner No. I Well; sec. 26, T. 25 S., R. 36 E. Sample No. 29-037; Texas Production Co. Sheppard No. I Well; sec. 6, T. 26 S., R. 37 E.

Gas in the Jal area occurs in large volume. It has the following analysis, as determined by the Helium Co.

[1] Lloyd, E. R., Capitan limestone and associated formations of New Mexico and Texas: Am. Assoc. Petroleum Geologists Bull. vol. 13, No. 6, p. 654, 1929.

Analysis of Gas from Continental Oil Co. Eaves No. 1 *Well, SE. ¼ sec.* 19, *T.* 26 *S., R.* 37 *E.*

Carbon dioxide	2.61 per cent
Nitrogen	7.76 per cent
Methane	58.4 per cent
Ethane	31.2 per cent
Oxygen	.05 per cent

It is probable that large volumes of gas will be found by wells drilled over a large area, and that a considerable number of moderate sized oil wells will be found down dip west of the gas.

MISCELLANEOUS STRUCTURES

That part of the Southeast Area west of the Pecos River where natural rock exposures are frequent has been studied in considerable detail by geologists, and numerous anticlinal folds have been mapped. Several structures have been drilled, but none has proven productive of commercial oil or gas. Considerable information is available concerning certain of these structures and the wells drilled, but concerning many, particularly those as yet untested, the information is meager. The logs of some of the deep wells on structures west of the Pecos River furnish exceedingly interesting and valuable information regarding the character and thickness of formations below the San Andres limestone, the lowest formation yet tested in eastern Eddy and Lea counties. One of the most valuable logs is that of the Texas Production Co. well on the Dunken dome. (See pages 143, 144.) This well penetrated lower formations than any other so far drilled in southeastern New Mexico.

East of the Pecos River rock formations are largely obscured, and determination of structure is exceedingly difficult in some places and impossible in others. However, a few structures, besides those whose detailed discussion has already been given, have been mapped and tested.

The following table includes a summary of the information available concerning miscellaneous structures shown on the map, Plate XXIII, and not discussed in more detail on preceding pages.

Miscellaneous Structures in the Southeast Area

Name.	Location. T.	R.	County.	Surface Formation.	Remarks.
Big Eddy anticline.	22 S.	29 E.	Eddy.	Permian.	Drilled to 3,260 feet, dry.
Big Four anticline.	22 S.	25 E.	Eddy.	Permian.	100 feet of closure, untested.
Black Hills anticline.	17 S.	20 E.	Chaves.	Permian.	Untested.
Black River anticline.	24 S.	27 E.	Eddy.	Permian.	50 feet of closure, well 3,096 feet deep, show of oil and gas.
Bluewater anticline.	17 S.	16 E.	Chaves.	Permian.	Untested.
Buchanan anticline.	1 & 2 N.	20 & 21 E.	DeBaca.	Triassic.	Well 3,210 feet deep, dry.
Buffalo Creek anticline.	1 S.	27 E.	DeBaca.	Triassic.	100 feet of closure, well 4,508 feet deep, dry.
Dog Canyon anticlines.	24 to 26 S.	19 & 20 E.	Otero.	Permian.	Untested.
Dunken dome.	17 S.	18 E.	Chaves.	Chupadera formation.	250 feet of closure, well 4,900 feet deep, 1,000,000 cubic feet gas in Yeso. (See log, pages 143, 144.)
Elkins anticline.	8 S.	27 E.	Chaves.		Well 5,040 feet deep, show of oil and gas.
Jones anticlines.	22 & 23 S.	25 E.	Eddy.	Carlsbad limestone.	100 feet of closure, untested.
Manning anticline.	14 & 15 S.	17 E.	Chaves.	Chupadera formation.	150 feet of closure, dry hole, 3,380 feet deep.
McKittrick anticline.	22 & 23 S.	25 E.	Eddy.	Carlsbad limestone.	Untested.
McKnight anticline.	12 S.	18 E.	Lincoln.	Chupadera formation.	300 (?) feet of closure, untested.
Picacho anticline.	11 S.	18 E.	Lincoln.	Chupadera formation.	600 (?) feet of closure, well 2,191 feet deep, show of oil and gas, granite reported.
Pomeroy anticline.	1 N. & 1 S.	30 E. 30 E.	Roosevelt.		Well 4,510 feet deep, dry.
Carlsbad dome.	21 S.	26 E.	Eddy.	Capitan limestone.	Pseudo anticline on Capitan reef, well 5,885 feet deep, dry.
Twin Mounds anticline.	6 S.	27 E.	Chaves.		Shallow well, 665 feet deep.
Y-O Overthrust anticline.	16 to 18 S.	18 to 20 E.	Chaves.	Permian.	Untested.

MEDIAN AREA

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 XIV) 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, Ladrones Mountains, Socorro Mountain, Magdalena Mountains, Oscura Mountains, Black Range, San Andres Mountains, Franklin Mountains (mostly in Texas), Los Pinos 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 sediments, 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 XXIII. To date this testing has given negative results except in the Estancia Valley where carbon dioxide gas has been developed on the Eilcox 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[1] has given the following description of the Upper Rio Grande Valley:

[1] Darton, N. Geologic structure of parts of New Mexico: U. S. Geol. Survey Bull. 726, p. 217, 1922.

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 January, 1931, a well was reported drilling at 1,685 feet in sec. 26, T. 21 N., R. 9 E., in hard gray lime. The log of the well to 1,610 feet shows mostly sandy shale, brown shale, and some thin sandstone and lime shells. This well is located on a reported anticlinal fold, the Santa Cruz anticline, whose axis trends in a general northeast-southwest direction. No detailed information is available regarding the structure.

RIO GRANDE VALLEY IN CENTRAL NEW MEXICO

South of the 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 Ladrones Mountains form the western limit near Socorro. Between the Ladrones Mountains and the main line of the Santa Fe railway to the north, the valley is bounded by a series of high mesas, consisting principally of sediments of Carboniferous age. 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 lapping 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 that may be present is available. But few wells have been drilled to sufficient depth to furnish information even on the depth of the valley fill, and the correlation of hard rock formations described in the logs of the deeper wells is impossible. Darton[1] has described the general structural conditions as follows:

The entire west front of the Sandia and Manzano mountains and the Sierra 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-ManzanoPinos 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, 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 XXIII). 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

Each of these wells, except Nos. 2 and 3 which were drilled only 12 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 leads the writer to suggest that after passing through the valley fill deposits the wells penetrated only Cretaceous formations probably never reaching the Dakota sandstone. The detailed log of No. 3 well (the deepest) is given, as it furnishes information

[1]Darton, N. H., Geologic structure of parts of New Mexico: U. S. Geol. Survey Bull. 726, pp. 220-221, 1921.

regarding the general character of the formation below the valley at this point.

Log of Harlan et al. Harlan No. 3 Well
Sec. 5, T. 6 N., R. 2 E.
Drilled, 1931

	Bottom, feet.
Sand and gravel	108
Sand and gravel, streaks red clay	276
Sand and gravel	457
Sandy clay	502
Sandy clay, streaks gum clay	588
Sandy clay, yellow clay streaks	718
Gumbo and shale	883
Gumbo streaks sand and fine gravel	1021
Gum shale, sand streaks	1190
Hard sand	1243
Gumbo	1348
Hard and soft red gumbo	1820
Red clay, hard sand streaks	2007
Red clay, thin streaks sandy lime	2266
Gray shale	2334
Limy shale, streaks hard black sand	2456
Sandy shale, thin lime crust and gyp	2512
Hard sandy lime	2528
Hard baked black sand	2536
Hard slate-like crust, hard black quartz; very hard	2551
Hard slate-like crust, with shale	2570
Hard and soft limy shale	2620
Gum shale	2643
Chalky lime	2673
Gumbo and gum shale	2798
Blue shale	2874
Sandy shale; hard crust sand	2941
Gum shale red	3007
Sand and lime; cored 3007-3,009 feet	3014
Sand streaks and blue shale; cored 3,032 feet	3034
Broken sand, streaks gum shale	3102
Hard sand	3142
Blue gum shale	3163
Hard sand streaks and blue gum shale	3213
Blue shale, streak hard sand	3281
Gum shale	3294
Gum shale, hard sand streaks	3346
Gum shale	3381
Blue gum shale	3511
Hard sand	3519
Hard slate-like shale	3546
Hard sandy shale	3571
Blue gum shale	3809
Soft blue shale, thin streaks gumbo	4006
Gum shale	4019
Hard sandy shale	4020
Hard sand	4021
Hard sand	4024
Sand and shale	4052
Shale	4136
Shale, thin sand streaks	4190
Sandy shale	4217
Sandy shale, hard sand rock	4220
Hard tough gumbo	4251
Tough gumbo	4317
Sandy shale	4318
Sand	4320
Shale	4397
Red and blue shale	4418
Gray shale	4420
Gummy shale	4478
Sandy shale, showing more *gas*	4506
Blue gum shale	4573
Sandy shale	4594
Hard streak sand rock	4602
Sand rock and sandy shale	4611
Gum shale	4627
Streaks of sand	4639
Variegated gum shale	4688
Gum shale	4746
Sandy shale	4754
Soft sandy shale	4805
Green gum shale	5082
Dry shale, hard streaks of slate	5171
shale, hard streaks of lime, showing more gas	5204
Hard limy shale, some red, gray; thin sand. *Oil* and *gas* showing	5211
Hard limy shale, some tight sand	5232
Gum shale	5283
Hard shale	5291
Gum shale	5313
Sand shale, hard, tight streaks	5328

	Bottom, feet.
Hard, limy cap; petroleum odor stronger	5343
Hard shale with dry lime, cored	5345
Limy shale	5348
Gum shale	5388
Gum shale	5406
Hard, tight, sandy lime	5413
Hard sandy crust	5417
Hard, tight, sand rock	5421
Hard, dry, dark red shale	5424
Hard, tight sand rock, slate streaks	5436
Hard shale, streaks soft lime	5452
Hard shale, gum streaks, enough sand to cut bit badly	5467
Hard sandy shale	5481
Sand shale, getting gummy	5496
Blue gum shale	5546
Hard shale, little sandy	5576
Hard shale, some sand, no gum	5589
Red shale showing more sand	5595
Sandy lime, shale streaks	5617
Blue shale, soft	5749
Blue shale, red streaks	5789
Dry red shale	5824
Red sandy shale	5839
Red sandy shale, sticky at bottom	5847
Blue gum shale, soft at bottom	5886
Blue shale	5931
Blue shale, soft	5997
Blue shale	6008
Sandy shale, hard lenses	6019
Hard sandy shale	6027
Hard sandy shale, some lime	6127
Hard sandy lime and shale	6164
Hard sandy lime	6169
Hard formation, sandy streaks	6176
Tight sandy formation	6183
Blue-black, tough gumbo, some white sandy-lime	6185
Hard blue shale, white sandy lime, softer at bottom	6208
Blue sticky shale	6323
Blue sticky shale, streaks sandy lime	6331
Blue shale, hard	6351
Hard blue shale	6360
Hard blue shale	6372
Hard blue shale	6446
Hard formation	6448
Cored; failed to get core	6454
Cored; got good core; Dyke material	6456
Hard brittle formation	6461
Hard formation, cuttings show black	6464
Very hard volcanic rock; abandoned	6464
Steel line measurement	6474

NOE DOME

So far as known to the writer only a single closed structure has been mapped in the Middle Rio Grande valley in central New Mexico on the basis of surface exposed beds. The Noe dome located east of the Rio Grande near the south line of the La Joya grant 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 several years ago to a depth reported as approximately 800 feet without finding anything of interest.

LOWER RIO GRANDE VALLEY

The following data on the Lower Rio Grande valley are from Darton.[1]

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

[1] Darton, N. H., op. cit., pp. 232-234.

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 can not 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.

A few deep holes that have been bored along the Southern Pacific and El Paso & Southwestern railroads in southern Dona Ana County throw light on the character of the underlying rocks. One at Strauss is 1,330 feet deep. Down to 120 feet the material is sand and clay on a bed of "cemented sand"; from 120 to 360 feet are yellow clay, sand, and red clay of unknown age; the material below is not reported. Three holes at Noria are 565, 600, and 1,000 feet deep. The deepest one went through 160 feet of sand, clay, and gravel; the material from 160 to 220 feet was not reported; from 220 to 1,000 feet were sand, shale, and shells alternating. The 565-foot hole was reported to have penetrated 375 feet of sand, clay, and gravel, 100 feet of shale with red clay at the top and bottom, and 90 feet of alternating shale, "pack sand," and red clay.

A hole 515 feet deep at Mount Riley siding was reported to have penetrated clay to 80 feet, alternating clay and sand from 80 to 240 feet, silt from 240 to 275 feet, and clay, gravel, and rock from 275 to 515 feet. Another one 715 feet deep was reported as follows: 0-170 feet, clay and sand with streaks of white rock; 170-280 feet, clay; 280-300 feet, clay and sand; 300-325 feet, water sand; 325-715 feet, clay, sand, gravel, and boulders, in part cemented.

A 950-foot well sunk by the Southern Pacific Co. at Lenark had the following record:

Record of Deep Test Well at Lenark, N. Mex.

	Feet.		Feet.
Red soil	0- 13	Sand	456-562
Chalky clay	13- 15	Red clay	562-590
Sandrock, hard	15- 78	Yellow clay	590-640
Cemented stones	78-125	Sandstone, soft	640-666
Red clay	125-186	Sandstone, hard	666-668
White sand	186-204	Yellow clay	668-700
Sandy clay	204-214	Sand	700-710
Sand	214-226	Sandy clay	710-730
Red clay	226-252	Clay	730-750
Sand	252-290	Sand	750-775
Cemented sand, hard	290-294	Clay, hard	775-781
Red clay, hard	294-336	Yellow clay	781-800
Yellow clay	336-382	Sand	800-810
Sand	382-396	Sandy clay	810-840
Red clay, hard	396-428	Sand	840-870
Quick sand	428-446	Sandy clay	870-892
Cemented sand	446-452	Clay	892-900
Clay	452-456	Sandy clay	900.950

A 1,077-foot hole at Kenzin siding, Dona Ana County, had the following record;

Record of *Deep Test Well at Kenzin, Dona Ana* County, *N. Mex.*

	Feet.		
Soil and sand	0- 50	Clay and rocks; water	515-550
Clay and sand	50-140	Solid rock	550.802
Cement, clay, and sand alternating	140-324	Conglomerate	802-807
Solid rock	324-326	Solid rock	807-827
Sand, cement, and clay with gravel	326-395	Solid rock, lava (?), and conglomerate	827-844
Clay	395-515	Solid rock and conglomerate alternating	844-1,027

A 445-foot well at Malpais siding passed through 108 feet of clay, 262 feet of lava, and 75 feet of sand and clay.

