

STRATIGRAPHY OF THE EL DORADO OIL FIELD, ARKANSAS, AS DETERMINED BY DRILL CUTTINGS.

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INTRODUCTION.

The problem of constructing a stratigraphic column of the rocks of the El Dorado oil field, Ark., with the aid of drill cuttings was undertaken by the United States Geological Survey in order to facilitate development in the field and to furnish a guide to oil operators prospecting in surrounding territory. If it were possible either to get perfect well records or to interpret correctly the imperfect well records available, the difficulties in developing such a field would be greatly decreased. Extensions to the field would be found quickly and cheaply, the total amount of oil produced would be larger, water troubles would be reduced to a minimum, and prospecting in adjacent territory would go forward with a minimum expenditure for dry holes and greater probability of success. If the driller knew at all times just what formation his drill was passing through he would also know where the water-bearing strata were, if any existed, and where to look for shows of oil and gas. He would rarely drill too deep into the oil sand and thus ruin his well by permitting water to come in, as has been done in many wells in El Dorado. If the oil sand proved dry and he was sure he had reached the sand, he would not have to drill deeper, spending time and money to prove that his chances of success had vanished.

Unfortunately, perfect well logs, like 20,000-barrel oil wells, are rare. In fact, it could hardly be otherwise. It is absurd and unreasonable to expect a driller, whose principal job is not classifying but drilling rocks, to avoid serious mistakes when geologists who have spent years studying the rocks often make grievous errors in interpreting the available data, even where rock exposures are abundant.

In south-central Arkansas the identification of formations pierced by the drill is particularly difficult. Many of these formations are so similar that a geologist trying to differentiate between them can find little upon which to base his decision regarding their age and

correlation. The task is further complicated by the notoriously inaccurate records commonly obtained by the rotary method of drilling, which in southern Arkansas is used almost to the exclusion of other methods. The only plan that gives even approximately satisfactory results where the rotary drill is used is to keep a complete set of samples from the well, each sample representing not more than 10 feet of strata, supplemented by core samples. These samples should be examined by a geologist competent to pass upon their mineral character, and any fossils they may contain should be classified by a competent paleontologist. Such a plan has been followed in the El Dorado field. A complete set of samples from the Standard Oil Co. of Louisiana's Ingram No. 5 well, in the center of the north side of the NE. $\frac{1}{4}$ NE. $\frac{1}{4}$ sec. 25, T. 17 S., R. 16 W., was supplied to the United States Geological Survey by the company and was carefully studied by Mr. Gilluly, whose determinations form the basis for this paper.

POSSIBLE ERRORS.

The samples were taken at such intervals that each represents about 10 feet of section. However, the introduction of mud into the well and the mixing of material that is unavoidable in work with the rotary drill masked somewhat the character of the beds which the samples represent. The fact that it takes some time for each sample to reach the surface after it is cut introduces a possible error, as the driller's calculations may be wrong and the sample which he marks as coming from one depth may in fact belong to beds a short distance either above or below that depth. The impossibility of completely representing 10 feet of beds by 3 or 4 cubic inches of sample must also be recognized. Because of these shortcomings the limits of the formations can not be fixed closer than 10 feet, and in the determinations based on samples obtained near the bottom of the hole the possible error is at least 20 feet. However, in spite of all these difficulties, which impair precision, it is certainly possible under this plan of examination to obtain definite knowledge about the rocks that have been penetrated and to fix formation boundaries within 10 or 20 feet.

METHOD OF EXAMINATION.

The composition of the samples was determined by examination under a binocular microscope, magnifications of 8 to 50 diameters being used according to the fineness of grain of the material. The proportions of sand and clay in each sample were estimated. In making this estimate all material that would go through a screen having 100 meshes to the inch was classed as clay. Part of the sample was then treated with hydrochloric acid to determine the content of

calcium carbonate. Although the relative proportions of the different constituents determined by such estimates are undoubtedly inexact any attempt at refinement, such as weighing sifted samples, would also give erroneous results owing to the presence of drilling mud in the sample. After the percentage of sand, clay, and lime had been estimated, the clayey material was washed out and the residue was closely inspected for fossils and to determine the mineral character of the rock. Such fossils as were found were examined by L. W. Stephenson and Julia Gardner, of the United States Geological Survey, who succeeded in identifying forms that prove the presence of the Wilcox formation (Eocene) at 820 and 1,060 feet and of Upper Cretaceous beds at 1,760 feet.

Throughout the study a careful examination was made of the quartz grains that make up the sandy part of the samples, but no differences in degree of rounding, in sizing, or in surface etching were detected, except the natural association of the smaller grains with the prevailing shaly members of the section and of the larger grains with the sandy beds. Although careful study was made to discover any correspondence between the positions of the "boulders" and "gravels" reported by the drillers to occur at certain depths and the amount of lime and limonite, possibly indicative of concretions, in the samples from these depths, no such correspondence was noted. This failure might be due to the fact that a small sample is not fully representative of 10 feet of sediments, and hence the rock of thin members might not be reflected in the character of the samples, or to the fact that the state of aggregation of the constituents of the bed is not revealed by the rotary drill, which, except for occasional iron (limonitic) concretions of clay substance, discharges only finely divided material, with very few cohering grains. Thus the same percentage composition of lime might in one sample mean a limestone bed and in another merely a fossiliferous shale.

FORMATIONS ENCOUNTERED.

The different rock types are described below in the order in which they were encountered. The zones indicated are shown by numbers at the left of the percentage log on Plate XXIV.

