INFORMATION CIRCULAR 20-J

Geology of the Knoxville and Delaware Quadrangles, Johnson and Logan Counties and Vicinity, Arkansas

GEOLOGICAL SURVEY PROFESSIONAL PAPER 657-B

Prepared in cooperation with the Arkansas Geological Commission

Geology of the Knoxville and Delaware Quadrangles, Johnson and Logan Counties and Vicinity, Arkansas

By E. A. MEREWETHER

GEOLOGY OF THE ARKANSAS VALLEY COAL FIELD, PART 2

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GEOLOGY OF THE KNOXVILLE AND DELAWARE QUADRANGLES, JOHNSON AND LOGAN COUNTIES AND VICINITY, ARKANSAS

By E. A. MEREWETHER

ABSTRACT

The Knoxville and Delaware quadrangles enclose an area of about 122 square miles in Johnson, Pope, Logan, and Yell Counties in northwestern Arkansas. The quadrangles lie between lats 35°15′ N. and 35°30′ N., and between longs 93°15′00″ W. and 93°22′30″ W.

Sedimentary rocks of Pennsylvanian age crop out, and were penetrated by wells drilled for gas in the area. Locally, these strata are overlain by terrace deposits and alluvium of Pleistocene and Holocene age. Rocks of the Morrow and Atoka Series are recognized in the subsurface, and rocks of the Atoka and Des Moines Series are exposed in the two quadrangles. These rocks consist of dark-gray shale, light- to medium-gray siltstone and sandstone, and a few beds of coal and limestone.

The rocks have been folded into gently dipping westward-trending anticlines and synclines and have been broken by northward- or southward-dipping normal faults. The structural relief is about 2,800 feet, measured on the base of the Hartshorne Sandstone of the Des Moines Series.

Natural gas, coal, building stone, road metal, sand, and clay are of commercial importance in the area. The reported initial potential production of gas (Oct. 31, 1967) is about 248 million cubic feet per day from rocks of the Atoka Series. The Lower Hartshorne coal bed in the Des Moines Series contains an estimated reserve of about 2 million short tons of coal, which ranges in rank from low-volatile bituminous to semianthracite. Building stone has been quarried from the Hartshorne Sandstone, and additional stone can probably be found in sandstone beds of the Atoka Series and Hartshorne and Savanna Formations of the Des Moines Series. Sources of road metal are abundant and include outcropping sandstone, terrace deposits, and alluvium. Sand and gravel are available in the terrace deposits and alluvium, and clay can readily be obtained from beds of shale.

INTRODUCTION

This report is concerned with the geology of the Knoxville and Delaware quadrangles, Arkansas, and is one of a series of reports being prepared by the U.S. Geological Survey in cooperation with the Arkansas Geological Commission. The purpose of this report is to (1) provide a geologic map of the quadrangles on a topographic base; (2) provide a structure map of the rocks in the quadrangles; (3) describe the stratigraphy of the rocks exposed at the surface and present in the subsurface; (4) show the areal extent and thickness of coal beds and present estimates, where data permit, of the reserves of coal; (5) provide geologic information, and the author's interpretation of this information, relevant to the location of accumulations of natural gas; and (6) present geologic data pertinent to the location of deposits of building stone, gravel, sand, and clay.

This report is also distributed as Arkansas Geological Commission Information Circular 20–J.

The Knoxville quadrangle is in Johnson and Pope Counties; the Delaware quadrangle is in Johnson, Pope, Logan, and Yell Counties. The Knoxville quadrangle is north of and adjacent to the Delaware quadrangle (fig. 1). The quadrangles compose an area of about 122 square miles and lie between lats 35°15′00″ N. and 35°30′00″ N. and between longs 93°15′00″ W. and 93°22′30″ W.

General descriptions of the geology in the Knoxville and Delaware quadrangles are in reports by Collier (1907), Croneis (1930), and Haley (1960). The stratigraphic nomenclature and stratigraphic boundaries used in this report for the Middle Pennsylvanian rocks were derived mainly from the work of Hendricks and Read (1934), Hendricks, Dane, and Knechtel (1936), and Hendricks and Parks (1950) in the Arkansas Valley near the Arkansas-Oklahoma State line. Modifications of the nomenclature for Middle Pennsylvanian rocks of the Des Moines Series proposed by Oakes (1953) and Miser (1954) were accepted by Merewether and Haley (1961) and Haley (1961). In the area of this report the Lower Pennsylvanian Morrow Series has not been divided into formations. The stratigraphic classification adopted herein and the classification used in the Arkansas Valley and Ozark Mountains are compared in table 1.

The geology of the Delaware and Knoxville quadrangles was described by Merewether and Haley (1961) and Merewether (1967), respectively. Since completion of these reports the area has been mapped

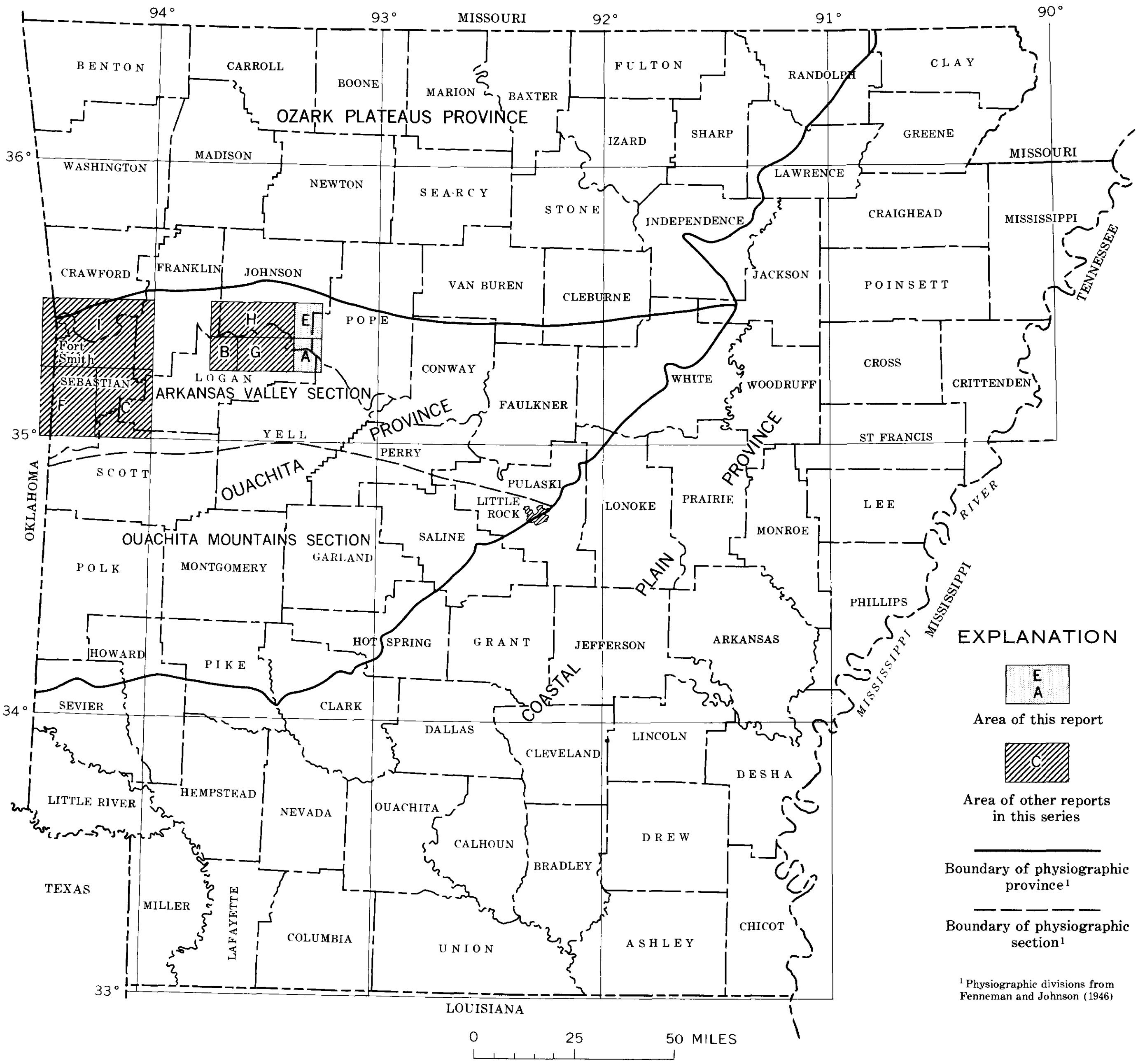

FIGURE 1.—Location of report area (*E*, *A*) and areas of previously published chapters of Arkansas Geological Commission Information Circular 20 or of U.S. Geological Survey Professional Papers 536 or 657: *A*, Delaware quadrangle (Merewether and Haley, 1961); *B*, Paris quadrangle (Haley, 1961); *C*, Barber quadrangle (Haley, 1966); *E*, Knoxville quadrangle (Merewether, 1967); *F*, Greenwood quadrangle (Haley and Hendricks, 1968); *G*, Scranton and New Blaine quadrangles (Haley, 1968); *H*, Coal Hill, Hartman, and Clarksville quadrangles (Merewether and Haley, 1969); *I*, Van Buren and Lavaca quadrangles (Haley and Hendricks, 1971).

topographically and more intensively drilled for natural gas. The purpose of this report is to provide a geologic map with a topographic base and to present geologic data and interpretations that have resulted from the additional drilling.

The Arkansas Geological Commission provided samples of drill cuttings from 14 of the wells drilled for gas in the report area. The Gulf Oil Corp. loaned

TABLE 1.—*Selected stratigraphic units in or near Knoxville and Delaware quadrangles, Johnson and Logan Counties and vicinity, Arkansas*

System		Series	Group	This report: Formation	This report: Member, zone, or bed	Arkansas Valley and Ozark Mountains: Formation	Arkansas Valley and Ozark Mountains: Member
CARBONIFEROUS	Pennsylvanian	Des Moines	Krebs	Savanna		Savanna	
				McAlester	Lower Hartshorne coal bed	McAlester	
				Hartshorne Sandstone		Hartshorne Sandstone	
		Atoka		Atoka	Sandstone unit C	Atoka	
							Greenland Sandstone
		Morrow		Rocks of the Morrow Series (locally in subsurface only)		Bloyd	Trace Creek Shale
							Kessler Limestone
							Dye Shale
							Woolsey
							Brentwood Limestone
						Hale	Prairie Grove
							Cane Hill

samples of drill cuttings and presented copies of electric logs from the three exploratory shallow holes in the Knoxville quadrangle. The contributions of personnel of the U.S. Geological Survey to this report are noted where appropriate. To these organizations and individuals the author expresses sincere appreciation.

STRATIGRAPHY

Sedimentary rocks of Middle Pennsylvanian age and unconsolidated sediments of Quaternary age crop out in the Knoxville and Delaware quadrangles. Wells in the two quadrangles have not penetrated strata older than Early Pennsylvanian.