It is difficult to interpret the records of these borings. They indicate that a diversity of rocks underlie the wide plains of southern Dona Ana County. To the south the sandstones and limestones of Comanche age may be extensively distributed, for they appear at El Paso and near Montoya and apparently were penetrated by the holes at Noria, Strauss, and Lenark.

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 the southern part of Santa Fe County. Altitudes in the valley area range from 6,100 to 6,400 feet above sea level, 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 high 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 and underlying Magdalena limestone series. The beds are well exposed in Abo Canyon to the southwest where the following detailed section was measured by Mr. E. F. Miller.

Section along Santa Fe Railroad between Sais and Scholle, T. 3 *N., Rs.* 4 *and* 5 *E., Valencia County, N. Mex.*

Top of Section.

Magdalena Limestone	Feet.
Black gray fossiliferous limestone, forming escarpment	4
Red shale, possibly weathered arkose	19
Blocky gray limestone. *Productus,* corals, fish teeth.	10
Red shale, thin beds of arkose	25
Massive thin-bedded limestone, forms escarpment	10
Red shale, thin beds of red arkose	10
Nodular gray limestone	3
Red shale, possible weathered arkose	30
Very hard blocky, fine grained to coarse, reddish-brown arkose	12
Red shale, thin beds of hard irony arkose	12
Gray slabby limestone, *Productus*	1
Red arkose shales, thin hard streaks	21
Reddish-brown limy shale, very hard	4
Blue cherty limestone, weathers to nodules on dip slopes	8
Gray nodular limestone	1
Red coarse grained arkose, limy at top	11
Gray limestone	1
Reddish-brown massive arkose, very hard and platy	10
Platy, micaceous fine-grained arkose	3
Thinly-bedded gray limestone	11
Buff shale	5
Gray massive cherty limestone	11
Buff shale, with plant life, carbonaceous at top	13
Blue to gray massive cherty limestone. Thin beds of black shale, matted along bedding planes. Makes escarpment	45
Red shale	7
Bluish gray, somewhat cherty, fossiliferous limestone	17
Gray shales, with thin micaceous sands	13

	Feet.
Bluish-gray limestone. Black shaly limestone at base, prominent marker is escarpment	22
Covered; possibly buff shale with thin limestone and sandstone	72
Bluish gray massive limestone. 4 feet of buff shale near base. Fossiliferous. Prominent marker is escarpment	35
Gray thin sands	2
Gray massive limestone	10
Gray micaceous sand	15
Covered; possibly buff shale with thin sands	30
Black fossiliferous limestone	2
Buff shale	5
Gray micaceous sandstone	11
Gray lime sand micaceous	4
Covered; possibly buff shale	62
Brownish-gray thinly bedded limestone, weathering yellow	25
Yellowish-gray coarse sandstone, conglomerate at top	4
Buff shale, numerous hard black shale and lime concretions	45
Greenish-gray mica sandstone	1
Green micaceous shale	3
Greenish-gray, massive micaceous sandstone, with lime cement	11
Greenish-gray, thinly bedded micaceous sandstone	18
Gray to buff, thinly laminated shale, with abundant plant life	85
- Bluish-black limestone	2
Buff shale	3
Gray limestone, weathers yellow	6
Buff shale	8
Buff limy sandstone	1
Gray shale	4
Buff coarse-grained sandstone	12
Green micaceous shale	5
Bluish-gray limestone	1
Buff shale, lime concretions	8
Brownish-gray massive limestone	14
Bluish-gray massive limestone	38
Buff shale	2
Bluish-gray to black massive limestone, thin black shale along bedding planes	31
Greenish-gray micaceous sandy limestone	2
Buff shale	16
Bluish-gray massive fossiliferous limestone	7
Buff shale	11
Bluish-gray limestone	3
Buff shale, lime concretions	8
Gray blocky fossiliferous limestone	2
Gray to black shale; fossils and plant life	19
Bluish-gray massive limestone, matted with fossils	5
Thinly-bedded fossiliferous limestone and black shale	7
Black shale, weathers gray, fossils and plant life	23
Gray massive limestone. *Productus*	25
Bluish-black limestone	3
Covered shale	3
Bluish-gray, massive, very hard fossiliferous limestone, thin shale partings. Close to fault	65
This bed lies unconformably on the pre-Cambrian quartzites.	
Total	1,108

Note.—This section includes all of the limestone in the Magdalena but there are a number of red arkose sands above the upper lime that are possibly of the same age and are different in character from the major thickness of the Abo Sandstone. In this general area the Abo and the Magdalena seem to be conformable. The Abo is possibly 500-600 feet in thickness and consists of red platy sandstone and red shales.

A small sample of black shale from the upper part of the Magdalena formation "near Scholle," probably from some one of the shale beds shown in the above section, 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 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 mctamorphosed 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, Estancia and Wilcox anticlines—have been studied in detail by the writer, and a fourth, the Punta del Agua anticline, is reported further 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.

ESTANCIA ANTICLINE

The Estancia anticline has a proven 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. SW ¼ sec. 5, to a total depth of 1,346 feet without finding commercial oil or gas. In a 5-foot sand at 1,027 to 1,032 feet, a small amount of non-inflammable gas, probably carbon dioxide, was found. The log of the well shows it to have been bottomed in green micaceous schist containing numerous quartz veins.

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 SE.¼ SW.¼ sec. 12, T. 7 N., R. 7 E. Two shallow wells were drilled for oil on the Wilcox anticline and a third finally reached a total depth of 1,470 feet. Considerable non-inflammable gas, estimated at 200,000 cubic feet, was found at 1,240 to 1,340 feet. This gas is 98 per cent carbon dioxide. Plans are being made for the development of this carbon dioxide gas and the manufacture of dry ice.

BUFFALO ANTICLINE

The Buffalo anticline, located to the north of the Wilcox structure, is less completely exposed than either the Wilcox or the Estancia anti-clines. From the available evidence, however, it appears that the Buffalo anticline may have a larger area within the lowest closing contour although perhaps less closure. The crest of the Buffalo anticline is located in the SW. ¼ sec. 32, T. 9 N., R. 8 E. The structure has not been drilled.

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 1,940 feet without finding production. The well was located in the SW. ¼ SW. ¼ sec. 36, T. 5 N., R. 6 E.

EAST SIDE OF THE VALLEY

East of Estancia, the San Juan Coal & Oil Co. drilled two wells, the deepest to a total depth of 5,321 feet. Nothing is known to the writer relative to possible structure in the vicinity of this well. The log of the well is interesting and is given below.

Log of San Juan Coal and Oil Co. *Randall No.* 2 *Well*
NE.¼ SW.¼ Sec. 20, *T.* 6 *N., R.* 10 *E.*
Drilled. 1927-28

	Bottom, feet.		Bottom, feet.
Salt, lime and gypsum	70	Hard sand	313
Coarse gravel	95	Lime and gypsum	318
Pink sand	97	Red sandy shale	325
Brown sand	102	Gray lime	331
Sandy shale	118	White lime	337
Lime shell	120	Flinty lime	345
Soft pink sand	124	Hard lime	353
Light sandy shale	130	Red sandy shale	377
Brown sandy shale	135	Gray lime	380
Gravel and shale	145	Red sandy shale	405
Brown and red sandy shale	185	Sandy lime	410
Gray water sand	190	Black sandy lime	422
Brown sandy shale	198	Blue sand with water	425
Red muddy shale	200	Blue sandy shale	435
Sandy shale	212	Brown sandy shale	449
Lime shell	213	Hard lime	455
Red shale	230	Sandy shale	480
Red sandy shale	236	Gray lime	485
Lime shell	237	Red sandy shale	495
Brown water sand	254	Lime shell	496
Brown lime shell	258	Red sandy shale, caving	540
Brown sandy lime	267	Red sand, dry	552
Brown sandy shale	280	Red sandy shale	590
Red muddy shale	295	Lime shell	592
Red sandy shale	310	Red sandy shale	651

	Bottom, feet.
Red shale and gypsum	655
Hard red sand	675
Red sandy shale	690
Red sand	700
Red sandy shale, caving	710
Blue shale	715
Red sandy shale	730
Lime shell	732
Red shale	769
Red sandy lime	774
Red sand	780
Red muddy shale	800
Sandy shale and gravel, caving	910
Blue and red sticky shale	930
Red sand	965
Sandy shale and gravel	975
Sandy lime shell	990
Blue and red soft shale	995
Red sandy shale	1012
Blue sand and shale	1020
Red sandy shale and gypsum	1040
Black lime	1045
Hard black lime	1052
Gray lime and gypsum	1060
Red shale	1067
Broken gray lime	1072
Water sand	1090
Sandy lime	1130
Sandy lime and gypsum	1145
Sandy lime	1175
Red shale	1202
Gray lime	1210
Gray shale	1218
Red shale	1340
Red and blue shale	1380
Red shale, caving	1440
Red broken shale	1474
Lime shell	1475
Red shale	1485
Red shale and broken lime	1495
Red broken shale	1578
Red shale and gravel	1625
Dark sandy shale	1695
Sandy shale, showing some water	1700
Red sandy shale	1711
Gray lime	1730
Dark gray lime	1743
Brown sandy shale	1753
Dark lime	1755
Brown lime	1782
Hard gray lime	1785
Red shale	1807
Gray shale	1848
Hard lime	1850
Broken gray shale	1890

	Bottom, feet.
Dark hard lime	1895
Sandy lime, strong salt water	1908
Gray sandy lime	1910
Red shale with broken lime	1960
Red shale	2010
Sandy lime	2015
Sandy lime, a little water but exhausted soon	2022
Black lime	2028
Brown shale and lime	2075
Sandy shale with water	2080
Lime and shale	2120
Hard sandy lime	2134
Blue shale	2138
Brown sandy lime	2217
Dark sandy lime	2234
Light sandy lime	2279
Sandy lime	2300
Sandy shale and lime	2385
Blue sandy shale	2400
Brown sandy shale	2405
Gray lime	2410
Red sandy shale	2452
White sandy lime	2462
Brown sandy lime	2535
Blue shale	2545
Coarse sandy lime	2560
Hard sandy lime	2583
Brown shale and lime	2702
Gray sandy lime	2725
Gray shale	2770
Arkose	2798
Brown lime	2854
Gray lime	2895
Gray sandy lime	2900
Dark gray lime	2910
Brown broken lime	2957
Sandy lime	2985
Gray and broken shale	3130
Gray sandy shale	3185
Brown sandy shale	3264
Gray sandy lime	3278
Blue shale and lime	3287
Gray sand	3297
Oil sand, well saturated	3310
Black sandy lime	3325
Hard black lime	3335
Hard gray lime	3340
Blue sandy lime	3350
Pink sandy lime	3360
Black lime with a lot of carbon	3370
Gray lime	3380
Brown lime	3390
Brown sandy lime	3405
Red sandy lime	3415
Blue salt sand with some	

	Bottom, feet.
strong salt water	3425
Broken shale with a lot of carbon	3440
Blue sandy shale	3460
Brown sandy lime	3485
Gray sand, saturated with *oil*	3500
Brown shale, strong carbon	3510
Brown sandy lime	3530
Sand, dark, coarse with paraffin wax	3550
Hard black lime	3570
Sandy shale	3600
Brown sandy lime	3610
Dark slate, cavey	3626
Brown shale with gypsum	3650
Hard gray sand with paraffin wax	3660
Arkose, white and red, coarse	3670
Sand, fine sugar	3675
Brown sandy lime	3750
Sand, brown sugar	3775
Sand, brown, coarse	3800
Sand, brown, quartzy	3815
Black lime	3840
Black lime, broken with shells	3850
Sand, strata of pink and black	3865
White marble	3870
Black slate	3875
Sand, gray, coarse with some salt water	3905
Red slate	3925
Pink sand	3935
Brown sand, fine	3940
Brown slate	3955
Brown sand	3975
Brown slate	4005
Sand, reddish quartz	4025
Sand, coarse red	4050
Brown slate	4055
Brown lime with mica	4090
Brown slate	4130
Sand, brown, coarse	4135
Slate	4150
Sand, gray	4160
Sand	4180
Shale, black, streaked with hard lime shells	4600
Sand, coarse, dark gray, showing some *oil*	4725
Lime, hard, gray	4785
Shale, dark gray, streaked with lime shells	5020
Shale, dark brown	5180
Lime, brown	5200
Shale, brown, showing *oil* and *gas*	5321

Shut down at 5,321 feet about 18 inches into a very hard, dark gray sand. Tools were lost and never recovered. Well abandoned.

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 is 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[1] 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 Chupader. formation dips gently to the west on the west slope of the San Andre Mountains and rises again on the east dip on the east slopes of the Fr. Cristobal and Caballo Mountains, thus forming a synclinal basin. * * *

CHUPADERA ANTICLINE

Location and Topography.—The Chupadera anticline (Oscura anti cline of Darton[2]) is located in eastern Socorro County at the north ens. of the Jornada del Muerto about 35 miles east of Socorro. The follow ing description and the accompanying map of the structure are taken fro a private report by E. H. Wells which has been checked by the writer i the field.

The Chupadera anticline extends in a general northward directio from the southern part of T. 4 S., R. 6 E., to the northeastern part of T. 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 Ives 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 above sea level, wherea the 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 Lower Chupader. (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 Lower Chupadera formation is approximately 2,100 feet.

The overlying Upper Chupadera formation (San Andres limestone), composed chiefly of limestone and gypsum, is the surface rock of most of the Chupadera Mesa and outcrops in a narrow area west of the cuestas.