Zone 1. From the surface to a depth of about 290 feet the strata are dominantly sandy shale. Some beds contain so much sand that they may appropriately be called shaly sand, but none of the samples were pure sand. The color ranges in general from light gray to medium gray but becomes brown in the samples near 290 feet. Clay makes up from 30 to 83 per cent of the material, averaging 56 per cent; sand averages from 15 to 80 per cent; and lime is present only in the basal part of the zone, where it constitutes from 2 to 10 per cent of the bulk of individual samples. Lignite and limonite are

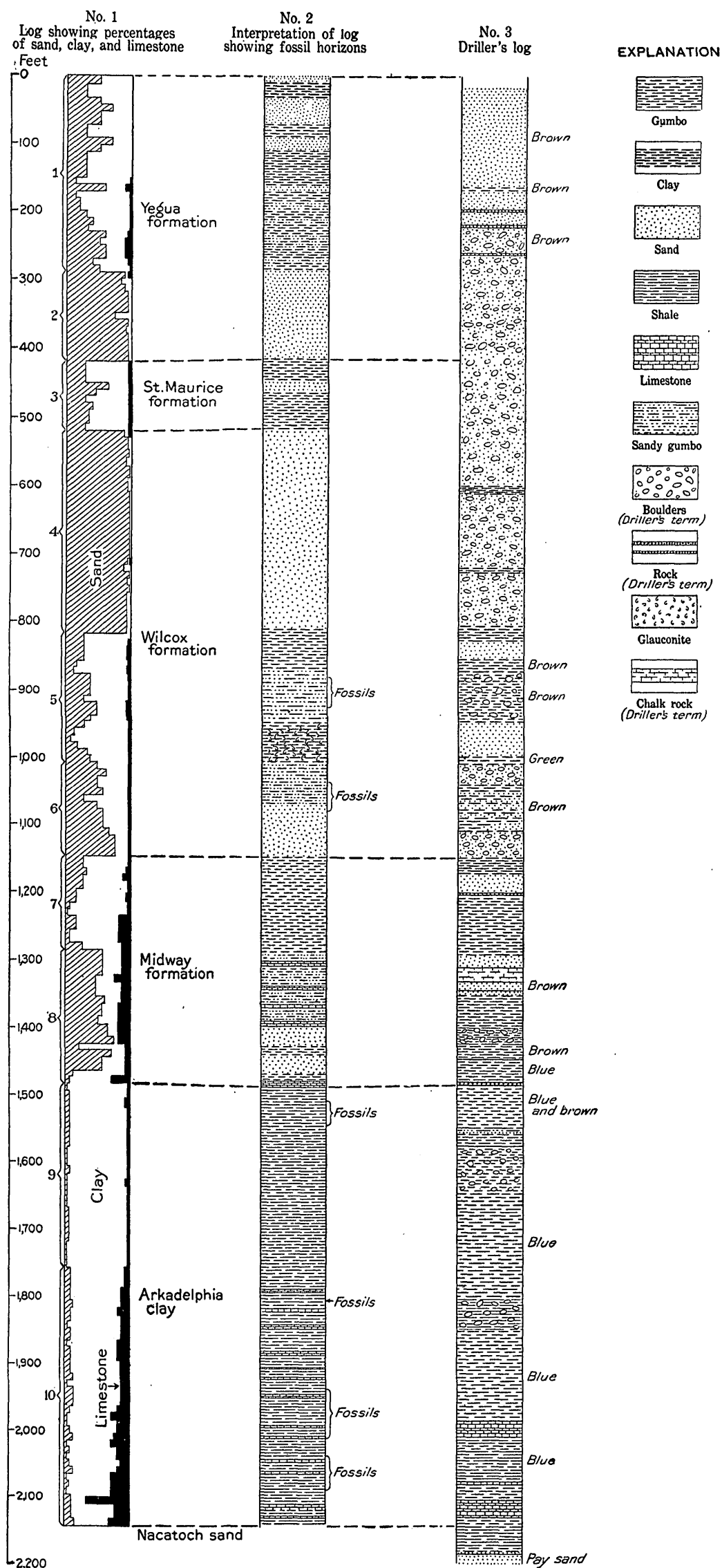
abundant in this zone. Glauconite is also common. No fossils were seen.

Zone 2. The group of beds from 290 to 420 feet is distinguished from the overlying beds by the absence of lignite and by the light-gray color throughout. It is also much more sandy, the beds consisting predominantly of sand, with a little clay and a very little lime near the top of the zone. The sand content of the samples averages 92 per cent and falls as low as 75 per cent in only one sample, so that most drillers would record this series as a single bed of sand. Only two of the samples studied contain lignite. Glauconite and limonite are common. No fossils were seen.

Zone 3. The group of beds from 420 to 520 feet may be distinguished from the overlying strata by its content of lime carbonate, which is uniformly present, by the common occurrence of lignite, and by a much greater percentage of clay. This zone is made up prevailing of sandy shale, with a few beds of almost pure sand. The color is light gray, slightly bluish when wet, with a noticeable green tinge near the bottom. Sand averages 37 per cent, with a maximum of 65 per cent in a single sample and a minimum of 30 per cent in many of the samples. Clay ranges from 30 per cent in one sample to 65 per cent in several and averages 58 per cent. Limy material is uniformly present to the extent of about 7.5 per cent. Lignite is common, and small quantities of glauconite are also present. No fossils were seen.

Zone 4. The beds in the part of the section from 520 to 820 feet differ from those in zone 3 by showing a much greater percentage of sand, no lime, no limonite, glauconite, or lignite, except in the top 80 feet of the zone, and a few fossils, the first to be found in the section. This zone is almost wholly sand (95 per cent), and the remaining material is practically all shale. The color is light gray but in wet material ranges from light brownish gray to medium grayish brown. Small quantities of lignite, glauconite, and limonite appear in the upper 80 feet. A few shell fragments at widely separated points were the only fossils found.