The surficial extent of some of these rocks is depicted on plate 1, and the lithology of most of these rocks is represented on plate 2. Strata in the subsurface were studied by examining the drill cuttings and electric or radioactivity logs from holes drilled in the search for natural gas. Most of the wells in the mapped area, as of October 31, 1967, are described in table 2. Shallow exploratory holes are described in table 3. Detailed lithologic descriptions of drill cuttings from wells 44 and 47, generalized on plate 2, and shallow holes 163, 164, and 166 are included in Arkansas Information Circular 20–J. The lithologic descriptions from wells 14 and 32 and surface sections D and G, shown graphically on plate 2, and wells 2, 3, and 25 are presented in Arkansas Information Circular 20–E (Merewether, 1967). The lithology of the rocks penetrated by well 46 is described in Arkansas Information Circular 20–A (Merewether and Haley, 1961).

PENNSYLVANIAN SYSTEM

MORROW SERIES

In northwestern Arkansas the Morrow Series consists of the Hale Formation and overlying Bloyd Formation (table 1), but in the Knoxville and Delaware quadrangles it cannot be divided with certainty into these formations. In this area the Morrow is not exposed, and the base of the series has not been intersected by drilling. Rocks of Morrow age were penetrated by eight wells (table 2); the thickest

TABLE 2.—*Description of selected wells in and near Knoxville*

Well No. (pls. 1–4)	Company	Lease name	Location (NL, north line; WL, west line; EL, east line; SL, south line)	Reported ground elevation (feet)	Bottom of well	
					Depth (feet)	Stratigraphic unit
1	W. A. Moncrief	Johnson 1	1,040 ft from NL and 1, 650 ft from WL of sec. 28, T. 10 N., R. 22 W.	565	4,682	Morrow Series
2	Arkansas Oklahoma Gas Co.	L. O. Wilkins 1	660 ft north, 510 ft west of SE cor. sec. 33, T. 10 N., R. 22 W.	[1]650	4,329	do
3	Industrial Oil and Gas Co.	Winningham 1	NW¼NE¼SW¼ sec. 5, T. 9 N., R. 22 W.	456	3,681	Atoka Formation
4	Gulf Oil Corp	Harold Smith 1	300 ft from NL and 1,000 ft from WL of SE¼ sec. 4, T 9 N., R. 22 W.	403	3,180	do
5	Dick Wegener	Lena Holland 1	460 ft from NL and 1,197 ft from EL of SW¼ sec. 3, T. 9 N., R. 22 W.	377	4,214	Morrow series
6	W. A. Moncrief, Jr	Crotts GU 1	900 ft south, 300 ft west of center sec. 2, T. 9 N., R. 22 W.	424	3,448	Atoka Formation
7	Apache Corp	Gray Davis Unit 1	1,980 ft from SL and 810 ft from WL of SE¼ sec. 8, T. 9 N., R. 22 W.	423	5,760	do
8	do	Horner Unit 1	660 ft from SL and 435 ft from WL of SW¼NE¼ sec. 9, T. 9 N., R. 22 W.	362	5,014	do
9	Gulf Oil Corp	Reynolds 1	507 ft north, 742 ft east of center sec. 10, T. 9 N., R. 22 W.	494	4,690	do
10	Skelly Oil Co	Mina Snow 1	2,150 ft from SL and 2,000 ft from EL of sec. 11, T. 9 N., R. 22 W.	647	2,959	do
11	Steve Gose	Treadway 1	1,000 ft south, 1,100 ft west of center sec. 12, T. 9 N., R. 22 W.	601	2,382	do
12	Gulf Oil Corp	Massey 1	500 ft from NL and 875 ft from EL of SW¼ sec. 7, T. 9 N., R. 21 W.	877	4,935	do
13	Steve Gose	Pomrenke Unit 1	820 ft north and 600 ft east of center sec. 14, T. 9 N., R. 22 W.	530	4,888	do
14	Gulf Oil Corp	J. J. Bauman 1	Center NE¼SW¼ sec. 13, T. 9 N., R. 22 W.	616	5,824	Morrow Series
15	Post Petroleum and Mid-America Producers, Inc.	Steuber 1	Center NE¼SW¼ sec. 18, T. 9 N., R. 21 W.	668	4,961	Atoka Formation
16	Apache Corp	H. F. Smith Unit 1	Center SE¼NW¼ sec. 17, T. 9 N., R. 21 W.	627	4,562	Morrow Series
17	Shamrock Oil and Gas Corp.	C. C. Robinson 1	2,002 ft from SL and 1,881 ft from EL of sec. 20, T. 9 N., R. 22 W.	505	7,117	Atoka Formation
18	Gulf Oil Corp	Johnson Heirs 1	577 ft. from SL and 378 ft from EL of SE¼NW¼ sec. 20, T. 9 N., R. 21 W.	801	5,375	do
19	do	Carothers 1	475 ft north and 900 ft east of center sec. 27, T. 9 N., R. 22 W.	369	3,370	do
20	do	Higby 1	560 ft from NL and 660 ft from WL of SE¼ sec. 26, T. 9 N., R. 22 W.	457	3,500	do
21	do	Williams Estate 1	607 ft south and 34 ft east of center sec. 31, T. 9 N., R. 22 W.	420	4,323	do
22	Gose Petroleum Co	Morin 1	738 ft south and east of center sec. 32, T. 9 N., R. 22 W.	413	4,329	do
23	Kingwood Oil Co	Stratton 1	Center NW¼SE¼ sec. 33, T. 9 N., R. 22 W.	392	3,460	do
24	Gulf Oil Corp	Wyss 1	Center NW¼SE¼ sec. 34, T. 9 N., R. 22 W.	593	4,308	do
25	do	Wharton 1	Center NW¼SE¼ sec. 35, T. 9 N., R. 22 W.	723	3,400	do
26	do	Missouri-Pacific 1	Center NE¼SW¼ sec. 36, T. 9 N., R. 22 W.	743	3,216	do
27	Stephens, Inc	R. E. Cochran 1	700 ft south and 600 ft west of center sec. 31, T. 9 N., R. 21 W.	678	3,331	do
28	Gulf Oil Corp	Edna Dunlap X-1	717 ft south and 742 ft east of center sec. 6, T. 8 N., R. 22 W.	429	4,250	do
29	Steve Gose	Higgs 1	Center NW¼SE¼ sec. 5, T. 8 N., R. 22 W.	385	3,881	do
30	do	Blackburn 1	300 ft north and 800 ft east of center sec. 4, T. 8 N., R. 22 W.	541	3,590	do

[1] Elevation estimated from plate 1.

and Delaware quadrangles, Arkansas, as of October 31, 1967

Producing zone			Reported initial production of gas (cubic feet per day)	Completion date	Remarks (Displacement and depth of faults are estimated)
Formation	Zone No.	Depth reported (feet)			
Atoka------	109	3,904–3,913	2,895,000	Oct. 1967	Discovery well of Hagarville field.
----------			Dry	Sept. 1945	Rock samples examined and logged by W. A. Chisholm.
----------			Dry	Aug. 1940	Fault with a displacement of 850 ft cut at depth of 2,800 ft. Rock samples examined and logged by S. E. Frezon.
Atoka------	99	2,972–2,984	15,700,000	Aug. 1963	Fault with a displacement of 1,700 ft cut at depth of 1,540 ft.
----do-----	98	2,875	3,000,000	Apr. 1962	Fault with a displacement of 1,700 ft cut at depth of 1,850 ft.
	99	2,982 and 3,020	40,000,000		
----------			Dry	Oct. 1965	Fault with a displacement of 1,380 ft cut at depth of 2,050 ft.
Atoka------	100	5,665–5,682	4,750,000	Apr. 1966	
----do-----	98	4,630–4,707	33,600,000	Nov. 1965	Fault with a displacement of 75 ft cut at depth of 1,350 ft.
----do-----	67	2,200	(2)	Nov. 1966	
	98	4,386–4,396	8,800,000		
	99	4,478–4,480	} 19,200,000		
	99	4,494–4,504			
----do-----	67	2,324–2,330	2,640,000	Mar. 1966	
----do-----	59	1,584	(3)	Sept. 1964	
----do-----	83	3,648	(2)	July 1963	
	83	3,661	300,000		
----do-----	67	2,762–2,776	15,750,000	Jan. 1963	Faults with 250 and 175 ft of displacement cut at depths of 2,200 and 3,230 ft, respectively.
----do-----	98	4,531–4,538	5,000,000	Nov. 1959	Discovery well of Ross field. Fault with a displacement of 800 ft cut at depth of 3,150 ft. Rock samples examined and logged by E. A. Merewether.
----do-----	98	4,176–4,282	4,000,000	Nov. 1960	Faults with 90, 60, and 800 ft of displacement cut at depths of 1,140, 1,980, and 2,490 ft, respectively.
----do-----	98	3,766–3,866	4,700,000	Jan. 1962	Faults with 500 and 760 ft of displacement cut at depths of 920 and 1,320 ft, respectively.
----------			Dry	Oct. 1967	
Atoka------	55	1,755	(2)	Mar. 1963	
	98	5,219–5,222	375,000		
----------			Dry	May 1965	Fault with a displacement of 260 ft cut depth of 270 ft.
Atoka------	67	3,129	319,000	Dec. 1960	Fault with a displacement of 130 ft cut at depth of 2,840 ft. Rock samples examined and logged by E. A. Merewether.
----do-----	67	3,336–3,460	} 83,500	July 1967	Fault with a displacement of 385 ft cut at depth of 1,700.
	71 } 74	3,896–4,273			
----do-----	67	3,276–3,384	3,550,000	Apr. 1966	Faults with 240 and 70 ft of displacement cut at depths of 1,740 and 1,930 ft, respectively.
----do-----	67	3,250–3,290	2,000,000	May 1964	Fault with a displacement of 165 ft cut at depth of 1,420 ft.
----do-----	67	3,324–3,370	35,000,000	Jan. 1959	Fault with a displacement of 50 ft cut at depth of 190 ft. Rock samples examined and logged by E. A. Merewether.
----do-----	67	3,215–3,271	7,500,000	Dec. 1958	Rock samples examined and logged by E. A. Merewether and B. R. Haley.
----do-----	67	3,131	2,750,000	Apr. 1959	Rock samples examined and logged by E. A. Merewether.
----------			Dry	June 1962	Fault with a displacement of 90 ft cut at depth of 1,000 ft.
Atoka------	67	4,005–4,125	1,418,000	Oct. 1966	
----do-----	67	3,595–3,687	6,000,000	July 1965	
----do-----	67	3,428–3,436	} 1,800,000	May 1963	Fault with a displacement of 190 ft cut at depth of 2,130 ft.
	67	3,449–3,460			

[2] Show of gas.
[3] Slight show of gas.