The Abo sandstone which underlies the Chupadera formation is approximately 1,100 feet thick and is composed of interbedded red sandstone and red shale.

The Magdalena group(Pennsylvanian age), below the Abo, is well

[1] Darton, N. H., op. cit. (U. S. G. S. Bull. 726), p. 231.

[2] Darton, N. H., op. cit. (U. S. G. S. Bull. 726), p. 239.

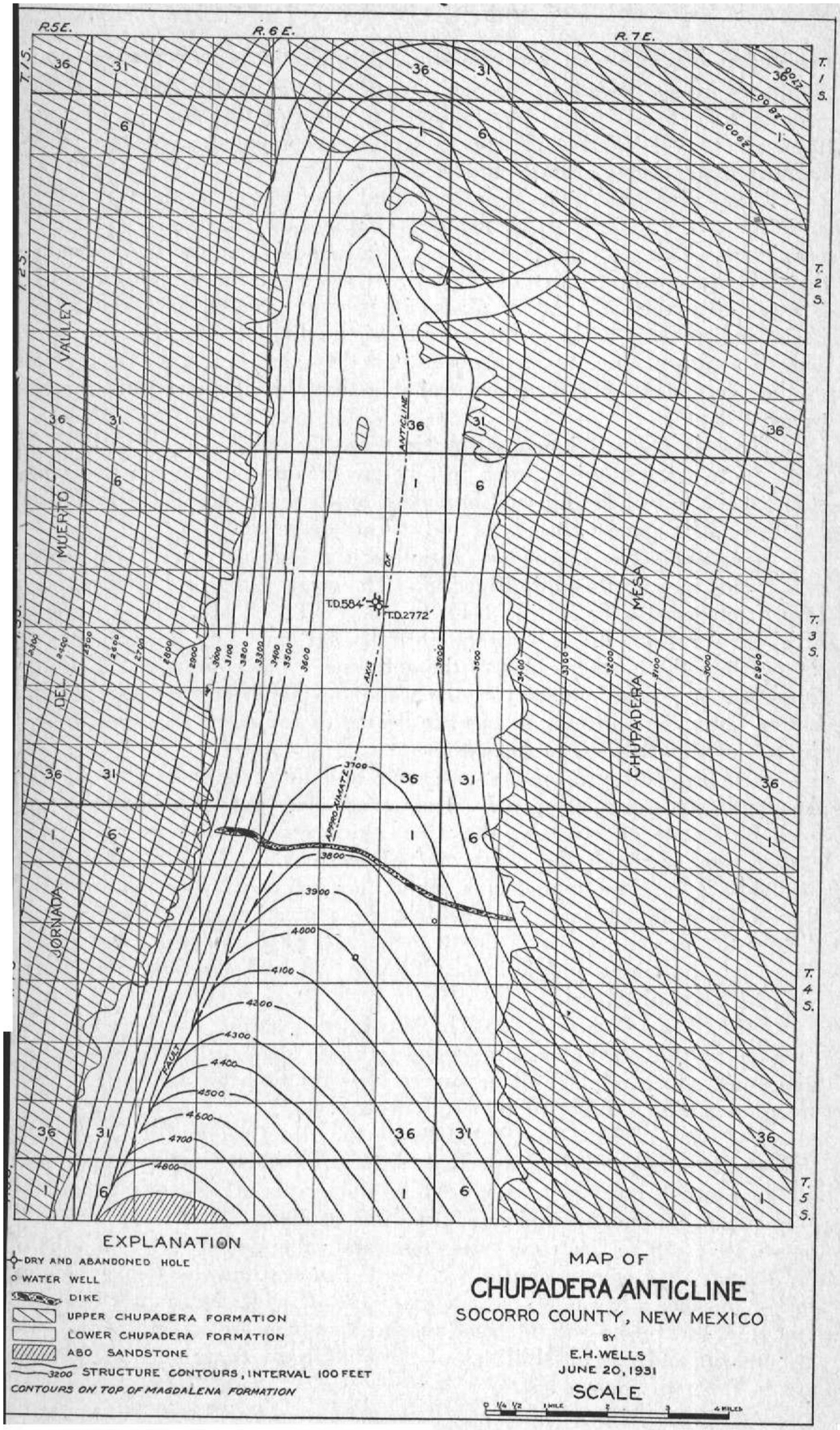

R.5E.
R.6E.
R.7E.
T.1S.
T.2S.
T.3S.
T.4S.
T.5S.
JORNADA DEL MUERTO VALLEY
CHUPADERA MESA
ANTICLINE
APPROXIMATE AXIS OF
FAULT
T.D.584'
T.D.2772'
EXPLANATION
DRY AND ABANDONED HOLE
WATER WELL
DIKE
UPPER CHUPADERA FORMATION
LOWER CHUPADERA FORMATION
ABO SANDSTONE
3200 STRUCTURE CONTOURS, INTERVAL 100 FEET
CONTOURS ON TOP OF MAGDALENA FORMATION
MAP OF
CHUPADERA ANTICLINE
SOCORRO COUNTY, NEW MEXICO
BY
E.H.WELLS
JUNE 20, 1931
SCALE

Figure 11.

exposed in Abo Canyon near Scholle, 25 miles to the north where it is composed of fossiliferous limestone, organic shale, arkose and sandstone. (See section, pages 188, 189.) The total thickness of the Magdalena is approximately 1,100 feet in Abo Canyon. The Magdalena rests 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. 11.) 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 sandstone at the top of the Chupadera, but it seems probable that this igneous wall reache 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" sand stone at the top of the Lower Chupadera 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 whos axis trends in a north-south direction. The crest of the fold is essentiall level from sec. 14, T. 2 S., R. 6 E., to sec. 35, T. 3 S., R. 6 E., a distance of about 9 miles. It rises rather abruptly farther south and plunges t the north in the northern part of the anticline. The contours of the map figure 11, are based on elevation on the top sandstone member of th Lower Chupadera formation but are drawn to represent the structure on the top of the Magdalena formation.

Structural closure on the east, west and north is well defined. To the south structural closure 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 Magdalena 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 Lower Chupadera, reached the Abo at about 1,610 feet, and the Magdalena, the most promising formation, at about 2,700 feet. (See log pages 197, 198.) 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.

Log of Rio Grande Oil Co. Stackhouse No. 1 Well
NE. Cor. SE.¼ Sec. 14, *T.* 3 *S., R.* 6 *E.*
Drilled, 1929-30

	Bottom, feet.
Cellar	13
Soil	33
Dark lime	53
Lime and clay	75
Dark lime	90
Gray lime	120
Lime and red beds	135
Lime and dark gray lime	150
Dark lime	180
Red beds and sheiks	200
Red beds and lime	220
White gypsum	235
Gypsum	250
Slate	255
Water sand	260
Black lime	275
Gypsum	290
Anhydrite	305
Slate	310
Black lime	330
Sandy lime	340
White gypsum	355
Zed beds	365
Gypsum	440
Red beds	490
Anhydrite	500
Lime	510
Hand lime	530
Lime	545
Red rock	635
Pink rock	645
Sand; 2 bailers water per hour	650
Anhydrite	695
Pink rock	750
Red beds	845
Red beds and gypsum shells	855
Red beds	895
Sand	905
Dark lime	920
Sand	935
Blue slate	945
Red beds	1120
Gypsum	1125
Anhydrite	1135
Blue slate	1140
Anhydrite	1175
Red sand	1225
Anhydrite	1305
Red beds	1350
Red sand and gypsum	1365
Red beds	1385
Gypsum and red beds	1385
Red sand	1392
Hard gray lime	1398
Gray lime	1410
Red sand	1438
Anhydrite	1448
Red sand	1465
Anhydrite	1480
Red sand	1505
Gray lime	1510
Lime	1520
Red sand	1530
Gray lime	1535
Lime	1645
Red sand; 1,100 feet of water	1660
Red sand, hard	1675
Red rock	1685
Lime	1690
Red sandy lime	1710
Lime	1730
Broken lime	1745
Brown lime	1760
Lime	1795
Red sand	1800
Lime	1810
Red beds	2005
Sandy lime	2010
Sharp sandy formation	2015
Red sandy shale and little lime	2030
Red shale	2045
Brown shale	2050
White lime, hard	2060
Gray lime shells	2065
Red sandy shale	2075
Red sandy shale and little lime	2085
Red sandy shale	2095
Hard sandy shale and some lime	2100
Red sandy shale and conglomerate	2110
Red sand	2115
Red mud	2130
Brown shale	2140
Sharp sandy red beds	2170
Red beds	2175
Broken sandy lime	2190
Broken red and gray formation	2230
Red rock	2240
Hard sandy formation	2255
Broken formation and flint	2275
Broken formation	2290

	Bottom, feet.
Red rock	2300
Broken red and gray formation	2350
Gray shale	2355
Red rock	2405
Hard shells	2410
Red rock	2415
Broken formation	2475
Red rock	2505
Red and gray rock	2515
Red rock	2518
Lime	2525
Brown and gray lime	2540
Shale	2545
Broken lime	2555
Red rock	2565
Shale and lime	2570
Dark gray lime	2595
Brown shale and shells	2618
Brown and gray lime	2625
Red rock	2647
Brown shale and lime	2662
Hard shells	2665
Blue shale	2675
Red shale	2687
Lime shells and brown shale	2707
Blue shale and lime shells	2715
Gray and white lime and blue shale	2726
Lime and red rock	2742
Brown shale; total depth	2772

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[1] in the following language.

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 Spring 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.

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, including Triassic "Red Beds;" Chupadera formation and Abo sandstone of Permian age; limestone, shale and sand-

[1]Darton, N. H., op. cit. (U. S. G. S. Bull. 726), p. 238.

stone of the Magdalena group (Pennsylvanian) ; and underlying formations of Carboniferous, Devonian, Silurian, Ordovician and Cambrian age 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. The following table of formations of the area, and remarks about the possibilities of the formations are from Darton.[1]

Sedimentary formations in Tularosa Basin and Adjoining Ridges.

Age.	Group and Formation.		Character.	Thickness (feet).
Upper Cretaceous.	Mesaverde (?) formation.		Sandstone and shale, coal bearing.	630
	Mancos (?) shale.		Shale; some sandstone; limestone in lower part.	900
	Dakota (?) sandstone.		Sandstone, massive, hard, gray to buff.	150
Triassic.			Red sandy shales with layers of brown sandstone and limy concretions.	340
Permian.	Manzano group.	Chupadera formation.	Upper part limestones and gray sandstones; lower part gypsum, soft red sandstones, then limestones and gypsum.	1200-1600
		Abo sandstone.	Brown-red sandstones and red sandy shales; thin toward the south.	500-900
Pennsylvanian.	Magdalena group.		Limestones with beds of shale and sandstone; several sandstone beds in lower part.	2200-2500
Mississippian.	Lake Valley limestone.		Coarsely crystalline limestone and limy shale.	0-150
Devonian.	Percha shale.		Gray shale.	0-125
Silurian.	Fusselman limestone.		Limestone, massive, dark above; weathers white below.	0-200
Ordovician.	Montoya limestone.		Massive limestone, cherty above, dark below, sandy at base.	0-200
	El Paso limestone.		Limestone; weathers light gray, slabby in part.	0-350
Cambrian.	Bliss sandstone.		Sandstone, massive, gray.	0-125
Pre-Cambrian.			Granites, schists, and quartzites.	

The Bliss sandstone is coarse and porous. The overlying limestones present considerable variety in character. Some of them are compact, some are mixed with considerable clay and sand, and some are cherty. The Fusselman limestone, which is especially massive and compact, thins out not far north of latitude 36°. The base of the Montoya is a sandstone at most places, and locally this member is 10 to 20 feet thick. The Percha shales are dark and carbonaceous and should be tested. The basal portion of the Magdalena group includes much coarse gray sandstone, and layers of sandstone occur at intervals higher up in the formation. These sandstones would afford suitable reservoirs for oil. It is not known, however, whether the carbonization of the organic debris in these formations has proceeded so far as to preclude the occurrence of oil in commercial amounts, though gas may be present.

The red sandstones of the Abo formation appear not to be favorable sources of oil, but owing to their porosity they might serve as reservoirs. In the Chupadera formation there are alternations of massive, compact

[1]Darton, N. H., op. cit. (U. S. G. S. Bull. 726), p. 224.

gray limestone, thick gypsum beds, red sandstone, and porous gray sandstone. The gray sandstones may prove to be oil bearing in some portions of the area. They are known to underlie the upper part of the basin and are believed to extend far southward under it. * * *

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, [1] "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 [2] 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 Hill's, 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 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 5 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 [3] 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 5 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 the Magdalena group 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

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[1] Darton, N. H., op. cit. (U. S. G. S. Bull. 726), p. 223.
[2] Darton, N. H., op. cit. (U. S. G. S. Bull. 726), p. 226.
[3] Darton, N. H., op. cit. (U. S. G. S. Bull. 726), p. 227.

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 red beds and gypsum to 1,302 feet. Darton[1] 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 Magdalena. 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.

MISCELLANEOUS STRUCTURES IN THE MEDIAN AREA

Several anticlines occur in the Median Area outside the smaller divisions described on the preceding pages. Among these are the Galisteo anticline and the Tijeras anticline.

GALISTEO ANTICLINE

Southeast of Galisteo in southeastern Santa Fe County the Cretaceous sediments are steeply upturned and arched into what is shown on the Oil and Gas Map, Plate XXIII, as the Galisteo anticline. The axis of this fold is shown extending in a general northeast-southwest direction for some 15 miles. No information is available to show the character of the fold nor the amount of its closure. Jurassic and Triassic beds form the surface and 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. 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.

TIJERAS ANTICLINE

The Tij eras 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 5 miles long by 2 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 is exposed at the surface surrounded by beds of Mesaverde age. The crest of the structure is located in the southwest quarter of 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 of practically no interest as an economically valuable area.

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[1] Darton, N. H., op- cit. (U. S. G. S. Bull. 794), p. 219.

SOUTHWEST AREA

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 XIV.) 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 above sea level. 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.