Zone 5. The beds from 820 to 1,010 feet can be distinguished from the lower beds of zone 4 by the presence of glauconite and limonite, by the presence of calcium carbonate, which occurs in every sample tested, and by their much more shaly character. The change from beds that are practically all sand to beds that are mostly clay or shale is abrupt. The beds of this zone are sandy shale, with small amounts of lime. The sand averages 31 per cent but ranges from 10 to 50 per cent. Clay averages 66 per cent and ranges from 45 to 85 per cent. Limy material averages 3 per cent and does not exceed 5 per cent in any sample. Lignite is completely absent. Glauconite is present through the entire zone but is especially per-



LOG OF STANDARD OIL CO.'S INGRAM WELL NO. 5, SEC. 25, T. 17 S., R. 16 W., ELDORADO, ARK.

sistent in the lower 20 feet, where it gives a decided greenish tinge to the clay. Limonite occurs in most of the samples. Fossil fragments which, according to Miss Gardner, probably represent forms of Wilcox age were found throughout this zone and are especially abundant at a number of horizons in the upper 100 feet.

Zone 6. The beds from 1,010 to 1,150 feet may be difficult to distinguish from those of zone 5, although strongly glauconitic beds plainly mark the base of that zone, and zone 6 also differs from zone 5 in that it contains lignite and a much greater percentage of sand. This zone is made up largely of shaly sand, which becomes a purer sand toward the base. The proportion of sand ranges from 30 to 80 per cent and averages 56 per cent. Clay ranges from 18 to 68 per cent and averages 42 per cent. About 2 per cent of limy material is commonly present. Limonite occurs in almost every sample, but only small quantities of lignite and glauconite are present. Fossil fragments were found throughout and are prominent at a number of horizons in the upper 70 feet, where the typical Wilcox association of forms was recognized by Miss Gardner.

Zone 7. The zone from 1,150 to 1,290 feet differs from zone 6 in that it contains an abundance of lignite and is also very shaly. The basal part of the zone may be identified by its high content of lime carbonate. The clay content of the samples from this zone ranges from 60 to 94 per cent. Sand ranges from 5 to 25 per cent and averages 21 per cent. Limy material increases from 2 per cent near the top to 15 per cent just above the base. The color ranges from light gray to grayish brown and is slightly darker in wet material. Lignite is abundant, glauconite was found in every sample, and limonite in almost every one. Shell fragments are common throughout the zone and are particularly abundant near the middle, but no recognizable forms were noted.

Zone 8. The zone from 1,290 to 1,470 feet differs from zone 7 in being much more sandy. The beds of this zone are limy, sandy shale, with some thin beds of pure sand and of pure clay. The sand content averages about 60 per cent. Clay ranges from 5 to 70 per cent and averages 20 per cent. Limy material ranges from 5 to 20 per cent and averages 12 per cent. The color ranges from light gray to brownish gray and is more strongly brown in wet material. Lignite is present in most of the samples. Glauconite occurs near the top and near the base, but beds near the middle of the zone seem to have little or none. Limonite occurs in almost every sample. Fossil fragments were found in many of the samples and are particularly abundant about 110 feet below the top.

Zone 9. The zone from 1,470 to 1,760 feet should be easily distinguished from the overlying zone 8 by the almost complete absence of sand, which ranges from 2 to 15 per cent and averages about 6 per

cent. Limy material ranges from 2 to 25 per cent and averages 3 per cent. The bed containing 25 per cent of lime is at the top of the zone and probably represents a thin bed of limestone. Clay makes up 90 per cent of the samples. The color of the samples from this zone is gray, with a noticeable bluish tinge in samples obtained near the top. When wet the samples range in color from dark gray to brown. Lignite is present only in the upper 100 feet of the zone. Glauconite is present throughout but is not conspicuous. Limonite is commonly present. Many Foraminifera and other fossils were found, especially in the top part of the zone. A fragment of *Inoceramus*, an Upper Cretaceous form, was identified by L. W. Stephenson in a sample representing a depth of 1,760 feet.

Zone 10. The zone from 1,760 to 2,143 feet is distinguished from the overlying zone only by a slightly greater content of sand and by its high content of lime. Sand ranges from 4 to 15 per cent, with an average of about 10 per cent. Clay ranges from 7 to 85 per cent and averages 15 per cent. The samples are light gray to medium gray, with a bluish tinge. They become darker when wet but show no other appreciable color change. Glauconite is present in most of the samples. Limonite is common. Lignite occurs sparingly near the top of the zone. The middle part of the zone is free from limonite, but some is present near the base.

The formations represented by the ten zones above described are thought to be the Yegua, St. Maurice, Wilcox, and Midway, all of Tertiary age, and the Arkadelphia, of Upper Cretaceous age. It is not possible to determine exactly the boundaries of these different formations because of the lack of sufficient fossil evidence. However, fossils were found that definitely fix the Wilcox age of zone 5 and the upper part of zone 6, and the Upper Cretaceous age of the basal part of zone 9. With these bits of evidence, combined with the known characteristics of the formations at their outcrops, the positions of the formation boundaries in this well may be tentatively assigned with a strong probability of accuracy. On this basis, then, zones 1 and 2 are assigned to the Yegua formation, of Eocene age. The Yegua at the type locality is a prevaillingly sandy formation, and its thickness agrees with the 420 feet included in these two zones. Zone 3 probably represents the St. Maurice formation, of Eocene age. The St. Maurice has been described as a soft shale, and the thickness of zone 3 (100 feet) is about what the thickness of the St. Maurice should be at El Dorado, which is near the margin of the area where it was laid down. Zone 4 on the basis of lithology should be equivalent to part of the Wilcox formation, of Eocene age. Zones 5 and 6 are shown definitely by fossils to be of Wilcox age, and their composition agrees with the descriptions of exposures of the lower part of that formation. The Wilcox at El Dorado is therefore

about 630 feet thick. The 320-foot section comprising zones 7 and 8 is referred to the Midway formation (basal Eocene). This correlation is based upon the amount of lime in the samples, for the Midway is characterized by its high lime content. In other respects these zones do not agree well with the typical Midway. For example, they are very lignitic, and the Midway at its outcrop contains very little lignite. It is possible that the Midway is so thin as to be undetectable in the El Dorado field and that these beds should be assigned to the Wilcox. Zones 9 and 10 are thought to be unquestionably the Arkadelphia clay, of Upper Cretaceous age. This correlation is based on the Cretaceous age of several fossils identified by L. W. Stephenson and on the similarity of the beds in these zones to the Arkadelphia at its type locality. The thickness of 650 feet given to these zones agrees well with the thicknesses measured where the boundaries of the formation could be definitely determined.