TABLE 2.—*Description of selected wells in and near Knoxville*

Well No. (pls. 1–4)	Company	Lease name	Location (NL, north line; WL, west line; EL, east line; SL, south line)	Reported ground elevation (feet)	Bottom of well	
					Depth (feet)	Stratigraphic unit
31	Gulf Oil Corp	B. Hicks 1	Center SW¼NE¼ sec. 3, T. 8 N., R. 22 W.	554	3,450	do
32	do	W. H. Tackett 1	Center SW¼NE¼ sec. 2, T. 8 N., R. 22 W.	690	7,525	Morrow Series
33	do	Herbert Schinn 1	560 ft from SL and 260 ft from EL of NW¼ sec. 1, T. 8 N., R. 22 W.	795	3,335	Atoka Formation
34	Stephens, Inc	O. L. Ware 1	500 ft north and 400 ft west of center sec. 5, T. 8 N., R. 21 W.	[1]650	3,176	do
35	Gulf Oil Corp	Lamb 1	1,030 ft north and 175 ft east of center sec. 7, T. 8 N., R. 22 W.	365	4,446	do
36	do	Dolores Higgs 1	742 ft north and west of center sec. 8, T. 8 N., R. 22 W.	369	4,214	do
37	do	Vardaman 1	742 ft north and west of center sec. 9, T. 8 N., R. 22 W.	376	3,875	do
38	Steve Gose	Whorton Unit 1	200 ft north and 900 ft east of center sec. 10, T. 8 N., R. 22 W.	541	6,787	do
39	Gulf Oil Corp	G. L. Hardgrave 1	Center SW¼NE¼ sec. 11, T. 8 N., R. 22 W.	520	3,650	do
40	Stephens, Inc	Clyde Vinson 1	920 ft north and 300 ft west of center sec. 12, T. 8 N., R. 22 W.	574	3,754	do
41	Tenneco Oil Co	Alfred Martin Unit 1	Center SW¼NE¼ sec. 8, T. 8 N., R. 21 W.	633	5,802	do
42	Skelly Oil Co	G. A. Gifford 1	25 ft south and 296 ft west of center NW¼ sec. 16, T. 8 N., R. 22 W.	544	4,400	do
43	Steve Gose	Savage and Roberts Unit 1.	Center SE¼NW¼ sec. 18, T. 8 N., R. 21 W.	700	4,553	do
44	do	Stanfield 1	950 ft north and 150 ft west of center sec. 31, T. 8 N., R. 22 W.	759	8,996	Morrow Series
45	Arkansas-Louisiana Gas Co.	J. W. Roberts 1	679 ft south and 771 ft east of NW cor. sec. 33, T. 8 N., R. 22 W.	956	4,748	Atoka Formation
46	Gulf Oil Corp	do	530 ft from NL and 2,310 ft from WL of sec. 33, T. 8 N., R. 22 W.	968	7,813	do
47	Shell Oil Co	T. V. Jones et al 1	1,000 ft from NL and 660 ft from WL of sec. 19, T. 7 N., R. 21 W.	512	10,509	Morrow Series

[1] Elevation estimated from plate 1.

TABLE 3.—*Description of shallow holes drilled by Gulf Oil Corp. in Knoxville quadrangle, Johnson and Pope Counties, Ark.*

[Hole numbers are company designations. Samples were examined and logged by E. A. Merewether]

No. (pls. 1, 4)	Location (NL, north line; WL, west line; EL, east line)	Reported ground elevation (feet)	Depth of hole (feet)	Stratigraphic position of bottom of the hole relative to the top of the Hartshorne Sandstone (feet, below top)	Remarks (lithologic and electric logs available)
163	1,400 ft from NL; 380 ft from EL, sec. 6, T. 8 N., R. 21 W.	658	905	1,227	100-ft fault at depth of 64 ft.
164	2,220 ft from NL; 1,380 ft from EL, sec. 6, T. 8 N., R. 21 W.	642	152	510	
166	1,200 ft from NL; 30 ft from WL, sec. 30, T. 9 N., R. 21 W.	545	625	517	

stratigraphic section, about 1,450 feet, is from well 47 in the southeastern part of the Delaware quadrangle (pl. 2). At well 1, near the north boundary of the Knoxville quadrangle, the Morrow is more than 525 feet thick.

Regional studies (E. E. Glick, written commun., 1964) indicate that the thickness of the Morrow Series increases toward the south and southeast in the Arkansas Valley. In the Clarksville, Hartman, and Coal Hill quadrangles, adjoining and west of the Knoxville quadrangle, the Morrow is about 820–955 feet thick (Merewether and Haley, 1969). In the northern part of the Scranton quadrangle, about 8 miles west of the Delaware quadrangle, the Morrow is 1,135 feet thick (Haley, 1968).

The rocks of Morrow age observed in the Knoxville and Delaware quadrangles are mainly interstratified shale, siltstone, and sandstone but include limestone (pl. 2). The shale is generally dark gray to grayish black, silty, micaceous, and in units as much as 125 *and Delaware quadrangles, Arkansas, as of October 31, 1967*—Continued

Producing zone			Reported initial production of gas (cubic feet per day)	Completion date	Remarks (Displacement and depth of faults are estimated)
Formation	Zone No.	Depth reported (feet)			
----do-----	67	3,228–3,269	2,750,000	Oct. 1958	Faults with 160 and 80 ft of displacement cut at depths of 1,480 and 1,790 ft, respectively. Rock samples examined and logged by E. A. Merewether.
----do-----	67	3,308–3,376	8,000,000	Dec. 1957	Discovery well of Knoxville field. Faults with 20 and 125 ft of displacement cut at depths of 400 and 1,040 ft, respectively. Rock samples examined and logged by B. R. Haley.
----do-----	67 67	3,257–3,266 3,282	1,250,000	Apr. 1959	Fault with a displacement of 120 ft cut at depth of 170 ft. Rock samples examined and logged by E. A. Merewether.
------------			Dry	Dec. 1963	
Atoka------	67	4,160–4,320	2,526,000	June 1967	
----do-----	67 67	3,914–3,958 4,025–4,032	2,899,000	Mar. 1967	
----do-----	67 67	3,640–3,680 3,730–3,740	3,128,000	Aug. 1966	
----do-----	67	3,620–3,678	3,100,000	Jan. 1963	Fault with a displacement of 245 ft cut at depth of 6,090 ft.
----do-----	67 67	3,535–3,540 3,565	2,600,000	Mar. 1959	Fault with a displacement of 150 ft cut at depth of 1,290 ft. Rock samples examined and logged by E. A. Merewether.
------------			Dry	June 1962	Fault with a displacement of 225 ft cut at depth of 1,660 ft.
Atoka------	67	3,136–3,216	475,000	Sept. 1967	Faults with 500 ft of total displacement cut at depths of 3,240 and 3,320 ft.
------------			Dry	Jan. 1967	
------------			Dry	July 1962	
------------			Dry	July 1965	Fault with a displacement of 460 ft cut at depth of 3,400 ft. Rock samples examined and logged by E. A. Merewether and B. R. Haley.
------------			Dry	Jan. 1944	
Atoka------	53	2,615	146,000	Apr. 1958	Fault with a displacement of 480 ft cut at depth of 4,600 ft. Rock samples examined and logged by B. R. Haley.
----do-----	67	3,882–4,065	333,000	Sept. 1959	Rock samples examined and logged by B. R. Haley.

feet thick. The siltstone is light gray to dark gray, micaceous, and locally sandy and limy. Units of siltstone are as much as 85 feet thick. Sandstone in the Morrow is mostly light gray to medium gray, very fine to fine grained, silty, and micaceous, but is, in part, fine to coarse grained and limy. The sandstone units are as much as 100 feet thick. The limestone is light to dark gray, granular, sandy, and, in part, oolitic. Units of limestone are as much as 20 feet thick. Invertebrate fossils, mostly crinoid columnals, are common in the limestone and sparse in the sandstone and siltstone.

ATOKA SERIES, ATOKA FORMATION

In Arkansas the Atoka Series consists of the Atoka Formation. The formation is a thick sequence of interbedded shale, siltstone, and sandstone, which rests unconformably on rocks of the Morrow Series. In the area of this report the lower boundary of the Atoka is in the subsurface and is generally at the base of the first sandstone above rocks typical of the Morrow. This basal sandstone is overlain by a unit of shale which commonly includes a distinctive thin bed of bentonite(?) (Frezon and Schultz, 1961).

The Atoka crops out in the northern part of the Knoxville quadrangle and along the south boundary of the Delaware quadrangle (pl. 1), and has been penetrated in all the wells described in table 2. The thickness of the exposed part of the formation is, at most, about one-fourth of the total thickness of the formation. Few lithologic units within the Atoka can be projected from outcrops to well logs, but electric logs of the formation from wells less than 3 miles apart can be correlated in detail.

The tops of numbered lithologic zones in the Atoka shown on plates 2 and 3 and given in tables 2 and 4 are correlative horizons selected from electric logs, and were mainly established in the Van Buren and Lavaca quadrangles, Arkansas, to the west (Haley and Hendricks, 1971). These zones and the informal

TABLE 4.—*Divisions of the Atoka Formation in Knoxville and Delaware quadrangles, Arkansas*

Zone referred to in this report	Parts of Atoka discussed in this report		Informal nomenclature used by local oil and gas industry	
1	Upper part			
4				1st Atoka sand
5		Sandstone unit C		
6				
15				
18				Carpenter sand
24				
28			Alma series	Upper Alma sand
50				Middle Alma sand
53				
55				Lower Alma sand
58	Middle part			Lower Carpenter sand
59				
60				Glassy sand
62				
66				
67				Tackett sand, Morris sand
71			Areci zone	
74				Areci Sand
79				Self sand
80				
83	Lower part			Bynum sand
84				
85				Lower Bynum sand
90				
92				Freiburg sand
93				Casey sand
95				Vernon sand
97				
98			Cecil series	Dunn "A" sand, McGuire sand
99				Dunn "B" sand, Ralph Barton sand, Upper Allen sand
100				Dunn "C" sand, Lower Allen sand
101				Paul Barton sand
105				Cecil Spiro sand
108				Patterson sand
109				Kelly sand

names applied to some of them by oil and gas companies are presented in table 4. A few of the informal names used for sandstone units in the Arkansas Valley have apparently been assigned to more than one unit. Names used in both the Van Buren-Lavaca area (Haley and Hendricks, 1971, table 2) and the area of this report are not everywhere applied to the same zone.

The thickness of the Atoka in the Knoxville and Delaware quadrangles ranges from about 4,800 to about 10,700 feet. Along the north boundary of the area the formation is estimated to be 4,800–4,900 feet thick, and at well 47 near the south boundary it is about 10,660 feet thick. Thicknesses or partial thicknesses from 20 wells, mostly in the Knoxville quadrangle, indicate that the maximum rate of thickening is generally southward. No abrupt change in the thickness of the formation was detected in the report area. The thickening is greatest in the middle part of the Atoka, between the tops of zones 58 and 83, and least between the top of zone 83 and the base of the formation. Some of the formation thins locally —for example, between the tops of zones 24 and 67 in the northern part of the Knoxville quadrangle, and does not thicken uniformly toward the south. The striking southward increase in thickness of the Atoka in the Arkansas Valley was described by Collier (1907, p. 14). In the area of this report, thickening is accompanied by a small increase in the percentage of shale in the formation (Merewether, 1961).

The Atoka in the mapped area consists of 12–23 percent sandstone, 20–27 percent siltstone, 52–68 percent shale, and less than 1 percent coal, limestone, and bentonite(?). Generally, the percentage of sandstone decreases slightly, and the percentage of shale increases slightly from north to south. The formation where penetrated by well 14 is about 19 percent sandstone and 55 percent shale; at well 32 it is about 23 percent sandstone and 52 percent shale; at well 46 it is about 12 percent sandstone and 68 percent shale; at well 44 it is about 16 percent sandstone and 60 percent shale; and at well 47 it is about 14 percent sandstone and 62 percent shale.

