Oklahoma Geology Notes

OKLAHOMA GEOLOGICAL SURVEY / VOL. 46, NO. 3 — JUNE 1986

On the cover—

Meers Fault, Southwestern Oklahoma

The Meers fault is part of a major zone of NW-trending faults that form the boundary between the Wichita Mountains and the Anadarko basin in southwestern Oklahoma. Part of the Meers fault is exposed at the surface in northern Comanche County (cover photo). The surface expression of the Meers fault, which strikes approximately N.60°W., offsets Permian conglomerate and shale bedrock units for at least 26 km. The topography is consistently down to the south, with a maximum relief of 5 m near the fault trace center.

Anthony J. Crone

Recent mapping has identified dislocations by the Meers fault in Quaternary alluvium. Richard F. Madole, U.S. Geological Survey, conducted a reconnaissance study of the Quaternary stratigraphy in the vicinity of the Meers fault. Quaternary stratigraphic relationships supported by radiocarbon age dates demonstrate that the last movement on the Meers fault was recent (1,000–2,000 yr B.P.).

Anthony J. Crone, U.S. Geological Survey, conducted detailed geologic mapping in two trenches excavated across the fault scarp (see inset photo). The data indicate that the scarp was formed mainly by plastic deformation in the alluvium in the form of flexing and warping. The trench stratigraphy indicates a lengthy recurrence interval—perhaps many thousands of years between earthquake events.

Kenneth V. Luza

Cover photo by David B. Slemmons, University of Nevada, Reno.

Inset photo, above, by Kenneth V. Luza.

Oklahoma Geology Notes

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Short articles on aspects of Oklahoma geology are welcome from contributors. A set of guidelines will be forwarded on request.

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STATISTICS IN OKLAHOMA'S PETROLEUM INDUSTRY, 1984

Robert H. Arndt[1]

Introduction

Total footage accomplished in drilling decreased from about 48.6 million ft in 1983 to about 45.9 million ft in 1984, a drop of 5.6% (Table 1). Completed drilling projects diminished 1.6% in number in the same period. Contrastingly, production of crude oil rose 7.4% and that of natural gas rose 10.9% above production in 1983 (Table 2). Total value of output of each commodity also rose, and their combined value of almost $10 billion was 4% higher than in 1983.

Oklahoma ranked fifth among the states in production of crude oil and third in the production of natural gas in 1984. Output from the state accounted for about 5% of the nation's production of crude oil and about 10% of the natural gas produced in the United States that year.

Explanation and Credits

Most statistics on drilling and completions of wells provided in this text have been extracted from basic data compiled by the American Petroleum Institute (API). Data on production and value of oil and gas are based on records of the Oklahoma Tax Commission, Division of Gross Production. The use of statistics and information from other sources is noted in the text and tables. Extraction of statistics from API data was accomplished through the Energy Resources Institute at the University of Oklahoma.

Unless specifically noted to the contrary, the term *crude oil* means crude oil plus lease condensate when used in reference to production and value of the commodities. *Natural gas* production and value similarly mean natural gas plus casing-head gas. *Total liquid hydrocarbons* as used in the discussion of reserves means crude oil plus natural-gas liquids, and *natural gas* means dry natural-gas.

Regional statistics compiled for this annual review are related, for the first time, to the drilling districts used by the Committee on Statistics of Drilling of the American Association of Petroleum Geologists (AAPG).

[1]Geologist, Oklahoma Geological Survey, Norman; director, Oklahoma Mining and Mineral Resources Research Institute, the University of Oklahoma, Norman.

TABLE 1.—DRILLING ACTIVITY IN OKLAHOMA, 1983, 1984

	1984				
All Wells	**Oil**	**Gas**	**Dry**	**Total**	**1983 Total**
Number of wells	5,231	1,817	2,719	9,767[1]	9,935
Total footage	21,457,950	11,405,875	12,992,644	45,856,469	48,590,456
Average footage	4,102	6,277	4,778	4,695	4,891
Exploratory Wells					
Number of completions	93	65	372	530	642
Percentage of exploratory wells productive	17.5	12.3	70.2	29.8	32.4
Total footage	596,769	533,534	2,252,049	3,382,352	5,024,269
Average footage	6,417	8,208	6,054	6,382	7,826
Development Wells					
Number of completions	5,138	1,752	2,347	9,237	9,293
Percentage of development wells productive	55.6	19	25.4	74.6	71.9
Total footage	20,861,181	10,872,341	10,740,595	42,474,117	43,566,187
Average footage	4,060	6,206	4,576	4,598	4,688

Source: American Petroleum Institute.