No samples representing the Nacatoch sand, which is the producing formation of the El Dorado field,¹ were included in this set, so its character could not be determined.

The utilization of the descriptions given above should aid both in interpreting records of wells that have been drilled and in enabling those who are watching drilling that is in progress to tell just what zone the drill has reached. The 100-foot band of clay or shale which has been assigned to the St. Maurice should be easy to detect. Its top should lie from 350 to 500 feet below the surface in central Union County. The break between the Wilcox and the Midway is also sharp and should not be hard to locate if the driller is looking for it, as the drill would pass from a heavy sandstone into a shale that is only slightly sandy. It is particularly important to recognize this contact, as oil or gas may be encountered anywhere below it, and a constant lookout for showings should be maintained after the Midway has been reached. This contact should lie from 1,100 to 1,200 feet below the surface in the El Dorado region. The contact of the Midway and the Arkadelphia should also be easy to recognize, as it is marked by an abrupt change from a formation which is very sandy and which may also contain thin beds of limestone to one that is dominantly shale (which may be recorded in the log as "gumbo," "clay," or "shale").

Glaucinite and lignite should also help the observer in identifying the formations penetrated by the drill. The most strongly glauconitic beds occur in the lower part of the Wilcox, where in places there is so much glauconite that the sand looks decidedly greenish. The presence of abundant lignite at a depth of about 1,200 feet will indicate the Midway formation.

¹ Rubey, W. W., Oil from the Nacatoch sand, El Dorado, Ark.: U. S. Geol. Survey press notice, Feb. 7, 1922.

Fossils should, of course, be carefully looked for. Any company that proposes to drill extensively in Louisiana and Arkansas could to advantage maintain a paleontologist on its staff. Many of the forms that will be encountered will be new, and to obtain the best results from fossil study the paleontologist must devote much time to studying, describing, and portraying the forms he finds. He can not depend upon descriptions that have been already published, for only a comparatively small percentage of the microscopic forms he will find have ever been described. Yet such microscopic forms are in places very abundant and will furnish precise and conclusive evidence as to the age of the beds if they are painstakingly collected and studied.

INDEX.

A.	Page.		Page.
Acknowledgments for aid.....	1-2, 73, 111-112, 179, 192, 210, 216, 217	"Black lime," pay sands at the top and base of, in the Ranger oil field, Tex.....	137
Adams Branch limestone member, nature and occurrence of, in the Ranger oil field, Tex.....	120	stratigraphic place of.....	123
nature and stratigraphic place of... 58, 59, 60-61		use of, as a key bed.....	127
Ajax Oil Co., log of well of.....	152	Bourland, L. B., No. 1 well, Ranger oil field, Tex., log of.....	169-170
"Ammonite bed," nature and occurrence of, in southern Oklahoma and north- eastern Texas.....	3	Brad formation, nature and members of, in the Wiles area, Tex.....	58, 59
Amsden formation, features of, in the Crow Indian Reservation, Mont.....	41	Bransford No. 1 well, Ranger oil field, Tex., log of.....	167-168
Annona tongue of Austin chalk, nature and occurrence of, in northeastern Texas.....	6	Breckenridge lime. <i>See</i> Smithwick shale.	
Anticline, closed, definition of.....	65	Brelsford No. 1 well, Ranger oil field, Tex., log of.....	161-162
plunging, definition of.....	65	Brelsford sand, oil and gas from, in the Ran- ger oil field, Tex.....	137
Arbuckle oil pool. <i>See</i> Madill oil pool.		Brewer, Floyd, No. 1 well, Ranger oil field, Tex., log of.....	164-165
Ardmill Oil & Gas Co., wells drilled by.....	13	Brooks Saline Oil & Development Co., logs of wells of.....	199-208
Ardmore Oil Co., logs of wells drilled by.....	14, 15	Brooks salt dome, Tex., beds exposed on.....	209
Arkansas Natural Gas Co., log of well of... 166-167		development of.....	197, 198-209
Austin chalk, nature and occurrence of, in eastern Texas.....	6, 194-195	distances from, to producing oil fields.....	209
stratigraphic place of.....	237-238	geology of.....	193-198, 209
Avery Islands dome, La., age of.....	183	location and history of.....	191-192
		saline on.....	193
		structure of.....	197-198
		topographic map of.....	192
		topography of.....	192-193
		Bunger limestone member, probable occur- rence of, in the Ranger oil field, Tex.....	117
B.			
Bands, dark, in salt of domes, origin of.....	182	C.	
Barnes, J. E., No. 1 well, Ranger oil field, Tex., log of.....	153	Caddo Creek formation, in the Wiles area, Tex., nature and members of....	58, 59
Baumgartner No. 1 well, Ranger oil field, Tex.....	159, 160	Caddo lime. <i>See</i> Smithwick shale.	
Bearpaw shale, nature and occurrence of, in the Crow Indian Reservation, Mont.....	37	Canyon group, nature and divisions of, in the Ranger oil field, Tex.....	118-120
Beasley well No. 1, near Bonham, Tex., log of.	24	nature and divisions of, in the Wiles area, Tex.....	57-59
Beauchamp tract, Smith County, Tex., logs of wells on.....	199-202	Cap rock on salt domes, age of.....	183
Beauvais Creek uplift, Mont., features and oil possibilities of.....	42-43	origin of.....	182-183
Belle Fourche shale member, nature and oc- currence of, in the Osage oil field, Wyo.....	83-84	service of, in mining salt.....	225
"Bend series," divisions of.....	121-124	Carlile shale, nature and occurrence of, in the Crow Indian Reservation, Mont.	38-39
folding of beds of.....	131-133	nature and occurrence of, in the Osage oil field, Wyo.....	84-85
Bentonite, occurrence of, in the Osage oil field, Wyo.....	83	outcrop of the lower part of, plate show- ing.....	82
"Big pay" sand. <i>See</i> McClesky sand.		Carrington, B. W., & Co., acknowledgment to operation of salt works by.....	216 219-221
Bills Creek plunging anticline, Wiles area, Tex., description of.....	66	Catchings, J. T., acknowledgment to.....	216-217
Bitter Creek area, Mont., features of.....	45-46	Celeste, Tex., log of municipal well in.....	25
Black Gulch dome, Mont., features of and drilling on.....	51	Chugwater formation, nature and occurrence of, in the Crow Indian Reserva- tion, Mont.....	40-41
Black Hills, S. Dak., oil pools southwest of....	71, 72, 104-105		