Sandstone units in the Atoka commonly grade laterally into siltstone units. The sandstone is mostly very light to medium gray, very fine to fine grained, silty, and composed of quartz, but a few beds are fine to medium grained with scattered coarser grains and are limy. Units of sandstone containing thin beds of shale and siltstone are as much as 300 feet thick. Sandstone units apparently gradational with underlying shale units are most common in the middle part of the Atoka, in the subsurface; units with sharp basal contacts are more abundant in the parts of the formation above zone 67 and below the top of zone 83 (pl. 2). The siltstone in the Atoka is light to dark gray, argillaceous to sandy, micaceous, mainly quartz, and is in units as much as 200 feet thick. The shale in the formation is generally medium gray to grayish black, partly silty, micaceous, and in units as much as 400 feet thick. One sample of shale from the upper part of the Atoka in the center 2½ sec. 5, T. 9 N., R. 22 W., was analyzed (table 5) as part of a regional investigation of depositional environments. This shale is brownish gray, weathered, and contains abundant large pieces of fossil ferns. A few beds of coal (all less than 14 in. thick) are in the upper part of the formation, at either the top or the base of a sandstone unit. The coal seems to be confined to the upper part of the Atoka and is very sparse south of the Arkansas River. Thin lenticular beds of limestone are at two horizons in the upper part of the Atoka of the Knoxville quadrangle, about 1,790 and 1,975 feet below the top of the formation in well 26. The limestone is medium to dark gray, argillaceous to sandy, and partly fossiliferous. In the area of this report three thin beds of bentonite(?) were found in the lower part of the formation. The uppermost is near zone 98 (pl. 2), the lowermost is near the top of the basal sandstone, and the intermediate bed was penetrated in well 44 at a depth of 7,679 feet. The bentonite(?) is white to pale yellowish brown, mostly cryptocrystalline, soft, flaky, has a pearly to waxy luster, and commonly contains very fine to medium dolomite crystals and very fine quartz crystals.

TABLE 5.—*Clay-mineral, carbon, and selected trace-element contents of shale from the Atoka Formation, Knoxville quadrangle*

[Sample collected in center S½ sec. 5, T. 9 N., R. 22 W.]

Clay-mineral content (in approximate percent) [Analysis by X-ray diffraction; analysts: H. C. Starkey and T. Manzanares]	
Quartz	32
Goethite	Trace
Kaolinite	26
Mica [1]	23
Chlorite	1
Vermiculite [2]	3
Vermiculite (aluminum interlayered) [3]	7
Mixed layered mica-vermiculite (aluminum interlayered) [3]	7
Carbon content (in percent) [Analysis by induction furnace and a gasometric procedure; analyst, I. C. Frost]	
Organic carbon	0.5
Mineral carbon	<.01
Total carbon	.49
Trace-element content (in percent) [Quantitative spectrographic analyses; analyst, Nancy Conklin]	
B	0.0094
Cr	.015
Ga	.0026
Ni	.0034
Li	.0096
Rb	.014

[1] Mica is muscovite plus illite.
[2] Trioctahedral vermiculite.
[3] Nearly dioctahedral vermiculite.

The Atoka Formation is informally separated into three parts in the Knoxville and Delaware quadrangles, as it was in the Van Buren and Lavaca quadrangles (Haley and Hendricks, 1971). The lower part is between the base of the formation and the top of zone 83; the middle part is between the tops of zones 83 and 58; and the upper part is between zone 58 and the top of the formation (pl. 2). The boundaries were arbitrarily selected because of distinctive and persistent electric-log characteristics. The lower part includes thin beds of bentonite(?) and sandstone and siltstone units that are mainly thinner and better defined than those in the middle part of the Atoka. The thickness of the lower part increases southward from about 1,865 feet at well 1 to about 2,250 feet at well 44 and about 2,680 feet at well 47. The middle part of the Atoka contains thick sandstone and siltstone units that have sharp upper boundaries and are gradational with underlying shale units. It ranges in thickness from about 1,720 feet at well 9 to about 4,260 feet at well 47. The upper part of the Atoka in this area contains all the coal and limestone in the formation, and it also contains more sandstone units with the sharp lower contacts than the middle part of the Atoka. The thickness of the upper part of the formation ranges from about 2,000 feet at well 7 to about 3,150 feet at well 44.

The informal threefold division of the Atoka Formation described by Merewether and Haley (1969, p. C15) in the Coal Hill, Hartman, and Clarksville quadrangles differs from the division of the Atoka described in this report; there, the formation was separated at the tops of zones 98 and 67.

Where the upper part of the Atoka crops out, the sandstone is very thinly bedded to massive and regular bedded to irregular bedded. Sandstone units are locally crossbedded, foreset bedded, convolute bedded, or lenticular, and they display current ripple marks, current flow casts, or sediment flow structures. The lower contacts are gradational in some beds and sharp in others. The exposed siltstone is very thinly to thinly bedded and commonly ripple marked. Shale exposed in the Atoka in the report area is fissile to thinly bedded, contains concretions in some places, and occurs thinly interbedded with sandstone or siltstone, or in thick homogeneous units.

The rocks between the tops of zones 74 and 83, represented on plates 2 and 3, are typical of the middle part of the Atoka; at wells north of the Arkansas River they commonly consist of a unit of sandstone and siltstone paired with an underlying unit of shale. The units are intergradational, and the average grain size, in general, decreases from the top of zone 74 to the top of zone 83. These rocks are about 510–630 feet thick. South of the Arkansas River, at wells 44–47, the correlative rocks cannot be identified with certainty, but they probably are thick units consisting mainly of siltstone or shale; the sequence is about 810–860 feet thick. This part of the Atoka is continuous with zone S in quadrangles to the west (Merewether and Haley, 1969) and crops out in the Ozark Mountains, a few miles to the north. In the mapped area north of the Arkansas River the sandstone in these zones is probably continuous with the Self sand, an informal name used by the Fort Smith Geological Society Stratigraphic Committee (1960), but it is not continuous with the younger Tackett sand, also an informal name used by that committee, as indicated by Merewether (1967). The zone S described by Merewether (1967, p. 6, pl. 2) in the Knoxville quadrangle is the Tackett sand of drillers which is about 700 feet above zone 74 in well 32.

Sandstone unit C, a part of which is zone 5, is a widespread sandstone, about 100–200 feet thick, in the upper part of the Atoka Formation. The unit, depicted on plates 1–3, crops out in the northeastern part of the Knoxville quadrangle and the southeastern part of the Delaware quadrangle and can be recognized on the logs of many wells in the report area. It was identified in the Coal Hill, Hartman, and Clarksville quadrangles to the west (Merewether and Haley, 1969) and is well exposed in the Lee Mountain, Dover, and Russellville quadrangles to the east. In the Coal Hill, Hartman, and Clarksville quadrangles, and in the Knoxville quadrangle (Merewether, 1967), the unit was informally named zone C.

In the area of this report, sandstone unit C consists of sandstone interbedded with less siltstone and shale, and has a sharp lower contact. The sandstone is very light gray to dark gray, slightly micaceous, partly carbonaceous, and irregular bedded. Crossbedding is common. At most localities the coarsest grained sandstone is near the base of the unit. The average grain size of the sandstone in unit C seems to decrease toward the south. In the northern part of the Knoxville quadrangle the sandstone is very fine to medium grained and, near the bottom of the unit, contains scattered coarse and very coarse grains and sandstone pebbles as much as 3 inches in diameter. In the southern part of the report area the sandstone is very fine to fine grained and silty. At a few localities in the northern part of the Knoxville quadrangle, the sandstone in the lower part of the unit encloses thin irregular and lenticular beds of impure coal. The basal beds in that area commonly fill small channels and generally overlie a thin coal bed. In the vicinity of the Eastern Knoxville anticline, in the subsurface, sandstone unit C is also overlain by a thin bed of coal. The siltstone of the unit in the report area is medium to dark gray, argillaceous to sandy, micaceous, and irregular bedded. The shale is dark gray to grayish black, micaceous, and partly carbonaceous and coaly.

The boundaries of unit C are probably not exactly equivalent throughout the report area. In parts of the area unit C seems to include several overlapping sandstone units that have sharp lower boundaries and either fill irregular channels in the underlying rocks or change facies laterally. These sandstone units, at least in the northern part of the report area, were probably deposited in a succession of laterally migrating channels. Current directions were determined from crossbedding and ripple marks in unit C at five localities in the northeastern part of the Knoxville quadrangle. The six measurements obtained at those localities range from S. 60° E. to S. 60° W. and average S. 14° W.; the median direction is between S. 20° W. and S. 35° W.

Invertebrate fossils are sparse in the Atoka of the report area and nearly all of those found were in the upper and lower parts of the formation. Crinoid columnals were observed in sandstone penetrated by well 32 at depths of 5,917 feet (in unit 98) and 6,820 feet (basal sandstone) in the lower part of the Atoka. In the upper part of the formation some of the sandstone units and a thin limestone yield gastropods, crinoids, ostracodes, and bryozoans. Shale units in the upper part of the Atoka infrequently contain pelecypods, gastropods, brachiopods, and crinoids.

Plant fossils occur sporadically in the upper part of the Atoka, and small scattered fragments of plants are a common constituent of most of the rocks. Casts of wood have been observed in sandstone, and fossil leaves occur rarely in shale.

The succession of lithologic units in the Atoka reflect alternating shoreward and seaward migrations of environments of deposition on the flank of a downwarping marine basin. The slight differences between the lower, middle, and upper parts of the formation probably resulted mostly from different rates of basin subsidence and amounts of incoming sediments. Marine rocks are clearly represented by the sandstone, shale, and limestone containing marine fossils; nonmarine rocks are represented by the channel filling sandstone of unit C, the few beds of coal, and perhaps some other sandstone beds. The depositional environments of the lower and upper parts of the formation below the top of zone 83 and above zone 67, respectively, were probably similar but were different from those of the rocks in the middle part between the tops of zones 83 and 67.

The sandstone units in the middle part of the Atoka, which are widespread, thick, and have gradational lower contacts, were probably deposited in shallow marine or brackish water during periods of marine regression. The pronounced southward thickening and the presence of distinctive sandstone units in the middle part of the Atoka are evidence of a period of generally greater, but possibly intermittent, subsidence in the depositional basin during middle Atoka time. The sandstone units with sharp lower contacts, such as unit C of the upper part of the Atoka, were probably deposited in fluvial or deltaic environments. Sandstone unit C, however, is overlain and underlain by shale units that contain marine fossils at a few localities and consequently represents only a temporary or local withdrawal of the sea.

DES MOINES SERIES, KREBS GROUP

The Krebs Group includes, from oldest to youngest, the Hartshorne Sandstone and the McAlester, Savanna, and Boggy Formations. The Hartshorne Sandstone, McAlester Formation, and a lower part of the Savanna Formation occur in the Knoxville and Delaware quadrangles. The boundaries of these formations were either mapped into this area from the New Blaine quadrangle to the west (Haley, 1968) or were determined from well-log correlations. The boundary between the Kerbs Group and the underlying Atoka Formation is the base of the Hartshorne Sandstone and probably is a disconformity.

Rocks of the Krebs Group are very similar to some of the rocks in the upper part of the Atoka, and where faults are abundant, the formations are hard to tell apart. In particular, sandstone unit C of the Atoka Formation, the Hartshorne Sandstone, and the basal sandstone unit of the Savanna Formation have many characteristics in common.