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 bed rock surface below. But few wells have been drilled to depths sufficient to reach the bedrock floor, and logs of these are lacking or inaccurate. These beds 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 Mountains 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 areas in the mountains of the Southwest Area. The geology of several of the more important areas has been described in detail by Ferguson, [1]

[1] Ferguson, H. G., Geology and ore deposits of the Mogollon mining district: U. S. Geol. Survey Bull. 787, 1927.

Paige [1], Lindgren, Graton and Gordon [2] and others, and Darton [3] 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, and more recent bolson deposits 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 this oil 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-f orming substance. 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.

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[1] 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 Pinos 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.

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

[3] Darton, N. H., The geology and underground water of Luna County, N. Mex.: U. S. Geol. Survey Bull. 618, 1916.

REFINING AND TRANSPORTATION

Like other phases of the oil and gas industry in New Mexico, transportation and refining have had a phenomenal growth during the past two or three years. During 1931 the State produced 15,227,000 barrels of oil, 19,354,000,000 cubic feet of gas and 17,775,000 gallons of casing-head gasoline. At the present time there are six oil refineries with a total rated capacity of 7,000 barrels of oil per day.

Three natural gasoline plants are located in the State, and these are capable of handling 50,000,000 cubic feet of gas per day. There are in New Mexico approximately 350 miles of oil trunk lines and 750 miles of gas trunk lines.

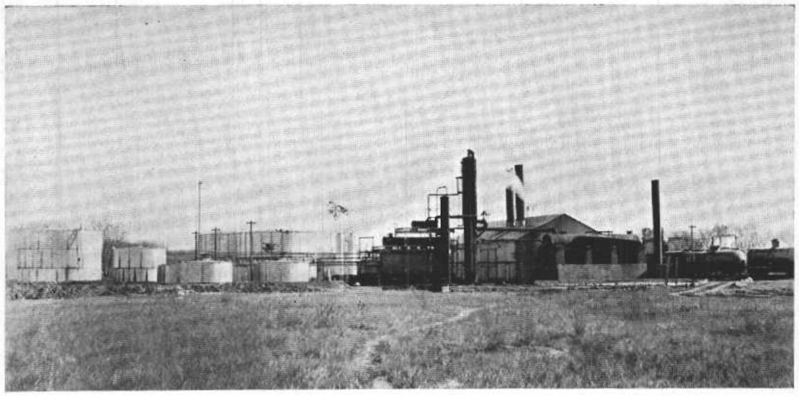
OIL REFINERIES

The Continental Oil Company's refinery at Artesia (see Plate XXXIII, C) has a rated capacity of 1,500 barrels of oil daily. Crude having a gravity of about 35° A. P. I. is obtained from the Artesia field 20 miles to the southeast. The plant is a continuous skimming plant producing gasoline, kerosene and fuel oil. The equipment consists of three shell stills and three regular-type fractionating towers of the bubble plate and cap type. In addition to the usual chemical treatment and refinement equipment, this plant is equipped with Gray towers for final refinement with clay or Fuller's earth. The equipment also includes the following tankage:

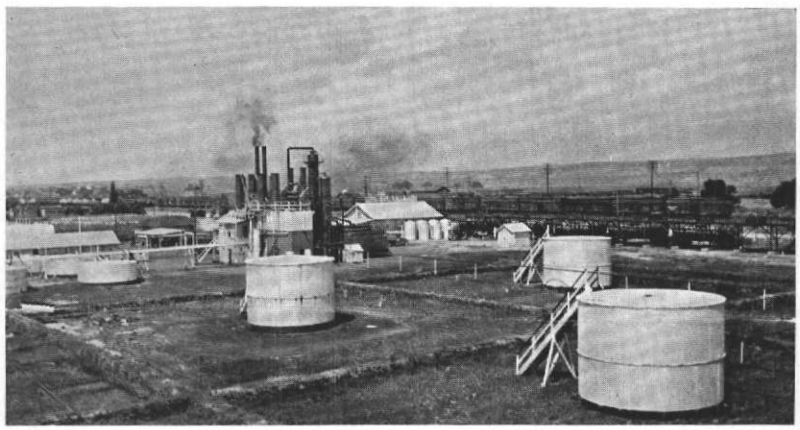
10,000 barrels crude storage, supplemented by a 55,000 barrel crude storage tank belonging to the New Mexico Pipe Line Co.
10,000 barrels finished gasoline storage.
6,000 barrels unfinished gasoline storage.
1,250 barrels kerosene storage.
45,000 barrels fuel oil storage.

The Malco Refineries, Inc., in 1931 constructed a 1,500 barrel refinery at Artesia (see Plate XXXII, B) to handle crude oil from the Maljamar and other fields east of Artesia. This plant began operations on Aug. 19, 1931, and at the end of the year was handling about 800 barrels of crude oil per day. The equipment was designed by the Southwestern Engineering Corp. and includes the latest type topping and treating equipment with automatic controls throughout. Approximately 25,000 barrels storage capacity is provided at the plant.

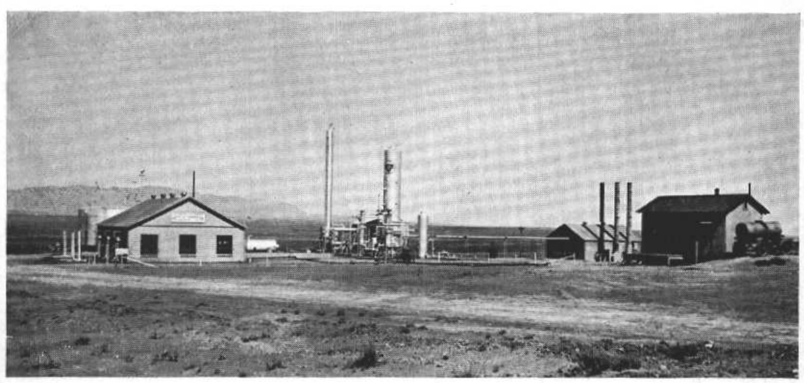
The Continental Oil Co. early in 1931 took over the refinery of the Gilliland Refining Co., located on the east edge of Albuquerque. This refinery (see Plate XXXII, B) has a daily capacity of 1,000 barrels of oil. The plant is of a continuous skimming plant type, producing gasoline, stove distillate and fuel oil. The plant is operated on crude from the Rattlesnake and Table Mesa fields in San Juan County, which is brought from the fields to Gallup by pipe line, thence to the plant by tank cars. Equipment includes one shell still and two regular-type fractionating towers of the bubble plate and cap design. In addition there are two shell stills directly connected to two baffle towers 3 by 15 feet in size for use in making special products.



A. Continental Oil Co.-Santa Fe Corp. refinery at Farmington. (Courtesy of Continental Oil Co.)



B. Continental Oil Co. refinery at Albuquerque. (Courtesy of Continental Oil Co.)



C. Crude Oil stabilization plant at Rattlesnake lease. (Courtesy of Continental Oil Co.)

C. Crude oil stabilization plant at Rattlesnake lease. (Courtesy of Con

Tankage at the Albuquerque refinery consists of:

7	500 barrel tanks
10	1,000 barrel tanks
2	1,500 barrel tanks
2	2,000 barrel tanks
1	3,000 barrel tanks
1	10,000 barrel tanks

The Continental Oil Co. and the Santa Fe Corp. have a 1,000-barrel refinery just east of the town of Farmington. (See Plate XXXII, A.) This unit operates on crude oil having a gravity of 60° to 62° A. P. I. from Rattlesnake lease. The crude after being stabilized at the lease is delivered by pipe line to the refinery. The refinery is a semi-continuous skimming plant consisting of one shell still and two regular-type fractioning towers of the bubble plate and cap design. The plant produces only gasoline and a high quality of fuel oil. The equipment includes up-to-date Ethyl gasoline blending equipment. The products from this refinery are marketed in the narrow-gauge railroad territory of southwestern Colorado and northwestern New Mexico.

The Valley Refining Co. has a refinery of 500 barrels daily capacity located at Roswell. The plant is of the batch process type and makes gasoline, kerosene, distillate and gas oil. The plant is operated on crude oil from the Artesia field. This plant also includes a cracking unit having a daily capacity of 300 barrels which is used occasionally for the manufacture of road oil.

One of the first refineries operated in the State is located at Dayton. In past years this plant has changed ownership several times, the last operators being the State Oil Refining Co. who used the plant for the manufacture of road oil for the State Highway Department.

NATURAL GASOLINE PLANTS

One casinghead gasoline plant is located in the Artesia field in Eddy County, and two are located in the Hobbs field in Lea County.

The plant of the Phillips Petroleum Co. in the Artesia field consists of five combination engine and compressor units designed and rated to handle 5,000,000 cubic feet of gas per day. The plant is connected to some 200 wells in the Artesia field. The gas treated is relatively rich in gasoline, averaging nearly 2 gallons per thousand cubic feet.

The plant of the Phillips Petroleum Co. in the Hobbs field uses the absorption method and was originally designed so that it might operate either as a well-pressure or compressor unit or both. The plant is rated to handle approximately 22,000,000 cubic feet of gas per day. In June, 1931, the plant was recovering approximately 1.6 gallons of gasoline per thousand feet of gas treated. Gas from the Hobbs field is slightly sour and corrosive, containing about 2½ to 3 per cent hydrogen sulphide, but the ultimate product of this plant is sweet and noncorrosive, due to the treatment of the raw gasoline.

The Hobbs plant of the Shell Petroleum Corp. and the Continental Oil Co. (see Plate XXXIII, A), has a capacity approximately the same as the Phillips Petroleum Co. plant in the same field. The equipment consists of seven 170-H. P. Bessemer engines and compressors and three 225-H. P. Watts-Miller engines and compressors. The distillation equipment is composed of two type-75 Southwestern distillation units. The gas treated has an average gasoline content of 1.75 gallons per thousand cubic feet. The natural gas contains considerable hydrogen sulphide, and therefore both engine fuel and finished product are being treated and the gasoline produced is Doctor Sweet Grade AA, although slightly higher in gravity than the AA specifications. In June, 1931, the plant was treating 11,000,000 to 12,000,000 cubic feet of gas per day and producing an average of about 20,000 gallons of gasoline per day.

OIL PIPE LINES

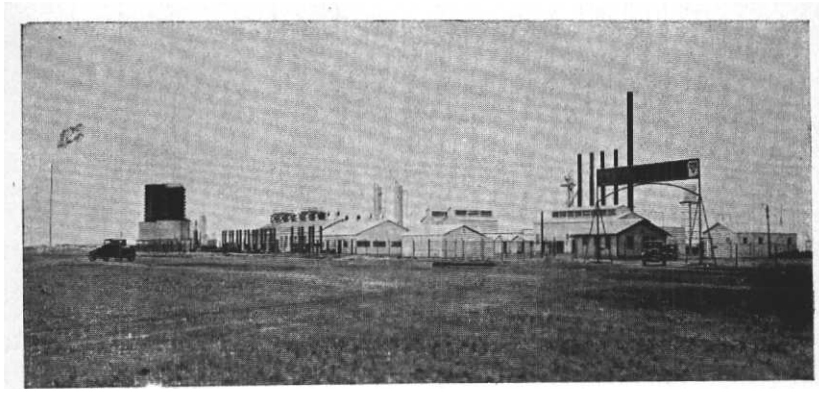
The phenomenal growth of oil production in New Mexico during the past few years has been met by the construction of pipe line transportation systems adequate to handle the oil. (See map, Plate XXIII.) Up to 1926 a few miles of pipe line carried the production of the Artesia pool to refineries at Artesia and Dayton, and the oil from the Hogback field to the railroad at Farmington. In 1926 the Continental Oil Co. and Santa Fe Corp. built a 4-inch line from the Rattlesnake field 96 miles to Gallup where the oil is placed in tank cars for transportation via standard gauge railroad to refinery points. This line also handles the production from the Table Mesa field. Part of the Rattlesnake field's production goes to the Farmington refinery via 13 miles of 2-inch line to Hogback and thence through the Midwest Refining Company's 3-inch line 22 miles long.

In 1930 three 8-inch oil lines were built into Hobbs to handle the crude from that field. The Atlantic Pine Line Co. line goes direct to Midland. Texas, and is 79 miles long. This line has a daily capacity of 25,932 barrels. The Humble Pipe Line Co. line from Hobbs runs south 40 miles to Jal and thence to Wink, Texas, a total distance of 80 miles. This line has a capacity of 20,000 barrels per day. The Shell-Texas Co. line goes south to Eunice and then to Wink. Its capacity is 18,000 barrels per day. Due to topographic conditions in the area traversed by these three lines the oil is transported the entire length of the line without intermediate booster stations. Oil from the Eunice, Cooper, Lea and Jal areas enters the Shell-Texas and Humble lines and is transported to Wink, Texas. Within the Hobbs field there are about 50 miles of gathering line, through which the oil is assembled at the tank farms of the pipe line companies located at the south end of the field.

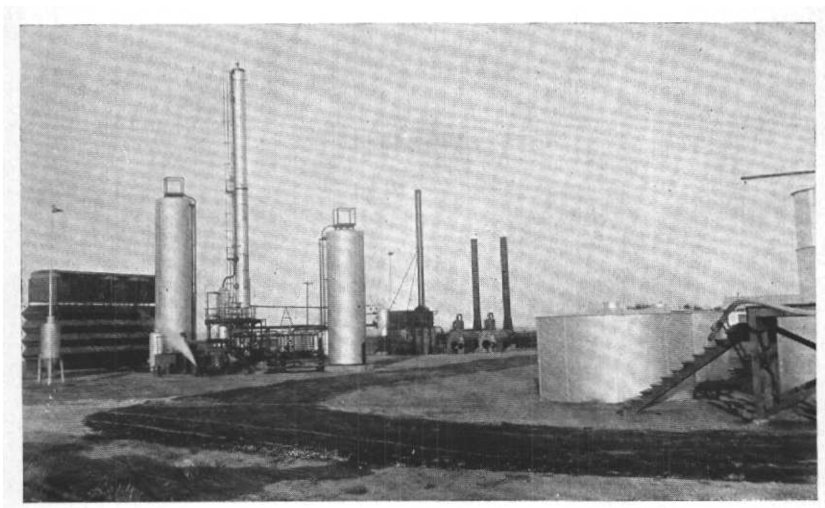
Oil from the Maljamar and intermediate pools east of Artesia is taken to refineries at Artesia through the New Mexico Pipe Line Company's 4-inch line.