	Page.		Page.
Cisco group, members of, in the Ranger oil field, Tex.	116-118	El Dorado oil field, Ark., stratigraphy of, difficulties in determining.	241-242
Civil War, production of salt in eastern Texas during.	191-192, 210, 216	stratigraphy of, formations included in.	243-248
Claggett formation, features of, in the Crow Indian Reservation, Mont.	38	method of examining drill cuttings to determine.	242-243
Clark, Robert E., acknowledgment to.	73	Ellenberger limestone, features of, in the Ranger oil field, Tex.	124-125
Cloverly formation, nature and occurrence of, in the Crow Indian Reservation, Mont.	40	wells drilled to.	125
Coal from the Newcastle sand, analysis of.	98-99	Enloe, Tex., log of well near.	27
Concretions, occurrence of, in the Bellefourche shale member.	83	Enos gas field, Okla., development of.	10-12
occurrence of, in the Carlile shale.	85	location of.	1
Connellee, C. U., No. 1 well, Ranger oil field, Tex., log of.	166-167	Erickson, E. T., analysis by.	98-99
Cooksey No. 1 well, Ranger oil field, Tex., log of.	165	Europe, salt domes of, origin of.	181-182
Cooper, Tex., wells drilled in and near.	26-27	salt domes of, workings in.	180
Crosby, J. E., No. 5 well, Ranger oil field, Tex., log of.	163-164		
Crow Indian Reservation, Mont., accessibility of.	36	F.	
examinations of.	35	"False Black lime." See Smithwick shale.	
map showing structure in part of.	42	Fannin County, Tex., wells drilled in.	23-24
rock formations in.	36-42	Fielder Salt Co., log of well of.	221
uplifts in.	42-53	"Fish-bed conglomerate," nature and occurrence of, in northeastern Texas.	5
Crumwell Oil & Gas Co., wells drilled by.	15	Fish teeth, occurrence of, in the Carlile shale.	85
		Five Islands, La., age of.	183
D.		Flat Rock Creek terrace, Tex., description of.	67
Dakota sandstone, nature and oil possibilities of.	79	Fleming, J. S., acknowledgment to.	210
Darton, N. H., acknowledgment to.	73	Fort Union formation, nature and occurrence of, in the Crow Indian Reservation, Mont.	36
Davis, Truman, No. 1 well, Ranger oil field, Tex., log of.	155-156	Fort Worth limestone, nature and occurrence of, in southern Oklahoma and northeastern Texas.	3-4
Definitions of structural terms.	126	Fortuna Oil Co., log of well drilled by, near Tom Bean, Tex.	21-22
Delta County, Tex., wells drilled in.	25-27	Fossils, occurrence of, on the Brooks salt dome, Tex.	194, 195, 196
Delta-Hunt Oil & Gas Co., log of well of, near Horton, Tex.	25-26	occurrence of, on the Grand Saline salt dome, Tex.	233-234
Denison, Tex., log of city well of.	21	on the Steen salt dome, Tex.	211
wells drilled near.	20-21	Fossils of the Washita group and Eagle Ford clay, plate showing.	4
Denison Oil & Gas Co., well drilled by.	20	Fox Hills sandstone, features of, in and near the Osage oil field, Wyo.	86-87
Domes, coastal, in Louisiana, statistics of.	186	Frontier formation, nature and occurrence of, in the Crow Indian Reservation, Mont.	39
coastal, in Texas, statistics of.	183-185	Fuson formation, nature of.	78
interior, in eastern Texas, statistics of.	188		
in Louisiana, statistics of.	187-188	G.	
manifestations of.	187	Gas, from Brooks saline prairie, Tex., analyses of.	209
salt, origin of.	180-183	occurrence of, in eastern Texas.	190
Drilling, methods followed in the Osage oil field, Wyo.	106-107	Goldman, M. I., acknowledgment to.	179
Dry Creek area, Mont., features of.	48	Goodland limestone, nature and occurrence of, in southern Oklahoma and northeastern Texas.	3
Dundee Petroleum Co., well drilled by, near Kinlock, Okla.	15	Graford formation, nature and members of, in the Wiles area, Tex.	58, 59
E.		Grand Saline, Tex., wells for public water supply at.	224
Eagle Ford shale, fossils of, plate showing.	4	Grand Saline Salt Co., acknowledgment to.	216
occurrence of, in eastern Texas.	194	logs of wells of.	221-223
Eagle sandstone, nature and occurrence of, in the Crow Indian Reservation, Mont.	38	Grand Saline salt dome, Tex., geology of.	218-219
East Tullock Creek dome, Mont., features of.	48-49	location and history of.	216-217
Ector tongue of Austin chalk, occurrence of, in northeastern Texas.	6	oil and gas in, location of test for.	238-239
Egypt, oil from salt domes in.	180	oil from.	216, 220, 221