HARTSHORNE SANDSTONE

The Hartshorne Sandstone in the report area is about 50–200 feet thick. It crops out in large areas in the southern part of the Knoxville quadrangle and in the Delaware quadrangle, and has been penetrated by many of the wells drilled for gas. The resistance to erosion of the Hartshorne has resulted in the development of synclinal valleys, as along the eastern part of the Clarksville syncline, and anticlinal ridges, as along the western part of the Prairie View anticline. The structure contour lines shown on plate 4 of this report are drawn on the base of the Hartshorne Sandstone.

Some of the rocks that I earlier reported to be in the Hartshorne Sandstone (Merewether, 1967), in secs. 28, 29, and 30, T. 9 N., R. 22 W., in secs. 18 and 19, T. 9 N., R. 21 W., and in secs. 13, 23, and 24, T. 9 N., R. 22 W., I now believe, on the basis of additional subsurface information, to be in the Savanna and McAlester Formations.

The thickness of the Hartshorne exceeds 190 feet at wells 20 and 39 on the flanks of the Eastern Knoxville anticline and in the area of well 14 on the Dover anticline; it is about 50 feet at well 17 and in the SW¼ sec. 9, T. 9 N., R. 22 W.; and it is probably less than 50 feet in secs. 5 and 6, T. 9 N., R. 22 W.

The Hartshorne is mostly sandstone, but it contains a few units of medium- to dark-gray argillaceous micaceous siltstone and medium-to dark-gray silty micaceous shale. The sandstone is very light to medium gray, very fine to medium grained, partly silty, and at places contains scattered coarse and very coarse sand grains. The sandstone, where exposed, is laminated to thick bedded, generally irregular bedded, and some is cross stratified and ripple laminated. At several places sandstone in the lower part of the formation contains shale pebbles and irregular stringers of coal. The lower contact of the basal sandstone is sharp and outlines shallow channels in the underlying Atoka.

Only plant fossils were found in the Hartshorne. Pieces of roots, trunks, and branches probably from sigillaria and lepidodendron are common in the formation.

The Hartshorne Sandstone in this area must have been deposited in a laterally migrating channel that perhaps was cut by a stream or streams. Current directions were determined from crossbedding and ripple marks in the sandstone at six localities. The seven measurements obtained at these localities range from S. 10° E. to S. 65° W. and average S. 16° W.; the median direction is south. Thin lenticular beds of coal in the Atoka underlie the Hartshorne at a few places, and the Lower Hartshorne coal bed of the McAlester Formation commonly overlies the Hartshorne. Apparently, the fluvial environment of the Hartshorne was preceded by a nearshore paludal environment and was followed by a longer lasting swamp or marsh environment.

MCALESTER FORMATION

The McAlester Formation consists mostly of shale, but it contains some siltstone and sandstone, and a few beds of coal. It conformably overlies the Hartshorne Sandstone and ranges in thickness from 500 to 800 feet. The McAlester is exposed in the large synclines south of the Clarksville fault, and has been penetrated by several wells in the report area.

The distribution of the McAlester Formation in the Knoxville quadrangle as I reported earlier (Merewether, 1967, pl. 1) has been revised on the basis of subsurface information. Rocks in secs. 18 and 19, T. 9 N., R. 21 W., and in secs. 13, 23, and 24, T. 9 N., R. 22 W., previously assigned to the Hartshorne, are now considered part of the McAlester (p. B11). Most of the rocks in secs. 17–21, T. 9 N., R. 22 W., and some of the rocks in secs. 31–33, T. 9 N., R. 22 W., formerly classified with the McAlester, I now believe to be part of the Savanna Formation.

Thickness measurements of the McAlester Formation in the Knoxville and Delaware quadrangles are sparse. The logs of wells 17, 21, 35, and 42, supplemented by logs from the Clarksville quadrangle to the west, indicate that the formation is 500–540 feet thick. In the southern part of the Delaware quadrangle, the McAlester is as much as 800 feet thick, as indicated by scattered surface sections. In the Scranton and New Blaine quadrangles (Haley, 1968), west of the Delaware quadrangle, it is about 680–900 feet thick.

The McAlester consists of shale interstratified with a few units of siltstone and sandstone and a few beds of coal. The shale is medium gray to dark gray, partly silty, micaceous, and commonly contains ironstone concretions and fossil plant fragments. Units of shale are as much as 130 feet thick. The siltstone is medium gray to dark gray and micaceous. Units of siltstone are laminated, ripple laminated, and irregularly bedded, and generally less than 2 feet thick. The sandstone is light gray to medium gray, very fine to fine grained, silty, micaceous, and contains fossil plant fragments. At a few localities the sandstone encloses pebbles of shale. Units of sandstone are laminated to thick bedded, irregularly bedded, cross stratified, ripple laminated, contorted, and generally have sharp lower contacts. Sandstone units are as much as 30 feet thick and grade laterally into siltstone units. Coal occurs in the lower and upper parts of the formation. The Lower Hartshorne coal bed is about 15 feet above the base of the McAlester and is as much as 25 inches thick in sec. 6, T. 9 N., R. 22 W. It thins southward and is 5 inches thick in sec. 25, T. 9 N., R. 22 W., about 1 inch thick in sec. 24, T. 8 N., R. 22 W., and absent south of the Arkansas River. Two coal beds, about 9 inches and 1 inch thick, crop out in sec. 29, T. 8 N., R. 21 W., within the upper 60 feet of the McAlester Formation. These beds may be equivalent to coaly shale near the base of the Savanna Formation in the NW¼NW¼ sec. 33, T. 9 N., R. 22 W.

Plant fossils are common, and invertebrate fossils are sparse in rocks of the McAlester. The shale above the Lower Hartshorne coal bed contains well-preserved plant fossils at several localities, and in the NE¼ sec. 7, T. 9 N., R. 22 W., it contains the leaves of sigillaria, lepidodendron, and ferns. Poorly preserved brachiopods, trilobites, and crinoids were collected from an iron-rich sandstone in the lower part of the formation on a small hill in the SW¼NW¼ sec. 20, T. 8 N., R. 21 W.

The depositional environments of the McAlester Formation were probably similar to those of the upper Atoka and included both shallow-water marine and continental. The coal, abundance of plant remains, paucity of invertebrate fossils, and stratification in the McAlester are evidence that deposition occurred mainly in continental and nearshore environments.

SAVANNA FORMATION

Only a lower part of the Savanna Formation is in the mapped area. These rocks consist of shale, siltstone, sandstone, and coal, and are as much as 230 feet thick. The Savanna and the underlying McAlester intertongue in some areas, but locally they are separated by a disconformity. The formation is most complete on the southern flank of the Clarksville syncline in secs. 20 and 21, T. 9 N., R. 22 W., but it also crops out in secs. 28–33, T. 9 N., R. 22 W., and in sec. 29, T. 8 N., R. 21 W. Well 17 is approximately on the top of the basal sandstone unit of the Savanna.

The Savanna Formation in the Knoxville quadrangle was previously reported to be the Hartshorne Sandstone and part of the McAlester Formation (Merewether, 1967, p. 8, 9, pls. 1, 2). Some of the rocks exposed in sec. 36, T. 9 N., R. 23 W., in sec. 31, T. 9 N., R. 22 W., and in the E½ secs. 18 and 19, T. 9 N., R. 22 W., of the adjacent Clarksville quadrangle were assigned to the McAlester Formation (Merewether and Haley, 1969, pl. 1), but they are now believed to be in the Savanna. Information obtained from gas wells, drilled since completion of these earlier studies, has permitted a more certain identification of these rocks.

In the report area the Savanna comprises, in ascending order, a unit mainly of sandstone as much as 120 feet thick, a unit mostly of shale about 70 feet thick, and a sandstone unit about 40 feet thick. The rocks in the two upper units are described in detail by Merewether (1967, p. 21, sec. H), but they were incorrectly assigned to the McAlester Formation. The upper sandstone is exposed in the W½ sec. 20, T. 9 N., R. 22 W., and is medium gray, very fine to fine grained, very thin bedded to thin bedded, and horizontally stratified to irregular. The underlying shale unit is medium gray to grayish black, partly silty, and contains ironstone concretions and a few very thin beds of claystone. Two coal beds were observed in the lower part of the shale unit. The lower coal is as much as 12 inches thick; the upper coal is about 2 inches thick.

The basal sandstone of the Savanna contains beds of siltstone, shale, and minor amounts of conglomerate and coal. It is laterally gradational and locally intertongues with underlying rocks, but generally it has a sharp lower contact. The sandstone is light gray to medium gray, very fine to medium grained, partly silty, micaceous, and contains plant fragments and shale pebbles at some localities. It is laminated to thin bedded, mostly flat bedded to irregular, and locally cross stratified and ripple laminated. The siltstone is light gray to medium gray, partly sandy, micaceous, laminated to very thin bedded, irregularly bedded, and cross stratified and ripple laminated in places. Shale in the basal unit is medium gray to dark gray, silty, micaceous, and contains plant fragments and bedding flow features. A lenticular bed of conglomerate crops out in the SE¼ sec. 28, T. 9 N., R. 22 W., at the base of the Savanna. The bed is as much as 27 inches thick and about one-fourth mile long and consists of ironstone pebbles. Coal in irregular lenticular beds as much as 2 inches thick and 3 feet long was observed near the base of the formation in the same area. Current directions were determined from crossbedding and ripple marks in the basal sandstone at four localities in the southwestern part of the Knoxville quadrangle. The six measurements obtained at these localities range from S. 55° E. to N. 80° W. and average S. 22° W.; the median direction is between south and S. 45° W.

The basal contact of the Savanna Formation is generally sharp in the area of this report. In the NW¼ sec. 28, T. 9 N., R. 22 W., the lower part of the formation fills channels in the underlying McAlester, and the lower surface of the sandstone at the contact has well-developed current flow casts, including flute casts and groove casts that indicate a current direction of N. 80° W. At this locality many irregularly shaped small plates of shale and siltstone are imbedded parallel to bedding planes in the basal sandstone; a small lens of coal separates the sandstone from the shale below. In the SE¼ sec. 28, T. 9 N., R. 22 W., much of the lower sandstone unit of the Savanna is ripple-laminated siltstone, which at one place overlies a thin basal conglomerate and at another place is interbedded with the conglomerate. A thin lens of coal crops out along the formation boundary at one exposure in this area.

Small carbonaceous and coaly fragments of plants are a common constituent of the Savanna Formation, but large plant fossils and invertebrate fossils were not found in the report area.

The depositional environment of the Savanna in the mapped area was probably much like that of the Hartshorne and lower part of the McAlester. The thick basal sandstone unit fills channels in the underlying rocks and is overlain by a coal bed which, in turn, is overlain by a thick unit of mostly dark-gray shale. A possibly fluvial environment, represented by the sandstone, was succeeded by a coastal swamp, in which the coal originated, and by a mainly paludal environment, represented by the shale. Sparse evidence from the south half of the Hartman quadrangle (Merewether and Haley, 1969, p. C20) indicates that the depositional environment of the lower part of the basal sandstone may change to marine in a westerly direction.

QUATERNARY SYSTEM

TERRACE DEPOSITS

Pleistocene deposits of alluvial material are on terraces at two levels along the Arkansas River and on terraces at several levels along the larger streams in the area. The levels of terrace deposits have not been differentiated on plate 1, but the deposits of the river are shown separately from those of the tributary streams.