NATURAL GAS PIPE LINES

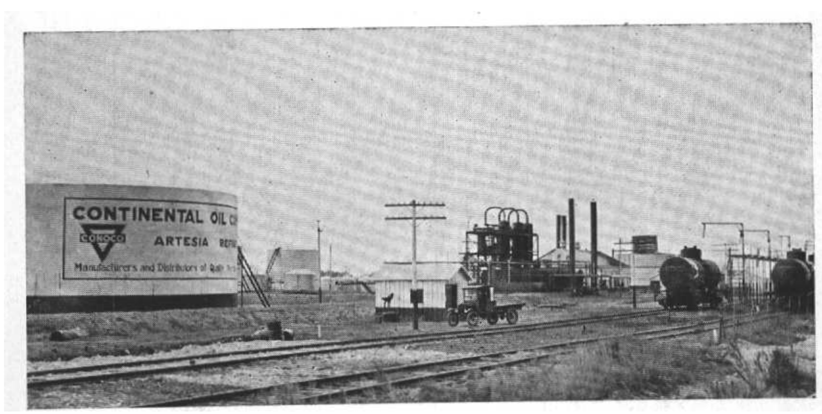
The large gas-producing area of southern Lea County, which includes the Jal, Cooper and Eunice areas, is supplying gas to El Paso, Texas,



A. Continental-Shell gasoline plant in the Hobbs field.



B. Malco refinery at Artesia. (Courtesy of Malco Refineries, Inc.)



C. Continental Oil Co. refinery at Artesia.

through the El Paso Natural Gas Company's 16-inch welded line and thence through southwestern New Mexico via Deming to southeastern Arizona and Cananea, Old Mexico, by the Western Gas Company's 12-inch line (see map, Plate XXIII).

Lovington in Lea County is connected with the Hobbs field by a line for the transportation of gas.

Gas from the Maljamar and Artesia areas is taken by the Pecos Valley Gas Co. line to Carlsbad, Artesia, Roswell and other towns in the Pecos Valley.

Gas from the Kutz Canyon field in San Juan County goes in part through a 2-inch line to Farmington and in part through a 10- and 12-inch line to Albuquerque, Santa Fe and Belen. (See map, Plate XXIII.) The Southern Union Gas Co., which owns this system, is also planning an extension of its Santa Fe branch to supply Las Vegas. The Kutz Canyon field wells have a rock pressure averaging 550 pounds per square inch and to date this pressure has been sufficient to force the gas through the 10- and 12-inch lines across the Continental Divide and to Albuquerque and Santa Fe. The altitude of the field is approximately 5,700 feet above sea level, while the Continental Divide has an elevation of about 7,000 feet and Albuquerque about 4,950 feet. No booster stations are used, although the distance between the field and Albuquerque is about 150 miles.

Gas from the wells at the Southern Ute dome near the north line of the State in San Juan County is taken to Durango, Colo., through a line owned by the Southern Union Gas Co. Late in 1932 construction was commenced on a pipe line to connect the wells on the Southern Ute dome with the Kutz Canyon-Albuquerque line.

In addition to the lines just mentioned, which transport gas produced within the State, there is the 20-inch line of the Colorado Interstate Natural Gas Co., connecting the Amarillo, Tex., gas field with Colorado Springs and Denver, Colo., which crosses the northeast corner of the State. Towns in New Mexico along this line are supplied with gas.

The Gas Company of New Mexico has a line from the Amarillo field into New Mexico, which furnishes gas to Portales, Clovis and Tucumcari.

BITUMINOUS SANDSTONE

DEPOSITS NEAR SANTA ROSA, GUADALUPE COUNTY

The Santa Rosa sandstone (Triassic) in Guadalupe County near Santa Rosa is saturated with bituminous material over a considerable area. Recently detailed studies of this deposit have been made by the New Mexico Construction Co. and the writer is indebted to Mr. Vincent K. Jones of that company for much of the information which follows.

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 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 4 to 8 per cent of bituminous substance, about one-fifth of which, according to Mr. Jones. 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 material 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 to date show that this particular deposit of bituminous sand contains approximately 2,000,000 tons having a residual asphaltic content of 5 per cent. The overburden, which is composed of similar sand though not saturated in this particular area. ranges in thickness from a few inches to forty feet.

At the present time the bituminous sand deposit near Santa Rosa is being developed in a small way for paving purposes. A quarry (see Plate XII, B) has been opened at a point where there is practically no overburden above the saturated material and where core-hole prospecting has shown the deposit to have a thickness of fifty feet. The sand at this point has a residual asphalt content averaging 5 per cent. Approximately 1,000 tons of bituminous sand have been quarried and most of it used in pavement Construction for the New Mexico State Highway Commission within the town of Santa Rosa. After mining, the rock is crushed to minus ¼-inch size and then mixed with 1 to 1½ per cent of asphalt, together with a small amount of gasoline or naphtha, the latter being added to make the added asphalt blend with the natural asphalt contained in the rock. The small treating plant used to crush and prepare the bituminous sand for use is shown in Plate XII, C. After this treatment, the product is laid cold. Apparently one inch of "this material laid on a substantial foundation is all that will be required for heavy traffic pavement.

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 large area. According to information furnished to the writer by J. M. McClave of Denver, Colo., the saturated sandstone has a thickness of not over 40 feet. The sand is coarse grained and hard. Analysis of the sand shows an oil content of as much as 24 per cent. No economic use for this sand has yet been developed.

GEOPHYSICS AND ITS USE

GENERAL FEATURES

During the last few years geologists have come to realize that information regarding the specific gravity, magnetic properties, conductivity of rocks (for both electric and elastic impulses), etc., may be used in the search for structure favorable for oil. Because of this realization, the science of geophysics and the use of geophysical instruments have advanced by leaps and bounds, and today it is possible by the aid of geophysical instruments to determine in many places subsurface structure in advance of the drill, even in areas where bed rocks are completely concealed by soil and recent formations. According to Wilson:[1]

> In 1920 there were very few people engaged in geophysical prospecting work in the United States and by 1922 there were probably not more than 25. By 1924 there were probably about 40, but by 1926 the number had risen to about 300 men. At the present time (1928), when there are 100 torsion balances, 175 magnetometers, 85 seismograph's, 30 electrical prospecting crews and several miscellaneous instruments in operation, there are probably not less than 1,000 men in North America engaged in geophysical work, not counting the ordinary laborers that are needed for the clearing of survey lines, station sites and the transportation of equipment. The equipment used by these men is valued at about $1,250,000.

In all geophysical methods improvements are being made daily, and that which was considered impossible yesterday is today being accomplished. Additional advances, both as to apparatus and as to the interpretation of information may be expected in the future, and data regarding subsurface conditions should be greatly increased thereby.

New Mexico's rapid rise among the oil producing states may be charged to these newly developed scientific methods. Vast areas, particularly in eastern and southern New Mexico, are practically impossible of solution by the student of surface geology, but by the aid of geophysics it may be possible to make wise selections of drilling sites and prophesies as to probable depth. Drilling in the Hobbs area was started because geophysical studies indicated a structural condition worth testing. Doubtless other areas in the soil-covered portions of the State have as good prospects of being productive.

The following brief discussion of geophysical methods and instruments as applied to the solution of the problems of the petroleum geologist is given so that the reader may better understand the usefulness of geophysical methods as well as their limitations. In this connection the writer is indebted to John H. Wilson, whose articles on geophysical prospecting have already been cited, and to Dr. E. U. von Buelow of Denver, Colo., whose published articles and personal advice have been freely drawn upon.

From a scientific standpoint, geophysical methods may be divided into two main classes, as follows:

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[1] Wilson, John H., Geophysical prospecting: Colo. Sch. of Mines Mag., July, 1928, p. 15.

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. Self-potential electric methods.
D. Radioactivity methods.
E. Geothermal 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

These methods are dependent upon the fact that the pull of gravity at any place depends upon the weight and distribution of the masses underlying and surrounding the place of observation. An abnormal distribution of the masses will result in a corresponding abnormal pull of gravity; hence, the presence of heavy ore bodies, buried granite ridges, structural uplifts or basins, salt domes, and other geologic features will Influence the pull of gravity, and from the irregularities or anomalies on the pull of gravity something as to the presence or absence of such occurrences in the ground beneath the station may be inferred. As a rule, positive anomalies are secured over uplifts and negative anomalies over synclines or basins and salt domes. In other words, the uplifts usually bring denser rocks nearer the surface, resulting in greater pulls of gravity. However, many localities are known where the inference that positive anomalies mean uplift in the sedimentary beds is erroneous and the reverse is the true condition. It is evident, therefore, that the geologist in interpreting the meaning of gravitational anomalies must be well fortified with detailed information regarding the physical properties of the subsurface rocks, particularly their specific gravities.

For making gravitational determinations, two types of instruments are used, these being the pendulum and the torsion balance. The first measures absolutely or relatively the total force of gravity at the point of observation. The second determines the horizontal direction in which gravity is increasing and gives information regarding equipotential surfaces of gravity (shapes of surfaces of equal gravity), etc. The torsion balance yields much more local (detailed) information than the pendulum. In addition it is much faster in operation and is, therefore, more commonly used in oil and gas work. The information obtained from torsion balance studies gives clues regarding the shape, size, density, depth and other features of any mass which is different from the other rocks in specific gravity. It is, therefore, suited especially well to the study of salt domes, buried granite ridges and like occurrences. Gravitational measurements are influenced by topography, and hence they are difficult to evaluate in areas of rough topography or near large mountain masses unless the anomalies due to subsurface beds of the area are comparatively large.

MAGNETIC METHODS

The use of the magnetometer as an aid to the solution of problems the oil geologist is based principally on the facts that magnetite exists in varying amounts in rocks, that granite is one of the most magnetic of common rocks, and that in many places the geologic structure in the sedimentary beds above the granite reflects the upper surface of the granite If unconformities exist between the top of the granite basement and the possible production horizons, the magnetic anomalies become less valuable for oil and gas work. In many areas, sedimentary structures (anticlines correspond in location with areas of greater magnetic anomalies. This is not at all universal, and in certain parts of the country, due perhaps to the existence of radical unconformities over the granite surface, to changes in the composition of the granite, or to both, anticlinal structure occur in areas of lessened magnetic pull.

Many magnetic influences, such as local attractions due to magnetic materials, pipe lines, etc., and also interferences by magnetic storm- may vitiate the magnetic information, and all readings must be corrected for regional influences, temperature variations, diurnal variation, etc.

Magnetic observations may be made with considerable speed, as good operator may occupy as many as 30 or 40 stations a mile apart in a day's time if roads and transportation are good. The apparatus use is easily portable, and costs of magnetometer surveys are not great Properly used, the magnetometer is an excellent scout instrument. When radical magnetic anomalies are found, the geologist should make intensive studies of all surface and subsurface formations, and probably use the more accurate and more expensive geophysical instruments.

SELF-POTENTIAL ELECTRIC METHODS

These methods are not adapted to use in oil and gas work, since the are based upon the measurements of electric effects set up in the rock themselves.

RADIOACTIVITY METHODS

Von Buelow[1] has given the following summary of the applicability of measurements of radioactivity to the solution of oil field problems

Water circulating in open faults often is charged with radioactive emanation. In case such occurrences then come close to the surface the emanation is given to the air contained in the soil. From here it slowly evaporates into the open air. By using this fact occasionally such faults and fractures can be detected and traced on the surface by measuring the amount of emanation present in the soil air. This naturally will be higher vertically above them than elsewhere. But the radiance of this method is small and in case the faults are sealed on top, or do not come close enough to the surface, no increase in emanation will be found.

Oil is known to be a great absorber of radioactivity. This fact cannot be used in locating oil deposits from the surface by radio active measurements, because of the rapid decay of the emanation. But if samples of

[1]Von Buelow, E. U., Essential points in the use of geophysics: Oil and Gas Jour., Jan 2, 1930, p. 67.

cores of a drilling well systematically and immediately after they come out of the hole would be tested as to radioactivity, then in many cases it would be found that in samples taken directly above the oil deposit, there is a sudden drop of radioactivity. By doing so it could also be said at what depth a well had closely missed an oil pool and maybe lateral drilling then still would hit it and save the well.

Radioactive measurements are very cheap and quick and, therefore, very economic. But their applicability is very restricted and there will be only a few cases where they will give good results.

GEOTHERMAL METHOD

This method consists in the determination of temperature changes in the rock formations. Normally, temperatures gradually increase with depth, but certain factors, such as the character of the rock formation, presence of certain types of oil, etc., may cause variations from the general rule. In certain areas, such as the Salt Creek oil field in Wyoming, there appears to be a definite relation between the geothermal gradient and the geologic structure. This has led some to believe that high geothermal gradients over oil fields are due to chemical reaction within the oil accumulation. However, similar high gradients are known over structural uplifts when no oil is present, and hence this view does not appear justified. Wilson[1] states that:

> In view of the common relationship between high geothermal gradients and structural uplifts, it would be well worth while for the wildcat operator to obtain depth temperature measurements for his well, especially where structural conditions are unknown or obscure.

It appears, therefore, that geothermal methods are not of value in making the location for a first test well but may yield information of value in developing an area where structure is indicated or known.

SEISMIC METHODS

The seismograph, first used to record natural earthquakes, was used during the World Ear to locate enemy guns, which latter use suggested its application to geophysical prospecting. Seismic methods in geology depend on the fact that different types of rock—sandstone, shale, limestone, salt, granite, etc.— respond differently when subjected to elastic (shock) waves, whether produced as earthquakes by nature or artificially by man. The velocity of the seismic waves depends upon the elastic properties, rigidity and density of the rocks. In general, crystalline and metamorphic rocks—salt, granite, etc.,—have velocities higher than other types. Like light waves, seismic waves exhibit the phenomena of reflection and refraction.

The essentials for seismic exploration are:

1. A seismograph for registering the vibration.
2. A source of vibrations (usually a dynamite explosion).
3. A method of marking on the seismogram small time intervals (usually by tuning fork, pendulum or oscillator).
4. A method of marking on the seismogram the time of the explosion.