	Page.		Page.
Grand Saline salt dome, Tex., structure of...	238	Kiamichi clay, nature and occurrence of, in southern Oklahoma and north-eastern Texas.....	3
topography of.....	217-218	Kimball tract, Smith County, Tex., log of well on.....	207-208
wells drilled on, diagram showing logs of.....	238	Kingston Dome Oil Co., well drilled by.....	12
deep.....	226-238	Kinlock, Okla., wells drilled at.....	15
salt.....	219-225	Kinney Oil & Refining Co., well drilled by..	13
Graneros shale, chemical character of, in the Osage oil field, Wyo.....	98-99	Klondike Oil & Gas Co., log of well drilled by, in Delta County, Tex.....	26
members of.....	79-84		
oil in.....	91	L.	
Grapevine dome, Mont., features of.....	44	Laccoliths, formation of.....	173-176
Grayson County, Tex., test wells drilled in..	18-23	Ladonia, Tex., log of well in.....	23
Great Southern Oil Co., log of well of.....	159-160	Lakota sandstone, features of, in the Osage oil field, Wyo.....	78
Greenhorn limestone, nature and occurrence of, in the Osage oil field, Wyo...	84	Lamar County, Tex., wells drilled in.....	27-28
Griffin, S. S., No. 1 well, Ranger oil field, Tex., log of.....	153-154	Lance formation, features of, near Osage, Wyo.....	87
Grouse-Alder dome, Mont., description of..	176-177	nature and occurrence of, in the Crow Indian Reservation, Mont.....	37
Guinn dome, Mont., description of.....	176	Leon Oil Co., log of well of.....	169-178
Gulf Oil & Refining Co., log of well of.....	161-162	Leonard-Celeste monoclinical nose, Tex., trend and uplift of.....	3
Gulfseries, key rocks of, in northeastern Texas.	5-6	Leonard Cotton Oil Co., log of well drilled by, in Fannin County, Tex.....	24
Gumbo Oil & Gas Co., log of well drilled by..	27	"Lime quarry," Steen salt dome, Tex., analysis of rock from.....	212
Gunsight limestone member, probable occurrence of, in the Ranger oil field, Tex.....	117	Limestone, from Brooks salt dome, Tex., analyses of.....	195
		quarrying of, north of Brooks salt dome, Tex.....	192
H.		Lindale, Tex., log of well east of.....	214
Hagaman terrace, Tex., description of.....	67-68	Lines connecting domes, significance of.....	187
Hallville Oil & Gas Co., logs of wells of.....	223-224, 226-232	Little Horn River, Mont., dome east of.....	52
Hamon & Westheimer Oil Co. et al, log of well of.....	161	Little Rocky Mountains, Mont., buttes and domes in.....	173-175
Hardin, Mont., gas well northwest of.....	49	geologic formations in and near.....	171-173
Hardin area, Mont., drilling and gas possibilities in.....	49-50	location of.....	171
Harris, R. S., No. 1 well, Ranger oil field, log of.....	162-163	oil south of.....	177-178
Harris sand, oil from, in the Ranger oil field, Tex.....	135-136	Location of salt domes.....	179-180
Heald, K. C., acknowledgment to.....	73	causes controlling.....	187
Herndon, J. H., analyses by.....	195, 212	Lone Star Gas Co., well drilled by, near Pottsboro, Tex.....	20
Holt High Waterworks Co., log of well of, near Honey Grove, Tex.....	23	Loper, M., No. 2 well, Ranger oil field, Tex., log of.....	152
Home Creek limestone member, nature of, in the Ranger oil field, Tex.....	118-119	Louisiana, salt domes in.....	179, 186, 187-188
nature and stratigraphic place of.....	58, 59, 62	Love, C. N., farm, near Madill, Okla., log of well on.....	13
Hopkins County, Tex., record of well drilled in.....	28	"Lower Bend" rocks, probable occurrence of, in the Ranger oil field, Tex.....	124
Humble Oil & Refining Co., logs of wells of..	155-157		
Hunt County, Tex., wells drilled in.....	24-25	M.	
I.		McCleskey, Dan, No. 3 well, Ranger oil field, Tex., log of.....	161
Illinois Chemical Co., analysis by.....	225	McClesky sand, importance of thickness of, in the Ranger oil field, Tex.....	139-140
Indian Chief Oil & Gas Co., well drilled by, near Enos, Okla.....	17	oil from, in the Ranger oil field, Tex....	137-138
Islands in Brooks saline, Tex., features of....	193	stratigraphic place of.....	124
		use of, as a key bed.....	128
J.		Madill, Okla., wells drilled in and near.....	14-15
Jackson Oil & Refining Co., log of well of....	165	Madill anticline, Okla., prospecting on.....	33
Jewell & North Texas Oil Co.'s well, log of.	234-236	trend and dips of.....	9
Johnson, Dr., No. 1 well, Ranger oil field, Tex., log of.....	168-169		
Jones No. 1 well, Ranger oil field, Tex., log of	156-157		
K.			
Kanoky Oil Co., well drilled by.....	10		
Keechi salt dome, Tex., features of.....	188		
101556°—23—17			