The terrace surfaces along the river were about 40 and 50 feet above the normal water level before construction of the Dardanelle Dam downstream. The deposits consist of clay, silt, sand, and pebbles and cobbles of sandstone, which are partly of local origin, and pebbles and cobbles of quartz, quartzite, granite, and chert from a distant source.

As many as five terrace levels are present along the larger tributary streams. The highest of these is about 280 feet above alluvium of Holocene age and is exposed in the NE¼ sec. 32, T. 10 N., R. 22 W. The materials in terrace deposits of the streams are probably of local origin and consist of clay, silt, sand, and pebbles, cobbles, and boulders of siltstone and sandstone.

Some of the terrace deposits at intermediate levels in the report area are probably equivalent to terrace deposits near Fort Smith, Ark. (Hendricks and Parks, 1950, p. 78), which were correlated with the Pleistocene Gerty Sand of Oklahoma (Miser, 1954). The uppermost deposits along streams in the area of this report may be older than any described by Hendricks and Parks in the Fort Smith district.

ALLUVIUM

The Holocene alluvium deposited by the Arkansas River is shown separately from the alluvium of tributary streams and creeks on plate 1. Along the river the alluvium is more than 20 feet thick and consists of clay, silt, sand, and gravel. The alluvium of the tributaries is mostly thinner and is composed of clay, silt, sand, and pebbles and cobbles of shale, siltstone, and sandstone. As mapped on plate 1, the stream alluvium includes the lowest adjacent terrace deposit in a few places where the area of the terrace deposit is small, and the difference in elevation of the two deposits is slight.

STRUCTURE

The Knoxville and Delaware quadrangles are near the center of the Arkansas Valley section of the Ouachita province (fig. 1). Rocks in these quadrangles are deformed by generally west-trending discontinuous folds and normal faults (pls. 1, 4). The synclines and anticlines have irregularly curved troughlines and crestlines, low dips, and are symmetrical in cross section. The surface traces of the faults are irregularly curved, and the fault planes dip either generally north or south. The structural relief in the area is about 2,800 feet, as measured on the base of the Hartshorne Sandstone from a low point on the axis of the Ouita syncline, in sec. 18, T. 8 N., R. 22 W., to the highest point on the flank of an anticline in sec. 19, T. 7 N., R. 21 W. Joints observed in the two quadrangles strike either between north and N. 10° W. or between east and N. 80° E., and most of the joints are vertical.

SYNCLINES

The major synclines in the area are, from north to south, the Clarksville, the Ouita, and the Paris. Smaller synclines are north of the Arkansas River and include the south end of the Hagarville syncline, several unnamed synclines, and the Piney syncline.

ANTICLINES

The major anticlines are, from north to south, the Dover anticline, the discontinuous Knoxville anticline, and the Prairie View anticline. The crest of the large Pine Ridge anticline is slightly south of the mapped area. Minor unnamed anticlines occur in the northeastern part of the Knoxville quadrangle, and the London anticline is in the northeastern part of the Delaware quadrangle.

FAULTS

The surface traces of all faults in the report area are north of the crest of the Prairie View anticline. Generally, the faults could be located on the surface where contacts between rock units are apparently displaced; they were extended between these locations on the basis of topography. The existence and approximate surface location of concealed faults can commonly be confirmed by projection from gas wells in which faults have been found. The faults are normal, and most of the fault planes dip southward. North-dipping fault planes are generally interpreted as terminating in the subsurface against the first south-dipping fault plane encountered. Fault planes are rarely exposed, but at two localities they dip 51° and 58°; fault planes that could be located on the surface and that were intercepted in wells commonly dip 35°–45°. The fault planes are depicted on plate 3 as being straight; but, in reality, they are probably locally irregular, and their average dip may decrease with depth.

In this report the term "displacement" is used for the stratigraphic throw. The amount of movement along the fault plane is everywhere greater than the amount of stratigraphic throw. The displacement of most of the faults seems to be less at the surface than in the subsurface (Merewether and Haley, 1969, p. C22). This difference in the amount of displacement is probably a consequence of movement penecontemporaneous with deposition of the displaced rocks, but it could result from the downward addition of the displacements of smaller intersecting faults. In the Van Buren and Lavaca quadrangles, in the Arkansas Valley west of the area of this report, Haley and Hendricks (1971) concluded "that faulting was occurring * * * during the deposition of the Atoka." The approximate displacements of many of the faults, where penetrated by gas wells, are given in table 2.

Clarksville fault.—The Clarksville fault is a major south-dipping fault that trends across the northern part of the report area. It is best exposed near the center of sec. 8 and in the SW¼ sec. 5, T. 9 N., R. 21 W. The displacement along this fault, at the surface, decreases from west to east, from a maximum of 1,400–1,500 feet in secs. 31 and 32, T. 10 N., R. 22 W. to less than 50 feet in sec. 8, T. 9 N., R. 21 W. Where the fault is penetrated by wells 4–6, the displacements are interpreted to be 1,700, 1,700, and 1,380 feet, respectively.

Big Piney Creek fault.—The south-dipping Big Piney Creek fault probably branches from the Clarksville fault in sec. 5, T. 9 N., R. 22 W., and divides into several faults to the southeast. These component faults rejoin in sec. 11, T. 9 N., R. 22 W., and to the east beyond the boundary of the area the Big Piney Creek fault is rejoined by the Clarksville fault. The Big Piney Creek fault plane can be observed in the NE¼ sec. 18, T. 9 N., R. 21 W. and in the SE¼ SE¼ sec. 11, T. 9 N., R. 22 W. The eastward decrease in the displacement of the Clarksville fault may be related to the eastward increase in the displacement of the Big Piney Creek fault system. At the surface the maximum displacement of the Big Piney Creek fault is about 700 feet in sec. 12, T. 9 N., R. 22 W. and sec. 18, T. 9 N., R. 21 W. The fault system, where intersected by wells 13–16, has total displacements of 425, 800, 950, and 1,260 feet, respectively. The large total displacement in well 16 could include the displacement of faults not elsewhere included in the Big Piney Creek system.

Big Danger fault.—The Big Danger fault extends within the area from sec. 19, T. 9 N., R. 22 W., on the western boundary of the area, to sec. 36, T. 9 N., R. 22 W., where it terminates. It can be located on the surface most accurately in the N½ sec. 28, T. 9 N., R. 22 W. Most of the fault was previously named the "Hickeytown fault" (Merewether, 1967) and was incorrectly interpreted as dipping north. Mapping and subsurface studies in the adjoining Clarksville quadrangle to the west and the log of well 17 provide evidence that this fault is the Big Danger fault of nearby areas (Merewether and Haley, 1969, p. C24) and that it dips south. In the area of this report the maximum displacement at the surface is about 260 feet in sec. 27, T. 9 N., R. 22 W.

A northwest-dipping fault branching from the Big Danger fault in sec. 27, T. 9 N., R. 22 W., extends northeast and joins the Big Piney Creek fault east of the report area. The surface trace is most accurately located in sec. 19, T. 9 N., R. 21 W. and sec. 24, T. 9 N., R. 22 W. The greatest displacement at the surface is about 200 feet in sec. 24, T. 9 N., R. 22 W.

Regan Mountain fault.—The surface trace of the Regan Mountain fault crosses the central part of the area, from the S½ sec. 30, T. 9 N., R. 22 W. to sec. 6, T. 8 N., R. 21 W., where it joins the London fault. The fault is best exposed in the N½ sec. 33, T. 9 N., R. 22 W. and the E½ sec. 1, T. 8 N., R. 22 W. Part of this fault was previously named the "Simmons Creek fault" (Merewether, 1967), but additional information obtained in the Clarksville quadrangle and evidence from well logs in the area of this report support the present revision of the name and location. The fault plane dips south, and the maximum surface displacement is about 200 feet, in sec. 33, T. 9 N., R. 22 W. In well 21 the displacement is about 385 feet. The fault is probably represented by two fault planes in well 22 that have a total displacement of about 310 feet. The displacements in wells 23 and 31–33 are about 165, 80, 125, and 120 feet, respectively.

Other faults.—A north-dipping fault, located north of the Regan Mountain fault and south of the east end of the Big Danger fault, extends east from sec. 34, T. 9 N., R. 22 W. to the boundary of the mapped area in sec. 5, T. 8 N., R. 21 W. It can be observed in the N½ sec. 35, T. 9 N., R. 22 W. At the surface the greatest displacement is about 200 feet, in sec. 36, T. 9 N., R. 22 W.; in the subsurface the displacements at wells 20 and 27 are about 130 and 90 feet, respectively.

A fault located south of the Regan Mountain fault and north of the crest of the Knoxville anticline extends from the boundary of the report area in sec. 31, T. 9 N., R. 22 W. to the London fault in sec. 1, T. 8 N., R. 22 W. It is most accurately located on the surface in the S½ sec. 33, T. 9 N., R. 22 W. and near the center of sec. 1, T. 8 N., R. 22 W. The fault plane dips south, and the maximum displacement along its surface trace is about 130 feet, in the SE¼ sec. 33, T. 9 N., R. 22 W. Where penetrated by wells 30–32 and 38, the displacement is about 190, 160, 20, and 245 feet, respectively.

The London fault extends from the NE¼ sec. 16, T. 8 N., R. 22 W., where the plane dips 58° SE. to the east boundary of the mapped area in sec. 5, T. 8 N., R. 21 W. The fault plane generally dips southward, and the maximum surface displacement is about 200 feet, in sec. 5, T. 8 N., R. 21 W. The fault, where intersected by wells 39–41, has displacements of about 150, 225, and 500 feet, respectively.

Three faults extend into the Knoxville quadrangle from the west, between the trough of the Ouita syncline and the crest of the Prairie View anticline. The northernmost of the three, the Dublin fault, dips south and has a maximum displacement of about 140 feet. The Shoal Creek fault dips north, and its greatest displacement is about 200 feet. The southernmost of the three faults dips 51° S., where exposed in sec. 30, T. 8 N., R. 22 W., and has a maximum displacement at the surface of about 50 feet, in sec. 22, T. 8 N., R. 22 W. Where penetrated by wells 44 and 46, the fault has displacements of about 460 and 480 feet, respectively.

ECONOMIC GEOLOGY

COAL

Coal was observed in all the formations that crop out in the area of this report, but most of the coal beds are impure, thin, and of local extent. Only the Lower Hartshorne coal bed of the McAlester Formation is more than 14 inches thick. The location, thickness, and mined areas, where known, of all exposed coal beds are shown on plate 4. Descriptions of these beds are presented by Merewether and Haley (1961, p. 11) and Merewether (1967, p. 12–13). The rank of the coal ranges from low-volatile bituminous, in the northeastern part of the Knoxville quadrangle, to semianthracite in the remainder of the area (Haley, 1960, pl. 62).

A widespread coal bed in the Atoka Formation has been mined in the N½ sec. 29, T. 10 N., R. 22 W., but reserves were not calculated because the bed is less than 14 inches thick. A bed of coal exposed beneath sandstone unit C of the Atoka Formation, in the northeastern part of the Knoxville quadrangle, is as much as 7 inches thick. A coal bed as much as 9 inches thick was observed in the upper part of the McAlester Formation in sec. 29, T. 8 N., R. 21 W., and a bed of coal as much as 12 inches thick overlies the basal sandstone of the Savanna in sec. 20, T. 9 N., R. 22 W.