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[1] Wilson, John H., Geophysical prospecting: Colo. Sch. of Mines Mag., Aug., 1929, p. 15.

To determine the velocity of surface formations, the seismograph is placed fairly near 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 formations has arrived.

In the so-called refraction methods of seismic work, determinations of beds at greater depths are made by increasing the distance between the shot and the seismograph, the strength of the explosion being necessarily increased. In this work, depths can be computed to beds of increase speed, 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.

In the so-called reflection method the shot point is close to the receiver, and the results depend upon the reflection of waves from contact surfaces between geologic beds of different speeds, as for instance, sandstone against limestone. By this method it appears possible to determine several contacts from a single shot and single seismogram and their depths below the point occupied by the seismograph. As a rule, reflection methods can reach greater depths than refraction methods.

Although quite expensive, seismic methods give details of actual depths at given points which often are not obtainable by other methods and appear, therefore, to have decided advantages in results obtained. Seismic methods were first used in the United States to locate and outline salt domes, one of the easiest of geophysical problems, because of the radical differences between the crystalline salt and surrounding sedimentary beds.

As a result of the recent perfection of apparatus and technique, the seismograph where applicable is very efficient in outlining buried structures.

ELECTRICAL METHODS (EXCEPT SELF-POTENTIAL)

The use of electrical methods in studies of sedimentary structure today is limited to those methods by which the relative resistivity of different beds to the flow of electric currents is determined. According to Schlumberger :[1]

> Rocks are capable of conducting electric current only by means of the water they contain. The more water they contain and the richer this water is in dissolved, salts, the more conductive they are. * * * The most conductive rocks are sands and marls saturated with salt water. They show resistivities of 0.5 to 10 ohms; next non-salty clays, between 10 and 30 ohms; the marls, between 20 and 100 ohms; the limestones, between 60 and- 200 Ohms; the schists, between 70 and 300 according to their

[1]Schlumberger, C. M., The method of the ground resistivity map and its practical application: Can. Min. and Met. Bull., 1931, reprint, p. 3.

degree of compactness and metamorphism; the sandstones, between 100 and 2,000 ohms; etc.

In connection with the location of salt domes, electrical resistivity methods appear to be quite useful, for according to Schlumberger: [1]

> Rock salt has a twofold property; it is in itself, electrically, a very resistant material; at the same time, it renders the surrounding rocks extremely conductive through the salt water which it furnishes to them.

When the geologic section includes porous beds known to contain salt water, electrical methods can probably be used to determine the structure based upon these beds. It should be borne in mind, however, that the salt water content may vary from place to place. In such cases the conductivity may be erratic, and false impressions of structure may result.

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[1] Schiumberger, C. M., op. cit., p. 11.

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INDEX

A

Abbott dome, 116, 119.
Abo sandstone, 21, 25, 62, 104, 110, 118, 121, 127, 140, 142 189, 190, 194, 198, 199, 200.
Ache, Paul S., 97.
Acknowiedgments, 13.
Acoma anticline, 114.
-- Basin, 60, 105.
Ambrosia Lake dome, 91.
Anaiyses, see Gas anaiyses and Oii analyses.
Animas formation, 20. 42.
Apishapa shaie, 20, 36, 37, 118.
Arkansas Fuei Oii Co., 121, 122.
Arkose, 116, 121, 124, 127, 129, 131, 133, 201.
Artesia field, 146.
Atiantic Production Co., 173.
Azotea anticiine, 64, 100.
Aztec gas fieid, 62, 98.

B

Baca anticline, 116, 138.
Bald Hiii dome, 130.
Barker dome, 62, 64, 65.
Barytes, 168.
Beartooth quartzite, 20, 35.
Beautifui Mountain anticiine, 62, 64, 84. Beii Farm anticline, 130.
Bell Mountain sandstone, 20, 37, 107.
Benita anticline, 133.
Benton shaie, 20, 118, 119, 138.
Big Eddy anticiine, 181.
Big Four anticline, 181.
Big Gas Pay, 142, 155, 157, 159, 165, 168, 174. Big Lime, 145.
Biitabito dome, 64, 81.
Bituminous sandstone, 128, 208, 209.
Biack Hiiis anticline, 181.
Biack River anticiine, 181.
Blanchard, W. G. and Davis, M. J., quoted, 141; cited, 169.
Blanco district, 99.
Biiss sandstone, 18, 21, 199.
Bioomfieid oil field, 62, 97.
Bloomfield Oil & Gas Co., 97.
Biuewater anticiine, 181.
Boison deposits, 48.
Bonita anticiine, 64, 86.
Bowers' sand, 142, 155, 156, 157, 159, 160, 163, 165, 168, 174.
Boyer, W. W. and Hansen, E. A., quoted, 98.
Brown iime, 142, 156, 157, 159, 165, 167, 174, 175, 177, 179.
Buchanan anticline, 181.
Buffaio anticiine, 190, 191.
Buffaio Creek anticiine, 181.
Burke, R. R., 85.

C

Cabezon anticline, 100.
California Co., 120, 173.
Cambrian system. 18, 21, 199.
Canada de ias Milpas anticline, 100.
Canadian anticline, 121, 130.
Capitan limestone, 21, 27, 28, 181 ; coral reef in, 26, 142, 146, 169, 177, 179.
Capulin anticiine, 117.
Carbon dioxide, 56, 116, 120, 121, 123, 124, 138, 182, 190, 191.
Carboniferous system, 21, 23, 105, 106.
Carica anticline, 64, 90.
Carlile shaie, 20, 36, 117, 118.
Carisbad dome, 181.
 limestone, 21, 142,145, 153, 156, 174, 181.
Carlton, A. E., 81.
Carpenter Gap anticiine, 130.
Carter Oil Co., 103, 104.
Castile gypsum, 21. 27, 29, 142, 145, 156.
Cathedral Rocks anticiine, 86.
Cedar Butte dome, 103.
Chama basin, 60, 61.
Chamiso formation, 20, 106.
Chavez anticiine, 64, 92.
Cherryvale dome, 123.
Chico anticline, 64, 100, 119, 120.
Chimney Rock dome, 62, 64, 66.
Chinle formation, 21, 29, 31, 62, 93, 104. Chromo anticline, 64.
Chupadera anticline, 194.
 formation, 21, 26, 62, 101, 103, 104, 110, 118, 121, 126, 127, 139, 145, 181, 194, 198, 199, 200.
Chuska sandstone, 42, 46.
Cimarron dome, 117.
Cimarron Valiey anticline, 138.
Ciapham anticline, 138.
Cliff House sandstone, 20, 39.
Coal, 37. 38, 40, 44, 62, 118, 184, 190.
Coiorado group, 20, 36, 118.
Comanche, 20. 34, 35, 127, 129, 187.
Compton, R. D., 66, 67.
Congress Oil Co., 99.
Con-O-Kul Oil Co., 123.
Continental Oil Co., 66, 71, 72, 82, 84, 90, 94, 147. 162, 173, 178, 204, 205, 206.
Cooper area, 146, 175.
Coral, see Capitan limestone.
Correlation, table, 20, 133.
Cow Springs anticline, 110.
Cranfill-Reynoids Co., 170, 176, 178.
Cretaceous system, 20, 34, 56, 62, 93, 97, 99, 100, 101, 105, 106, 116, 117, 118, 120, 126, 128, 182 184, 186, 188, 194, 198, 199, 201, 202, 203, 209.
Crystaliine lime, 142, 174.

D

Dakota sandstone 20, 36, 56, 62, 63. 64, 66, 84, 85, 92, 93, 95, 96, 97, 100, 103, 106, 107, 110, 111, 114, 117, 118, 119, 120, 121, 123, 126, 127, 129, 130, 131, 138, 198, 199, 203, 209; production from, 65, 66, 67, 69, 71, 77, 82.
Darton, N. H., quoted, 17, 120, 127, 183, 184, 186 194, 198.
Datil formation, 20, 52, 105, 106.
Defiance anticiine, 103.
DeFord, R. K. and Wahlstrom, E. A., quoted, 161; cited, 155, 165.
Delaware Mountain formation, 21, 28.
Devonian system, 21, 23, 199.
Divide anticline, 130.
Dockum group, 21, 29, 31, 117, 118, 120, 123, 127, 128, 131, 132, 138, 142, 156.
Dog Canyon anticlines,181.
Double Mountain formation, 145.
Drilling, tables:
  Cooper area, 176.
  Eunice area, 173.
  Harian ranch, 184.
  Hogback field, 67.
  Hospah dome, 89.
  Jal area, 178.

Maljamar area, 153.
Rattiesnake field, 76.
Dripping Springs anticline, 131.
Dulce dome, 64, 96.
Dune sands, 48.
Dunken dome, 142, 180, 181.

Elkins anticline, 181.
Ei Paso limestone, 19, 199.
Ei Paso Natural Gas Co., 177, 207.
El Vado anticiine, 64, 95.
Emery, W. B., cited, 112.
Empire Gas & Fuel Co., 150, 173, 178.
Eocene, 20, 44, 99, 118.
Estancia anticline, 190.
____ valley, 188.
Esterito dome, 127.
Eunice area, 172.
Evaporite series, 139, 140, 156, 157, 165, 172.

F

Farmington sandstone, 20, 41, 62; production from, 97, 98.
Fieid anticiine, 112.
Fierro iimestone, 21.
Flynn, Welch & Yates, 147.
French Mesa anticline, 64, 92.
Frio dome, 137.
Frontier Oil Co., 120.
Fruitiand formation, 20, 41, 62.
Fusselman limestone, 21, 22, 199.

G

Gaiisteo anticline, 201.
____sandstone, 20, 43, 118.
Galiego sandstone, 20, 37, 107, 110.
Gailina Mountain anticline, 64, 95.
Gaiiup dome, 103.
____ sandstone, 37, 40.
Gas, analyses of:
Aztec field, 99.
Bianco district, 99.
Hobbs field, 165, 166.
Jal area, 180.
Kutz Canyon field, 101.
Rattlesnake fieid, 78.
Southern Ute dome, 65.
Gasoline, 147, 152, 162, 205.
Geoiogic sections:
Chamiso formation, 106.
Chupadera formation, 27, 28.
Datil formation, 52.
Estancia vailey, 188.
Galisteo sandstone, 43.
Mesaverde formation, 40.
Miguel formation, 107.
Mogollon district, 51.
San Juan basin, 62.
Teritary, near Carthage, 46.
Tularosa basin, 199.
Geology, general, of state, 15; of oil and gas, 55; of Northwest Area, 60; of Northeast Area, 116; of Southeast Area, 139; of Median Area, 182; of Southwest Area, 202.
Geophysical methods, 126, 154, 210.
Getty pool, 146, 168. Getty, Geo. F., 168, 173. Gibson Oil Co., 133, 134.
Gila conglomerate, 20, 49, 202.
Glacial deposits, 49.
Glorieta sandstone, 132, 133, 142, 146, 194.
Graham anticline, 138.
Graneros shale, 20, 36, 118.
Grayburg structure, 146, 148, 150.
Greenhorn limestone, 20, 36, 118, 120, 121.
Gregory, H. E., quoted, 86; cited, 103.
Guadalupe group, 21.
___ anticline, 100, 138.
Gym limestone, 21, 28.
Gypsy Oil Co., 65, 84, 127, 128, 173, 178.

H

Harlan, et al., 184, 185.
Helium, 120.
Hershfield Drilling Co., 132.
Hobbs fieid, 146, 154.
Hogback fieid, 62, 64, 66.
Hoots, H. W., cited, 140.
Horse Lake anticline, 64, 100.
Hospah dome, 62, 64, 87.
Hudson anticiine, 131.
Hueco limestone, 21, 25.
Humbie Oil & Refining Co., 155, 178, 206.
Huntington Park Oil Co., 99.
Hurst, Welch, et al., 87.

I

Igneous rocks, 42, 49, 61, 105, 111, 112, 126, 183, 196, 200, 202, 203.
Illinois Pipe Line Co., 148.

J

Jackson pooi, 146, 148, 153.
Jal area, 146, 177.
Jaritas dome, 119, 120.
Johnson dome, 131.
Johnswood Oil Co., 92.
Jones anticlines, 181.
Jones, V. K., 208; dome, 132.
Jordan Ridge anticline, 134.
Jornada del Muerto, 193.
Jurassic system, 20, 32, 62, 93, 100, 105, 117, 118, 131, 138, 201.

K

Kelly limestone, 21.
Kinney Oil & Gas Co., 200.
Kirtiand shale, 20, 41, 62, 97, 98.
Kutz Canyon field, 62, 99.

L

La Cruz anticline, 110.
Lake Valley limestone, 21, 24, 199.
Las Vegas dome, 138.
La Ventana anticiine, 100.
Lawson anticline, 113.
Lea pool, 146, 170.
Lee, W. T. cited, 27, 28.
Leonard and Levers, 148, 150, 152, 178.
Lewis shale, 20, 40, 62.
Lindgren, Graton and Gordon, cited, 17, 203.
Lioyd, E. R., cited, 26, 142.
Lobo formation 21, 32.
Logan anticline, 138.
Logs, *see* well logs.
Lunsford dome, 119, 120.

M

McDermott formation, 20, 41.
McEimo formation, 20, 62, 64, 68, 91.
McGaffey anticline, 100.
McKittrick anticiine, 181.
McKnight anticline, 181.
McNutt, V. H., 147.
Madera limestone, 21.
Magdaiena group, 21, 24, 93, 110, 116, 118, 139, 140, 142- 146, 189, 194, 199, 200.
Magnolia Petroleum Co., 178.