	Page.		Page.
Madill-Denison area, Okla. and Tex., dia-		Niobrara shale, fault in, plate showing.....	90
grammatic well logs showing		nature and occurrence of, in and near the	
rocks underlying.....	In pocket.	Osage oil field, Wyo.....	85-86
location of.....	1	in the Crow Indian Reservation	
oil and gas possibilities in.....	28-32	Mont.....	38
prospecting in, suggestions for.....	32-33	North Leon limestone member, occurrence of,	
stratigraphic sections in, plate showing..	2	in the Ranger oil field, Tex.....	117
stratigraphy of.....	2-6	Norwood, G. D., No. 1 well, Ranger oil field,	
structure of.....	6-9	Tex., log of.....	166
map showing.....	In pocket.	Norwood, G. E., No. 1 well, Ranger oil	
topography of.....	2	field, Tex., log of.....	160-161
Madill oil pool, Okla., development of.....	10		O.
oil from, quality of.....	10	Oakland, Okla., wells drilled near.....	13
Madison limestone, features of, in the Crow		Oakland anticline, Okla., prospecting on.....	32-33
Indian Reservation, Mont.....	41-42	trend and dips of.....	9
Magnolia Petroleum Co., log of well of.....	162-163	Oil, occurrence of, in eastern Texas.....	190
Main Street limestone member, nature and		occurrence of, in salt domes.....	191
occurrence of, in southern Okla-		Oklahoma, southern, geologic map of parts of.	2
homa and northeastern Texas.....	5	Olden anticline, Tex., description of.....	130
Mat-Milan Oil Co., operations by.....	10	Opeche formation, nature and age of.....	77
Marble Falls limestone, nature of, in the		Ordovician rocks, occurrence of, in the Ranger	
Ranger oil field, Tex.....	123-124	oil field, Tex.....	124
nature of, in the Wiles area, Tex.....	64	Oriena, Tex., log of well near.....	18-19
oil sands in.....	69, 136-138	Osage, Wyo., artesian wells near.....	96
Melcher, A. F., determinations of pore space		plate showing.....	72
by.....	93-98	Osage oil field, Wyo., bringing in third deep	
Merriman anticline, Tex, description of.....	129	well in, plate showing.....	90
Merriman limestone member, nature and oc-		climate of.....	75
currence of, in the Ranger oil		Dakota sandstone in, accumulation of oil	
field.....	120	and gas in.....	101-102
Meyer tract, Smith County, Tex., logs of wells		discovery of oil in.....	71-72
on.....	203-207	drainage and water supply of.....	74
Mid-Kansas Oil & Gas Co., log of well of....	153-154	field work in.....	72-73
Midway formation, occurrence of, in eastern		fuel supply in.....	75
Texas.....	196, 211-212	location of.....	71
Miffin anticline, Mont., features and oil and		methods of drilling in.....	106-107
gas possibilities of.....	45	Newcastle sandstone in, accumulation of	
Minnekahta limestone, nature and oil possi-		oil and gas in.....	100-101
bilities of.....	77	oil in, accumulation of.....	100-102
Minnelusa sandstone, nature and oil content		origin of.....	100
of, in and near the Osage oil field,		quality of.....	96, 102-104
Wyo.....	76-77	recoverable quantity of.....	105-106
Mississippian shale, nature of, in the Wiles		Pioneer well in.....	93, 95, 101
area, Tex.....	64	possibilities of undiscovered pools near.	104-105
Morrison formation, features of, in the Crow		productive area of.....	91-95
Indian Reservation, Mont.....	40	soil of.....	75
nature and age of.....	78	stratigraphy of.....	75-87
Mounds, coastal, manifestations of.....	187	structure map of.....	88
Mount Selman formation, occurrence of, in		accuracy of.....	89-90
eastern Texas.....	197, 213	area covered by.....	87
Mowry shale member, features of, in the Crow		structure contours on.....	88-89
Indian Reservation, Mont.....	39	structure sections on.....	89
features of, in the Osage oil field, Wyo....	82-83	structure of.....	90-91
Muddy sand. See Newcastle sandstone.		relation of production to.....	95-96
	N.	surveying of.....	88
Nefsky shale member, nature of.....	82	topography of.....	73-74
New Hope anticline, Tex., description of.....	129	wells in, depths and distribution of....	91-95
Newcastle sandstone member, analysis of coal		statistics of.....	107-110
from.....	98-99	"Ostrea carinata" bed," nature and occurrence	
nature and oil content of, in and near the		of in southern Oklahoma and	
the Osage oil field, Wyo.....	80-82, 91	northeastern Texas.....	4
plates showing.....	80, 82		P.
porosity of, in and near the Osage oil field,		Pahasapa limestone, nature and distribution	
Wyo.....	96-98	of, in and near the Osage oil field,	
Ninemile area, Mont., features of.....	48	Wyo.....	76

	Page.		Page.
Paleozoic rocks, oil and gas possibilities of, in the Madill-Denison area, Okla.-Tex.	30-32	Ranger-Rock Island Oil Co., log of well of..	158-159
Palo Pinto limestone, nature and stratigraphic place of.....	58, 59-60	"Ranger" sand. See McClesky sand.	
Parkman sandstone, nature and occurrence of, in the Crow Indian Reservation, Mont.....	37	Ray sand, gas and oil from.....	135
Parrock No. 1 well, Ranger oil field, Tex., log of.....	154-155	Read, W. T., analyses by.....	209
Pecan Gap chalk member, nature and occurrence of, in northeastern Texas.....	6	Red River, cutting of channel by.....	2
stratigraphic place of.....	237-238	Richardson, S. Q., well, log of.....	222-223
Phillips dome, Mont., description of.....	176	Rohwer, F. W., acknowledgment to.....	43
Pierce, Mrs. A. O., exposures on farm of.....	212-213	Roper, E., Farm No. 2 well, Ranger oil field, Tex., log of.....	158
Pierre shale, features of, in the Osage oil field, Wyo.....	86	Roxana Petroleum Corporation, acknowledgements to.....	179, 217
Pine Ridge area, Mont., features of.....	47		S.
Pottsboro, Tex., wells drilled near.....	20	St. Xavier, Mont., possibilities of oil east of..	53
Prairie Oil & Gas Co., logs of wells of. 153, 158, 167-168		Saline on the Brooks salt dome, Tex., description of.....	193
Preston, Tex., wells drilled near.....	19-20	Salt, occurrence and composition of.....	225-226
Preston anticline, Okla.-Tex., prospecting on. trend and dips of.....	32 7-8	rise of, in domes.....	181
Pro Ratio Oil Co., wells drilled by, near Kinlock, Okla.....	16	source of, in domes.....	180-181
Pryor Creek, Mont., low anticline crossing..	51-52	Salt domes of the Gulf Coastal Plain, map showing.....	180
	Q.	Salt licks, cause and significance of.....	187
"Quarry" limestone, nature and occurrence of, in southern Oklahoma and northeastern Texas.....	4	Sammies Oil Co., log of well of.....	168-169
	R.	Sandstone in salt of domes, origin of.....	182
Ranger anticline, Tex., description of.....	129	Scott heirs, wells drilled by.....	214
Ranger limestone member, nature and occurrence of, in the Ranger oil field, Tex.....	119-120	Scott sand, gas and oil from.....	135
nature and stratigraphic place of.. 58, 59, 61-62		Shark teeth, occurrence of, in the Carlile shale.	85
use of as datum plane.....	119-120	Shively Hill dome, Mont., features of.....	44
Ranger oil field, Tex., Carboniferous rocks in.....	116-124	domes southeast of.....	52
discovery of.....	133-134	Signal Mountain Petroleum Co., well drilled by.....	11
extensions of, possible.....	142-143	Skull Creek shale member, nature and oil possibilities of.....	79, 80, 91
field work in.....	111	Smith, N. A. C., analyses of oil by.....	102-104
folding in, periods of.....	131-133	Smith-Coleman Co., wells drilled by.....	11
geography of.....	113	"Smithwick lime," oil from.....	136
geologic history of.....	115	Smithwick shale, nature and occurrence of, in the Ranger oil field, Tex.....	122-123
Lower Cretaceous rocks in.....	115-116	nature and occurrence of, in the Wiles area, Tex.....	64
maps showing oil and gas wells, structure of the rocks, thickness of the McClesky sand, and relations between these features.....	In pocket.	oil sands in.....	68, 136
origin of oil in.....	140	Snyder Oil & Gas Co., well drilled by, near Orlena, Tex.....	19
producing sands in.....	134-138	Southern Salt Co., log of well of.....	220-221
quality of oil from.....	140	Spearfish formation, nature of, in and near the Osage oil field, Wyo.....	77-78
salt water in.....	141-142	Sport Creek anticline, Mont., features of and drilling on.....	50
scope of report on.....	111	Staff limestone member, nature and occurrence of, in the Ranger oil field, Tex.....	120
stratigraphy of.....	114-125	Standard Oil Co.'s Ingram well at El Dorado, Ark., log of, plate showing.....	244
structure of.....	125-133	States Oil Corporation, logs of wells of.....	152, 154-155, 166
influence of, on the accumulation of oil and gas.....	138-139	Steen salt dome, Tex., date of uplift of.....	215
wells in, initial and average production of.....	140-141	geology of.....	211-215
logs of.....	152-170	location and history of.....	209-210
plate showing.....	In pocket.	possibility of oil and gas in.....	215-216
statistics of.....	144-151	structure of.....	215
		topography of.....	210-211
		map showing.....	210
		wells drilled on.....	209-210, 214
		Stephenson, L. W., acknowledgment to.....	179
		examination of cuttings from well at Grand Saline, Tex., by.....	232
		fossils determined by.....	194