The lower Hartshorne coal bed of the McAlester Formation is stratigraphically less than 15 feet above the Hartshorne Sandstone. In the area of this report it is as much as 25 inches thick, and has been explored and mined along the flanks of the Dover anticline in secs. 5, 6, 7, 8, 9, and 16, T. 9 N., R. 22 W. Where the lower part of the McAlester Formation is exposed in other parts of the report area, the coal bed is either very thin or absent. In sec. 24, T. 8 N., R. 22 W., it is about 1 inch thick, and in sec. 25, T. 9 N., R. 22 W., it is 5 inches thick.

Where the bed is 14 inches or more thick, in the western part of the Knoxville quadrangle (pl. 4), it underlies an area of about 2,500 acres. The overburden ranges in thickness from a featheredge to about 660 feet in the S½ sec. 18, T. 9 N., R. 22 W. Within the area enclosed by the 14-inch coal thickness line, the Lower Hartshorne coal bed contains an estimated 900,000 short tons of measured reserves, 1,400,000 short tons of indicated reserves, and 5,700,000 short tons of inferred reserves. The small amount of coal mined in this area during past years does not reduce these reserve estimates significantly. The reserves were determined in accordance with the standards and procedures adopted by the U.S. Geological Survey (Averitt, 1969, p. 14–31).

OIL AND GAS

Crude oil has not been found in or near the area of this report, but rocks older than Early Pennsylvanian have not been tested. Natural gas has been discovered in reported initial potential amounts exceeding 1 million cubic feet per day (table 2) in 27 of the 47 wells in the area. The total reported initial potential production of gas from all wells in the area (Oct. 31, 1967) is about 248.3 million cubic feet per day. The gas is in the Atoka, mainly in the middle and lower parts of the formation. Rocks of the Morrow Series contain gas in the adjacent Clarksville quadrangle (Merewether and Haley, 1969), but they have been only partially tested and are not yet productive in the Knoxville and Delaware quadrangles.

The shape of the gas fields, shown on plate 4, is a composite of the arbitrarily defined gas-producing areas surrounding the wells in the field. The gas-producing areas of the wells are delimited on the gas-bearing bed in the subsurface. A well is assumed to produce gas from the area within half a mile of the well, unless this area is crossed by a fault.

In the Hagarville and Ross fields, in the northern part of the Knoxville quadrangle, most of the gas is produced from sandstone units in the lower part of the Atoka (below the top of zone 83). In the Knoxville field, in the middle of the report area, all the gas is produced from the sandstone of zone 67 (the Tackett sand of drillers) in the middle part of the Atoka. However, beds below the Tackett sand have not been thoroughly explored in the Knoxville field. On the Prairie View anticline, near the middle of the Delaware quadrangle, two wildcat wells penetrated most of the sandstone units that produce gas in wells to the north. Both wells are commercially "dry," but in well 46 a small amount of gas was reported to be in the upper part of the Atoka. In the southeastern part of the Delaware quadrangle, well 47 was located slightly north of the crest of the large Pine Ridge anticline. The well was started in the upper part of the Atoka, stratigraphically about 1,600 feet below the Hartshorne, and was completed in the Morrow Series. A small amount of gas was recovered from a sandstone in the middle of the Atoka (probably the Tackett sand), but none was found in other units.

Nearly all the natural gas discovered in the report area is in two parts of the Atoka. The sandstone in zone 67, in the middle of the formation, and the first three sandstone units below the top of zone 98, in the lower part of the formation, are the source of 99 percent of the total reported gas. The many sandstone units above zone 67 have been adequately tested in much of the area and contain very little gas, although their lithology and structural setting at several places appears to be favorable. Most of the sandstones in the middle and lower parts of the Atoka, where explored, are nonproductive.

The natural gas is apparently concentrated mainly in anticlinal traps, fault traps, and combinations of both. However, the lithologies of the reservoir beds are not laterally consistent, and the relative porosity and permeability of parts of the beds also influences the location of the gas. In the Van Buren and Lavaca quadrangles to the west, Haley and Hendricks (1971) suggested that most of the gas in the Atoka was lithologically entrapped.

The major anticlines and several potential fault traps have been partly explored. Additional gas will probably be found in rocks of the Atoka and Morrow Series in anticlines, fault traps, and in locally porous parts of beds outside the area of structural traps.

BUILDING STONE

The Hartshorne Sandstone on the flanks of the Piney syncline and London and Prairie View anticlines is commonly very thin to thin bedded, and the beds are locally tabular. The sandstone has been extensively quarried for flagstone, but abundant potential building stone probably remains in these areas. Additional flagstone may be found where the Hartshorne and sandstone unit C of the Atoka are exposed in the southeastern part of the Delaware quadrangle. Building stone has also been obtained from small quarries in the Savanna Formation, in the NE¼ sec. 30, and the SW¼ sec. 20, T. 9 N., R. 22 W., and in the Atoka Formation, in the NE¼ sec. 11, T. 9 N., R. 22 W.

ROAD METAL

In the report area, road metal consists mainly of crushed sandstone and gravel. The sandstone is commonly obtained from thick well-cemented beds near the construction sites. Gravel can generally be obtained from the alluvium and terrace deposits along the Arkansas River and the major streams.

GRAVEL, SAND, AND CLAY

Gravel and sand are abundant in the alluvium and terrace deposits of the area but are possibly more concentrated and more accessible in the terrace deposits and stream alluvium. The river alluvium at the surface consists mainly of very fine sand, silt, and mud. Clay can be obtained from the alluvium and terrace deposits, but it generally contains less sand and is more readily available in the many exposures of shale in the Atoka and McAlester Formations.

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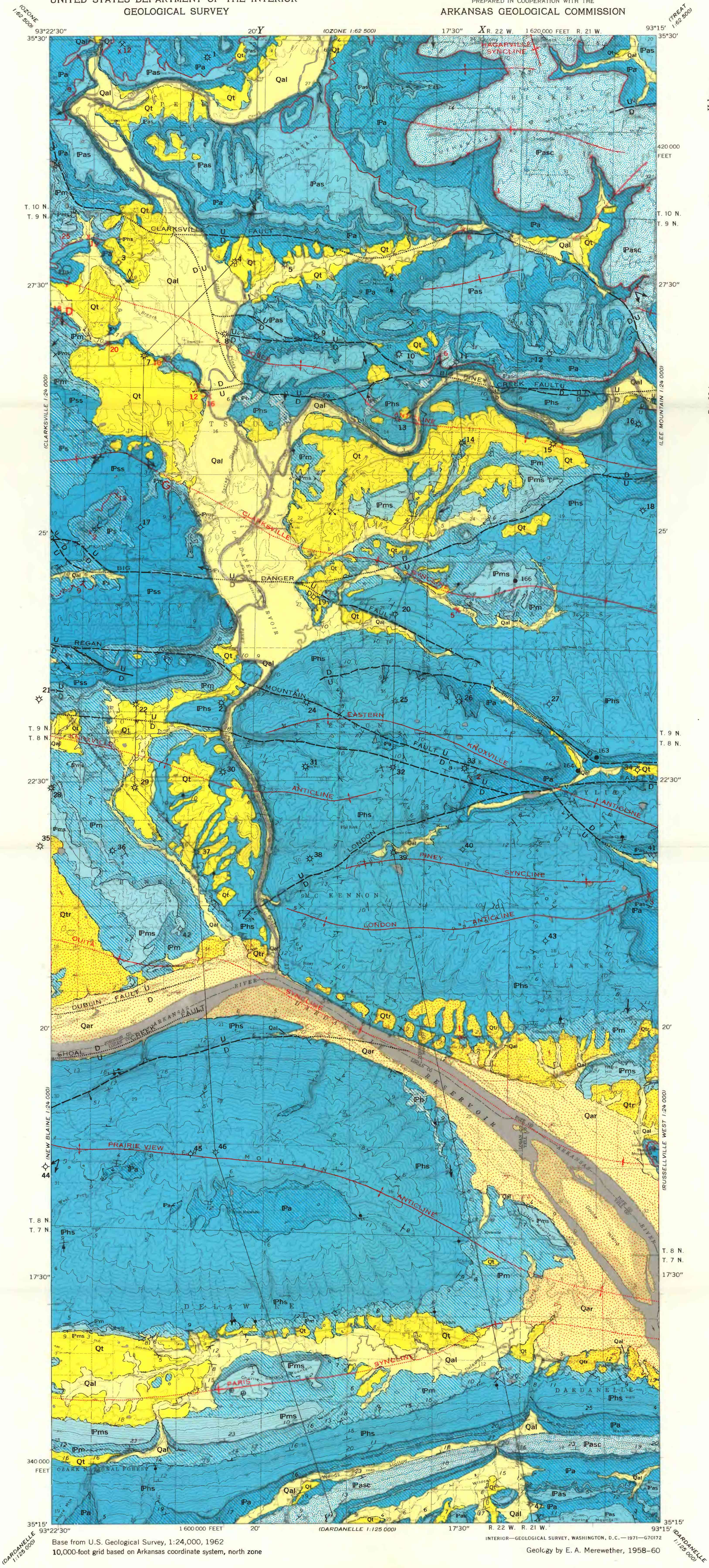


Base from U.S. Geological Survey, 1:24,000, 1962
10,000-foot grid based on Arkansas coordinate system, north zone

INTERIOR—GEOLOGICAL SURVEY, WASHINGTON, D.C.—1971—G70172

Geology by E. A. Merewether, 1958–60

GEOLOGIC MAP OF KNOXVILLE AND DELAWARE QUADRANGLES, JOHNSON AND LOGAN COUNTIES AND VICINITY, ARKANSAS

SCALE 1:48 000

1 ½ 0 1 2 3 MILES

1 .5 0 1 2 3 KILOMETERS

CONTOUR INTERVAL 20 FEET
DATUM IS MEAN SEA LEVEL

EXPLANATION

QUATERNARY

Holocene

Qal / Qar

Alluvium

Deposits along stream channels. In some places includes parts of lowermost terrace
Qal, *stream alluvium*
Qar, *river alluvium*

Pleistocene

Qt / Qtr

Terrace deposits

Alluvial deposits on several terrace levels
Qt, *stream terrace deposits*
Qtr, *river terrace deposits*

UNCONFORMITY

CARBONIFEROUS — PENNSYLVANIAN

Des Moines — Krebs Group

IPs / IPss

Savanna Formation

Alternating units of predominant shale or predominant sandstone
IPs, *shale, siltstone, and thin beds of sandstone*
IPss, *sandstone, silty sandstone, or interbedded sandstone, siltstone, and shale*

IPm / IPms

McAlester Formation

Alternating units of predominant shale or predominant sandstone
IPm, *shale, siltstone, and thin beds of sandstone*
IPms, *sandstone, silty sandstone, or interbedded sandstone, siltstone, and shale*

IPh / IPhs

Hartshorne Sandstone

Predominantly sandstone but with intercalated shale and siltstone in some places
IPh, *shale, siltstone, and thin beds of sandstone*
IPhs, *sandstone, silty sandstone, or interbedded sandstone, siltstone, and shale*