Malco Refineries, Inc., 204.
Maljamar area, 146, 148, 153.
Maljamar Oil & Gas Co., 153.
Maljamar pay, 150.
Mancos shale, 20- 37, 62, 64, 67, 92, 93, 96, 100. 103, 106. 110, 111. 114, 199, 201.
Manning anticline, 181.
Manuelito anticline, 104.
Manzano group, 21. 27, 118, 199.
Mariano Lake anticline. 64.
Marland Oil Co., 66, 103, 129, 132, 133, 173, 176, 177.
Media anticline, 131.
Median Area, table of formations, 20; defined, 57; described, 182.
Menefee formation, 20, 39.
Mesa Leon anticline, 138.
Mesa Lucero anticline, 115,
Mesa Rica anticline, 131.
Mesaverde group, 20. 39, 62, 64, 67. 90, 91, 92, 93, 96, 100. 103. 106, 199. 201; production from. 85, 86, 87.
Mescalero sands, 20.
Metals, 202.
Meyers. J. Q., anticline, 114.
Meyers structure, 146.
Midwest Refining Co., 65, 66. 67. 68, 85, 86, 87. 89, 91, 92, 132, 133, 137, 154, 166, 177, 178, 206.
Miguel Creek anticline 92.
Miguel formation. 20, 37, 106.
Miller anticline. 113.
Miller, E. F.. quoted, 188.
Miocene, 20, 47.
Mississippian system, 21, 24. 62, 199.
Mitchel, L. H., and Sons, 108.
Moenkopi formation, 21, 29, 30, 62, 104.
Monero dome, 64, 96.
Monilla Creek anticline. 131.
Montana group, 20, 41, 118.
Montoya limestone, 21. 22, 199.
Morrison formation, 20, 34, 62, 93, 117, 118-120, 123. 127, 129, 131.
Mud drilling fluid. 168.
Munoz, S. C., 69.

N

Navajo Co. 84, 191.
Navajo sandstone, 20, 34, 62, 93, 103.
New Mexico Construction Co., 208.
New Mexico Pipe Line Co.. 147, 206.
Niobrara formation, 20, *36,* 118.
Noe dome, 186.
Northeast Area. table of formations, 20, 118; defined, 57; described, 116; miscellaneous structures in, 138.
Northwest Area, table of formations, 20; defined, 57; described, 60. miscellaneous structures in, 114.
Nowels, K. B., cited, 66, 75, 78.
Nuevo anticline 138.

O

Ogallala formation, 20, 42, 47, 133, 139.
Ohio Oil Co., 27, 111, 112, 133, 134, 148,
Oil, analyses of:
Artesia field. 152.
Bloomfield oil field, 98.
Eunice area, 175
Getty pool. 169. 170.
Hobbs field, 164.
Hospah dome, 87.
Jal area, 179.
Lea pool, 172.
Maljamar area, 154.
Rattlesnake field, 77, 80.
Seven Lakes area. 86.
Table Mesa field, 83.
____and gas, general geology of. 55. accumulations, 56; summary of possibilities, 57; production, 59.
____ shale, 190.
Ojo Alamo sandstone, 20, 42, 62.
Ojo Caliente anticline, 101.
Oligocene, 20.
Olguin anticline. 100.
Ordovician system, 19,

P

Packard, Henry L., cited, 95.
Paleozoic, 202.
Palomas gravel, 20.
Pasamonte anticline, 138.
Payne anticline, 111.
Pennsylvanian system- 21, 56, 62, 64, 93, 95, 96. 105. 106, 116. 118, 131, 139, 142, 146, 188, 190. 196. 199; production from, 63, 71, 79.
Percha shale. 21, 23, 199, 203.
Perico anticline, 138.
Permian system, 21, 25- 56, 62, 93, 100, 105. 106. 114, 116, 118, 121, 133, 138, 139, 140, 142, 148, 150 156, 159, 181, 188, 194, 198, 199.
Phillips Petroleum Co., 147, 162, 205.
Picacho anticline, 181.
Picher Oil Co., 147.
Pictured Cliffs sandstone, 20, 41, 62; production from, 99, 101.
Pierre shale, 20, 38, 40, 118, 126.
Pino Mesa anticline, *132.*
Pinon Springs anticline, 101, 104.
Pipe lines. 65, 71- 82, 101. 147, 148, 154, 155, 168. 172, 175, 177, 204, 206.
Pittsburg Oil Development Co., 87.
Pleistocene, 20.
Pliocene, 20, 47, 118.
Point Lookout sandstone- 20, 39.
Poleo sandstone, 21. 28, 30, 62, 64, 93, 96.
Pomeroy anticline, 181.
Potash, 57, 140. 156.
Potential, rated, 160, 162.
Prairie Springs structures, 198.
Pre-Cambrian, *17,* 21, 49, 62, 93, 118, 182, 183, 188. 196, 199, 202.
Production, tables:
Artesia field, 147.
Hobbs field. 160. 161.
Hogback field. 67.
Hospah dome. 89.
Rattlesnake field, 76, 79.
State, 59.
Producers & Refiners Corp., 65, 69, 81, 82, 89.
Proration, 155, 160, 162.
Pueblo Oil Co., 178.
Puerco formation, 20, 42- 44, 62, 99.
Puertecito formation, 20, 111.
___ district, 110.
Punta de Agua anticline, 190, 191.
Punta de la Mesa sandstone, 20, 37.
Purgatoire formation, 20, 36, 118, 120, 127, 133.

Q

Quaternary system, 20, 48.
Quay County, structures in, 132.
Queen sandstone, 21, 142, 145.

R

Rail Canyon sandstone, 20.
Raton formation, 20- 44, 118.
Rattlesnake anticline, 129. 132.
___ field, 62, 63, 64, 69, 204.

Red Feather Oil Co., 110, 117.
Red Lake anticline, 107.
Red Sand, 153.
Refineries, 71. 147, 152, 162, 204.
Reserve Oil Co., 85.
Ribera anticiine, 138.
Rio Arriba County, table of formations in, 93.
Rio Chama Co., 94.
Rio Grande Oil Co., 196, 197.
Rio Grande valley, central, 183; lower, 186. upper, 182.
Rio Puerco anticline, 100.
Rio Salado anticline, 100.
Rito del Piano structure, 119.
Road oil, 205, 208.
Romero anticline, 138.
Rustler limestone, 21, 27, 29, 142, 156.

S

Salado anticline, 138.
Sait, 27, 48- 57, 133, 139, 156, 215.
San Andres iimestone, 21, 56, 131, 133, 140, 142, 145, 146 150, 153, 157, 168, 194.
Sandia formation, 21.
San Juan basin, 60; table of formations in, 62; structures in, 64, 100.
San Juan Coal & Oil Co., 86, 89, 191.
San Mateo dome, 64, 92.
San Miguel County, structures in, 127; formations in, 133.
Santa Cruz anticline, 183.
Santa Fe County, 69, 206.
Santa Fe Diox Tee Co., 123.
Santa Fe formation, 20, 42, 47, 118, 183.
Santa Fe Mutual Co., 66, 67.
Santa Rosa anticline, 138.
________ sandstone, 21, 116. 118, 121. 128, 131, 133, 138, 142, 156, 208.
Sarca anticline, 100.
Sarten sandstone, 20, 35.
Sears, J. D., quoted, 104.
Seven Lakes structure, 62, 85.
Seven Rivers gypsum, 21.
Shell Petroleum Co., 162, 173, 205, 206.
Shinarump conglomerate, 21, 29, 30, 62, 64, 104.
Sierra Grande upiift, 117, 123.
Sierra Negra anticiine, 138.
Silurian system, 21, 22, 199.
Skelly Oil Co., 178.
Snow, L. G., cited, 98.
South Ambrosia Lake dome, 100.
South Suwanee dome, 115.
Southeast Area, table of formations, 20, 142; defined, 57; described, 139; miscellaneous structures in, 181.
Southern Union Gas Co., 65, 101, 207.
Southern Ute dome. 65.
Southwest Area, table of formations, 20; defined, 57; described, 202.
Spalding dome. 138.
Standard Petroleum Co., 131.
Starr Oil Co., 124, 138.
State Bureau of Mines and Mineral Resources, 11; file of well logs, 13.
State Oil Refining Co., 205.
Stoney Buttes anticline, 62, 64, 85.
Structures, tables of:
Northeast Area, 138.
San Juan basin, 64, 100.
Southeast Area, 181.
_____, Quay County, 132.
_____, San Miguel County, 130.
Sundance formation, 34.

T

Table Mesa field, 62, 64, 81, 204.
Tankage, 204, 205.
Tate anticline, 138.
Tertiary system, 20, 42, 46, 62, 97, 128, 142, 156, 202, 203.
Texas Pacific Coal & Oil Co., 176.
Texas Production Co., 142, 143, 149, 154, 170, 172. 173, 177, 178, 180.
Tidal Oil Co., 168, 173.
Tierra Amarilla anticline, 100.
Tijeras anticline, 201.
Timpas limestone, 20, '37, 118.
Tocito dome, 64, 84.
___ sandstone, 20, 37, 62, 64. 66, 67, 84.
Todilto formation, 20, 33, 62, 93, 118.
Tohachi shaie, 42. 46.
Toltec Oil Co., 27, 201.
Torrejon formation, 20, 42, 45, 62, 97, 99.
Torrivio anticline, 103.
Tres Hermanas sandstone, 20, 37.
Triangle dome, 132.
Triassic system, 21, 29, 56, 62, 93, 100, 105, 110, 115- 118, 128, 131, 138, 139, 142, 156, 181, 198, 199, 201.
Trinidad sandstone, 20, 38, 118, 126.
Trujilio sandstone, 128.
Tucumcari Oil & Gas Co., 133.
Tularosa basin, 198.
Turkey Mountain dome, 126.
Twin Mounds anticline, 181.

U

Union Oil and Mining Co., 99.
Union Oil Co. of California, 126.
United Oil Co., 117.
Unitization, 163.
Upper Red Lake anticline, 113.
Ute dome, 62, 64,
_______ , southern, 65.

V

Valencia Petroleum Co., 184.
Valley Refining Co., 205.
Vermejo formation, 20, 38, 118, 126.
Vermejo Park dome, 126.
Vogt anticline, 64, 100.
Volcanic rocks, 51.
Von Buelow, E. U., quoted, 212.

W

Wagon Mound anticline, 116, 121.
Walker dome, 62, 64, 91.
Walker Dome Oil Co., 92.
Wasatch formation, 20- 42, 45, 62.
Water, in Hobbs field. 166.
Weathers, W. D., et al., 119.
Well logs, 13:
Artesia field, 148, 149.
Carica anticline, 90.
Chupadera anticiine. 197.
Dona Ana County, 187.
Dunken dome, 143.
Estancia vailey, 191.
French Mesa anticline, 94.
Harlan ranch, 185.
Hogback dome, 68.
Jordan Ridge anticline, 134.
Payne anticiine, 112.
Pinon Springs anticline, 104.
Rattlesnake anticline, 129.

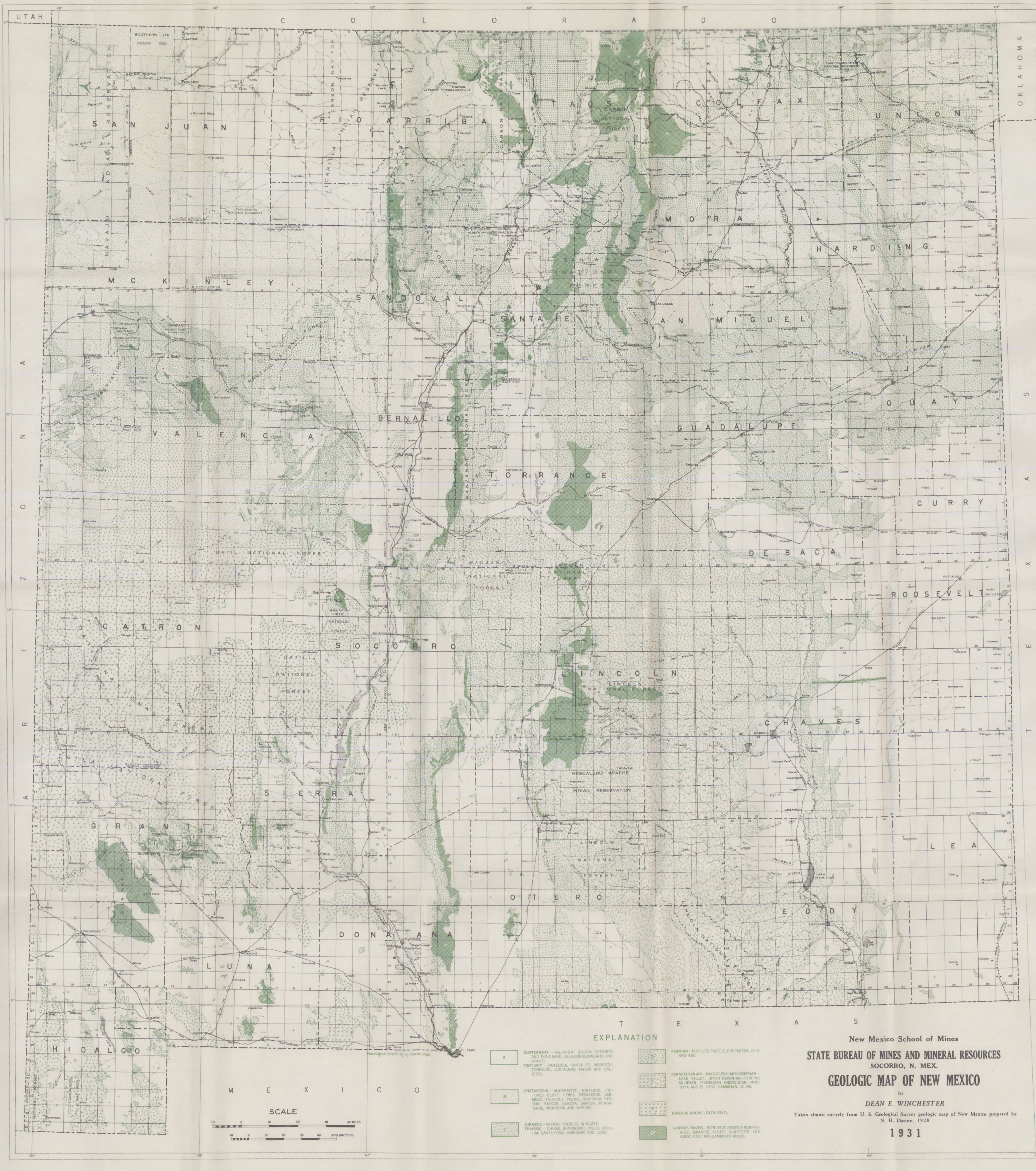
Rattlesnake field, 72.
Red Lake anticiine, 108.
Sierra Grande field, 124.
Table Mesa field, 82.
Wagon Mound anticline, 122.
Walker dome, 91.
Wells, E. H., preface by, 12; quoted, 111; cited, 105, 194.
White lime, 142, 153, 155, 156, 157, 159, 160, 161, 162, 163, 165, 166, 167, 168, 174, 177.
White sands, 48, 199.
Wiicox anticline, 190.
Williams, H. L., 89.
Williams Petroleum Co., 151.
Wiliow Creek anticline, 64, 100.
Wingate sandstone, 20, 32, 62, 64, 93, 96, 117. 118, 120, 123, 127, 128, 129, 131, 132, 133.