	Page.
Stratigraphy of eastern Texas.....	189
Strawn formation, nature and relations of, in the Ranger oil field, Tex.....	120-121
nature and relations of, in the Wiles area, Tex.....	63-64
oil sands in.....	68, 134-136
Structural terms, definitions of.....	65-66
Structure, method of determining.....	125-126
Sulphur Springs, Tex., record of city well at.....	28
Sundance formation, nature and age of.....	78
nature and occurrence of, in the Crow Indian Reservation, Mont.....	40
T.	
Taylor marl, occurrence of, in eastern Texas.....	195-196
Telegraph Creek formation, nature and occurrence of, in the Crow Indian Reservation, Mont.....	38
Telegraph Creek plunging anticline, Mont., features of.....	46
Tenmile plunging anticline, Mont., features of.....	46-47
Tensleep formation, nature and occurrence of, in the Crow Indian Reservation, Mont.....	41
Terrace, definition of.....	65-66
Texas, northeastern, diagrammatic well logs showing rocks underlying parts of.....	In pocket.
northeastern, geologic map of parts of.....	2
Texas & Pacific Coal & Oil Co., logs of wells of.....	160-161, 164-165
Texas Midland Railroad Co., log of well drilled by.....	25
Thermopolis shale, nature and occurrence of, in the Crow Indian Reservation, Mont.....	39-40
Tiffin plunging anticline, Tex., location of.....	67
Tolle, S. E., No. 1 well, Ranger oil field, Tex., log of.....	152
Toluca uplift, Mont., features of.....	47
Trenton, Tex., well drilled in.....	23-24
Trinity sand, oil and gas possibilities of, in the Madill-Denison area, Okla.-Tex.....	28-30
Two Legging uplift, Mont., features and oil and gas possibilities of.....	47-48

	Page.
U.	
Udden, Dr. J. A., examination of cuttings from well at Grand Saline, Tex., by.....	233-234
W.	
Wascomb Thorne Oil & Gas Co., wells drilled by.....	11, 12
Washita group, fossils of, plate showing.....	4
Westover, C. V., log of well drilled by.....	18-19
Whitesboro Oil & Gas Co., well drilled by, near Bed Branch, Tex.....	19
Whitewright Oil Co., wells drilled by.....	12
Wilcox formation, occurrence of, in eastern Texas.....	196-197, 212-213
Wiles area, Ranger district, Tex., cultural features of.....	55-56
field work in.....	56-57
location of.....	55
oil and gas sands in.....	68-69
oil wells in, initial production of.....	66-68
logs of.....	64
stratigraphy of.....	57-64
structure of.....	66-68
map showing.....	56
topography of.....	56
Wiles limestone, nature and stratigraphic place of.....	59, 60
Wiles plunging anticline, Tex., description of.....	66-67
Willow Creek dome, Mont., features of and drilling on.....	50-51
Winter, E. W., well No. 1 east of Lindale, Tex., log of.....	214
Woldert, Dr. Albert, acknowledgment to.....	199
Woldert tract, Smith County, Tex., logs of wells on.....	199, 202-203
Wolfe City, Tex., well drilled in.....	24
Wolfe City Petroleum Co., log of well drilled by, in Fannin County, Tex.....	23
Wolfe City sand member, nature and occurrence of, in northeastern Texas.....	6
Woodville, Okla., log of well drilled near.....	18
Woody Creek dome, Mont., features of.....	43-44
Worrell, S. H., analysis by.....	195
Wright No. 1 well, Ranger oil field, Tex., log of.....	158-159

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