Atoka

IPa / IPas / IPasc

Atoka Formation

Alternating units of predominant shale or predominant sandstone
IPa, *shale, siltstone, and thin beds of sandstone*
IPas, *sandstone, silty sandstone, or interbedded sandstone, siltstone, and shale*
IPasc, *sandstone unit C; sandstone, silty sandstone, or interbedded sandstone, siltstone, and shale*

Contact
Dashed where approximately located

58 D U

Fault, showing dip
Dashed where approximately located; dotted where concealed. U, upthrown side; D, downthrown side

Anticline
Showing crestline. Dotted where concealed

Syncline
Showing troughline. Dotted where concealed

10

Inclined — Horizontal
Strike and dip of beds
Symbols shown in areas of alluvial deposits were measured on bedrock exposures too small to be shown on this map

Inclined — Vertical — Horizontal
Strike and dip of joints

Direction of flow of Pennsylvanian depositional current
Based on measurements of dips of crossbedding and orientation of ripple marks in sedimentary rocks

Shale sample locality

Coal bed
Dashed where approximately located

x10
Exposure of coal bed
Number is thickness of coal, in inches

12
Surface opening to coal bed
Number is thickness of coal, in inches

166
Shallow hole
Number designates hole listed in table 3 in text

Strip mine or quarry

Gravel or shale pit

X——X'
Line of structural section shown on plate 3

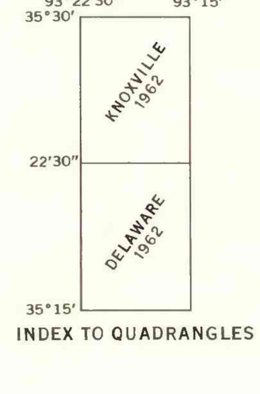
D
Measured stratigraphic section shown on plate 2

38
Gas producing

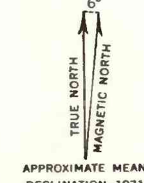
46
Show of gas

6
No show of gas

Wells
Number designates well described in table 2 in text



INDEX TO QUADRANGLES



APPROXIMATE MEAN DECLINATION, 1971

UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

PREPARED IN COOPERATION WITH THE
ARKANSAS GEOLOGICAL COMMISSION

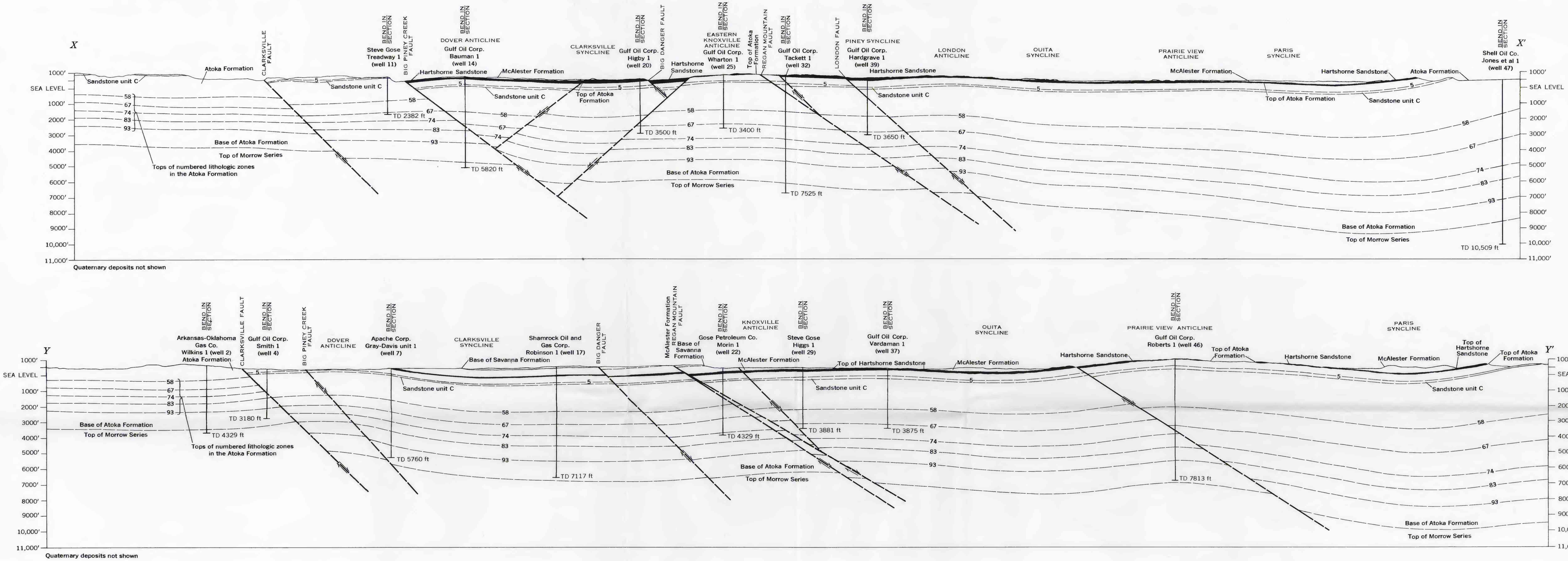
PROFESSIONAL PAPER 657–B
PLATE 2

STRATIGRAPHIC SECTIONS IN OR NEAR KNOXVILLE AND DELAWARE QUADRANGLES,
JOHNSON AND LOGAN COUNTIES AND VICINITY, ARKANSAS

UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

PREPARED IN COOPERATION WITH THE
ARKANSAS GEOLOGICAL COMMISSION

PROFESSIONAL PAPER 657-B
PLATE 3



STRUCTURAL SECTIONS IN KNOXVILLE AND DELAWARE QUADRANGLES, JOHNSON AND LOGAN COUNTIES AND VICINITY, ARKANSAS

SCALE 1:48 000

1 ½ 0 1 2 MILES

1 .5 0 1 2 KILOMETERS

UNITED STATES DEPARTMENT OF THE INTERIOR
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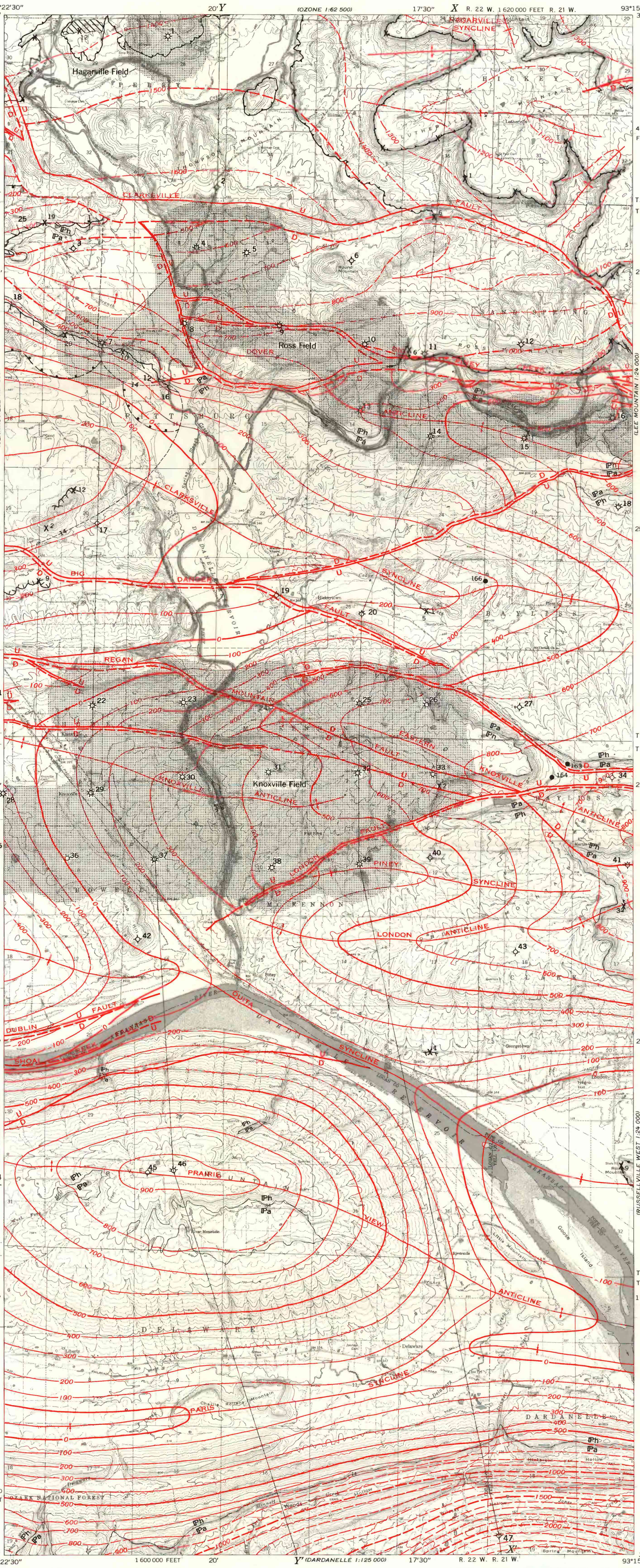
PROFESSIONAL PAPER 657-B
PLATE 4



Base from U.S. Geological Survey, 1:24,000, 1962
10,000-foot grid based on Arkansas coordinate system, north zone

INTERIOR—GEOLOGICAL SURVEY, WASHINGTON, D.C.—1971—G70172
Geology by E. A. Merewether, 1958–60

EXPLANATION

Symbols in red indicate data on contoured horizon

Structure contours
Drawn on base of Hartshorne Sandstone. Dashed where projected above surface. Contour interval 100 feet

Trace of synclinal axis

Trace of anticlinal axis

Fault
Dashed on downthrown block.
U, upthrown side; D, downthrown side

Surface trace of contact between Hartshorne Sandstone (IPh) and Atoka Formation (IPa)

Line of structural section shown on plate 3

COAL BEDS

Unnamed coal bed in Savanna Formation

Unnamed coal bed in McAlester Formation

Lower Hartshorne coal bed

Unnamed coal beds in Atoka Formation

Exposure of coal
Number is thickness of coal, in inches

Surface opening on coal bed
Number is thickness of coal, in inches

Mined area in coal bed

Lower Hartshorne coal thickness line
Number is thickness of coal, in inches

Boundary between measured and indicated reserves and inferred reserves of coal
Square on side of area of measured and indicated reserves of coal

Shallow hole
Number designates hole listed in table 3 in text

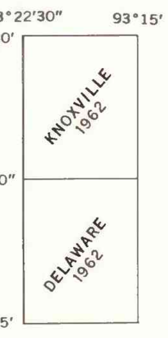
Gas producing

Show of gas

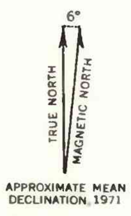
No show of gas

Wells
Number designates well described in table 2 in text

Gas field
Name of field shown



INDEX TO QUADRANGLES



APPROXIMATE MEAN DECLINATION, 1971

MAP SHOWING STRUCTURE CONTOURS, COAL BEDS, AND GAS FIELDS IN KNOXVILLE AND DELAWARE QUADRANGLES, JOHNSON AND LOGAN COUNTIES AND VICINITY, ARKANSAS

SCALE 1:48 000

1 ½ 0 1 2 3 MILES

1 .5 0 1 2 3 KILOMETERS

CONTOUR INTERVAL 20 FEET
DATUM IS MEAN SEA LEVEL