Y

Yeso formation, 21, 140, 142, 194. Y-O overthrust anticline, 181.

Z

Zuni basin, 60, 101.



New Mexico School of Mines

STATE BUREAU OF MINES AND MINERAL RESOURCES

SOCORRO, N. MEX.

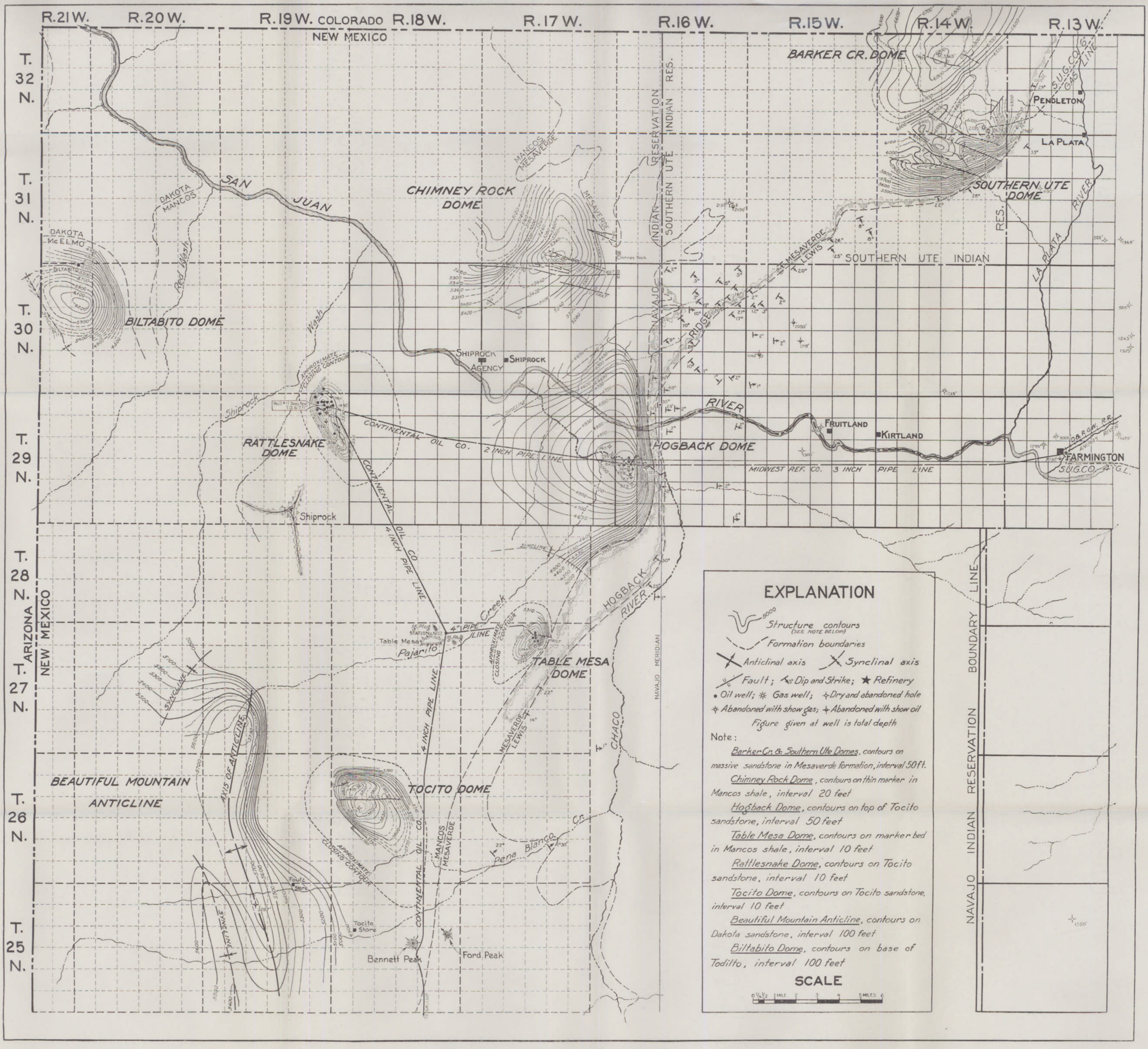
GEOLOGIC MAP OF NEW MEXICO

by

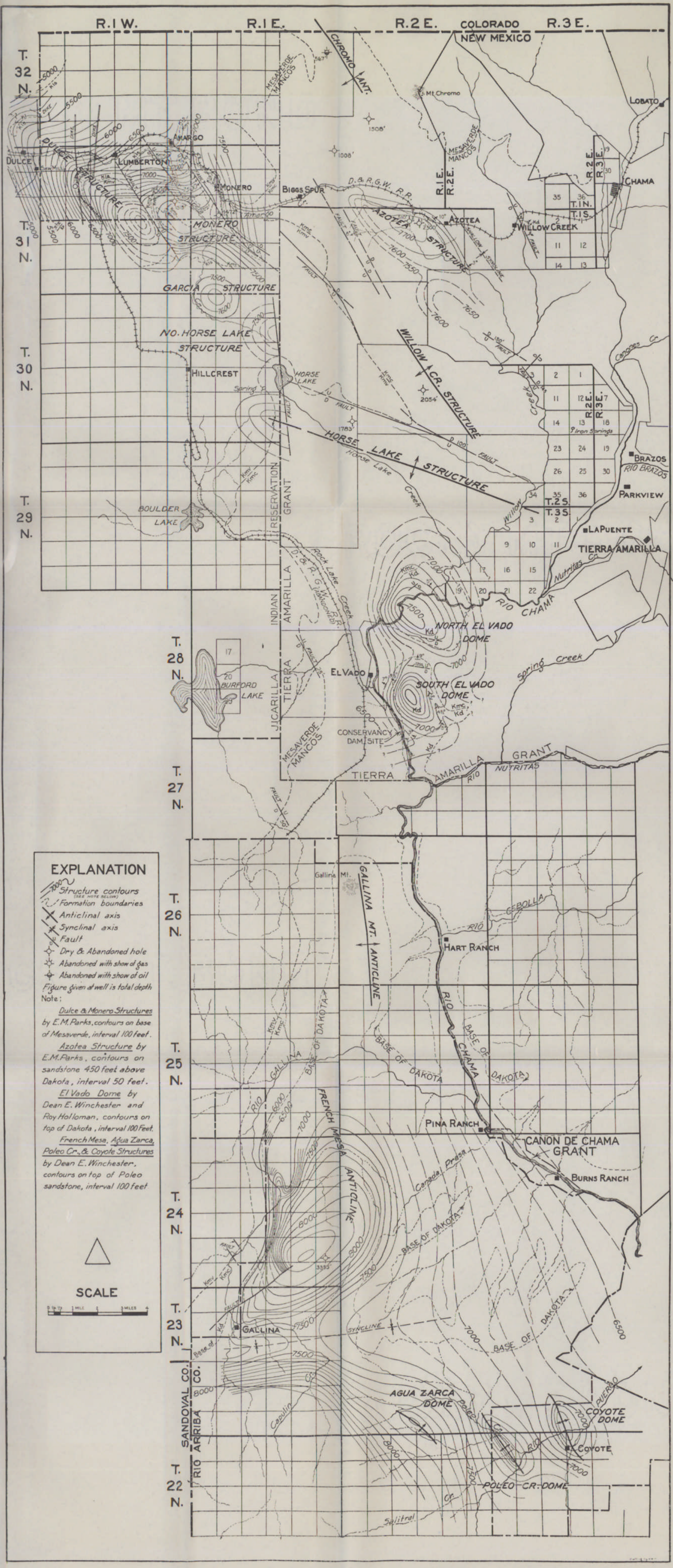
DEAN E. WINCHESTER

Taken almost entirely from U. S. Geological Survey geologic map of New Mexico prepared by N. H. Darton, 1928

1931



Map of northwestern San Juan County showing Geologic Structure.



Map of part of Rio Arriba County showing Geologic Structure.

New Mexico School of Mines

STATE BUREAU OF MINES AND MINERAL RESOURCES
SOCORRO, N. MEX.

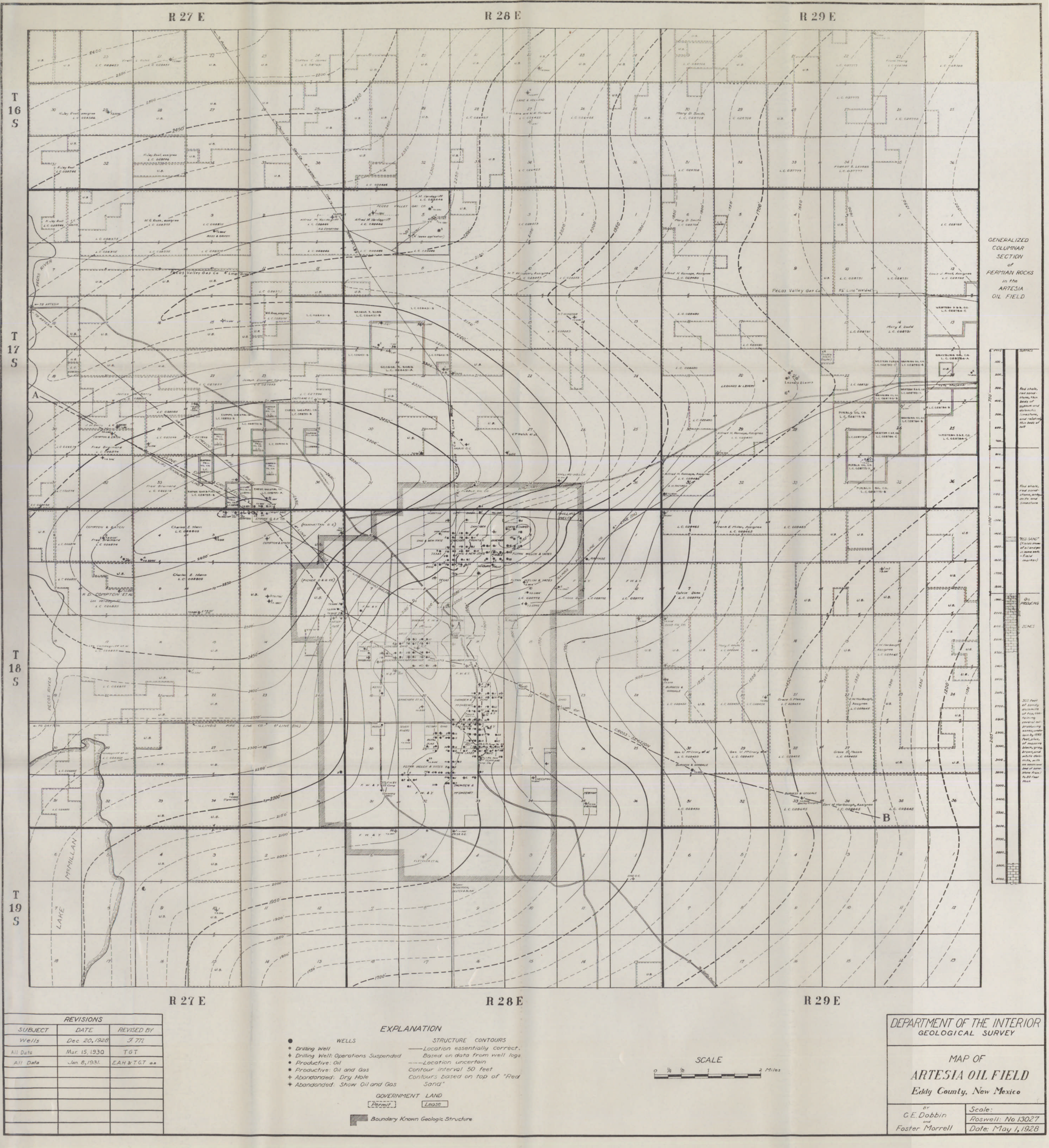
OIL AND GAS MAP OF NEW MEXICO

by

DEAN E. WINCHESTER (1931)

Revised by A. ANDREAS to July 15, 1936

Oil and gas information compiled from various sources. All wells not indicated in certain areas because of limitation of scale, and depth shown is maximum reached in these areas. Only typical wells shown in productive areas, which give average depth of producing horizon. Base modified from U. S. Geological Survey Base Map of New Mexico, edition of 1922.


R 27 E
R 28 E
R 29 E
T 16 S
T 17 S
T 18 S
T 19 S
GENERALIZED COLUMNAR SECTION of PERMIAN ROCKS in the ARTESIA OIL FIELD
REVISIONS
SUBJECT
DATE
REVISED BY
Wells
Dec 20, 1928
F. M.
All Data
Mar. 15, 1930
TGT
All Data
Jan 8, 1931.
EAH & T.G.T.
EXPLANATION
WELLS
Drilling Well
Drilling Well: Operations Suspended
Productive: Oil
Productive: Oil and Gas
Abandoned: Dry Hole
Abandoned: Show Oil and Gas
STRUCTURE CONTOURS
——Location essentially correct. Based on data from well logs
---Location uncertain
Contour interval 50 feet
Contours based on top of "Red Sand"
GOVERNMENT LAND
Permit
Lease
Boundary Known Geologic Structure
SCALE
0 1/4 1/2 1 2 Miles
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
MAP OF
ARTESIA OIL FIELD
Eddy County, New Mexico
BY
C. E. Dobbin
and
Foster Morrell
Scale:
Roswell: No 13027
Date: May 1, 1928