[1]Excludes service and stratigraphic test (core) boreholes and old wells drilled deeper.

Because the districts are delineated in respect to geologic conditions, they commonly cross political boundaries. Thus Oklahoma includes only one complete district, 355 (northeastern part of the state), and parts of five others: 345 (roughly the Arkoma Basin), 350 (south-central and southwestern Oklahoma), 360 (Anadarko Basin), 400 (Ouachita Mountains and Gulf Coastal Plain), and 435 (far western panhandle and southwestern corner). These districts are outlined in Figure 1 and on all other accompanying maps of Oklahoma. They have been used because they are recognized widely and accepted by members of the geological profession and others in the petroleum industry.

Drilling

The decline in drilling activity Oklahoma experienced in 1983 continued in 1984. Total drilling footage in 1984 reported by the API was 45.9 million ft, 5.6% below that of 1983 (Table 1). Footage in exploratory drilling was 32.7% less than in 1983 and footage in development drilling decreased by 2.5%. Exploratory drilling accounted for 7.4% of all footage in drilling in 1984, in contrast to 10.3% in 1983.

Depths of completed wells ranged from less than 5,000 ft to more than 20,000 ft (Table 3). More than 79% of the drilling footage was achieved in wells less than 10,000 ft deep, whereas drilling to depths of 20,000 ft or more accounted for only 0.4% of all drilling footage. Average depth

TABLE 2.—HYDROCARBON PRODUCTION IN OKLAHOMA, 1983, 1984

	1983	1984
Crude Oil and Lease Condensate		
Total annual production (1,000 bbl)[1]	159,354	165,257
Value ($1,000)[1]	4,761,280	4,773,570[2]
Daily production (bbl)[1]	436,586	452,759
Total number of producing wells[3]	95,868	99,600
Daily average per well (bbl)	4.6	4.5
Oil wells on artificial lift[3]	91,074	94,620
Natural Gas and Casing-head Gas		
Total annual marketed production (MMcf)[1]	1,807,758	2,007,388
Value ($1,000)[1]	4,818,885	5,193,223
Total number of producing gas or gas-condensate wells[3]	22,135	23,647
Natural Gas Liquids		
Total annual marketed production (1,000 bbl)[3]	80,000	86,000
Value ($1,000)	2,390,723	2,483,680

[1]Oklahoma Tax Commission, tax-paid production.
[2]Includes $29,663,626 value of gas liquids not included elsewhere.
[3]Published: *World Oil*, v. 198, no. 3, Feb. 15, 1984; v. 200, no. 3, Feb. 15, 1985; U.S. Department of Energy, various reports.

of all wells drilled was 4% less in 1984 than in 1983. Most of that was reflected in an 18.4% decrease in the average depth of exploratory wells.

Distribution of drilling by footage achieved in each CSD district is shown in Table 4. The 21.9 million ft drilled in district 360 was 47.7% of all drilling in Oklahoma. The remainder of drilling achieved in Oklahoma included 38.5% in district 355, 9.2% in district 350, 3.1% in district 345, 1.1% in district 435, and 0.2% in district 400.

The distribution of drilling footage by counties is shown in Figure 2. Drilling exceeded 1 million ft in 18 counties that collectively accounted for 54.5% of the state's total drilling footage in 1984. Eleven of the counties were in CSD district 360, where the leader was Beaver County with 1,894,767 ft. Others, ranked in order of decreasing footage, were Canadian, Dewey, Garfield, Kingfisher, Custer, Major, Grant, Caddo, Grady, and Roger Mills Counties. In CSD district 355, Creek, Pottawatomie, Noble, McClain, Logan, and Okmulgee Counties, also ranked in order of decreasing footage, each had more than 1 million ft of drilling.

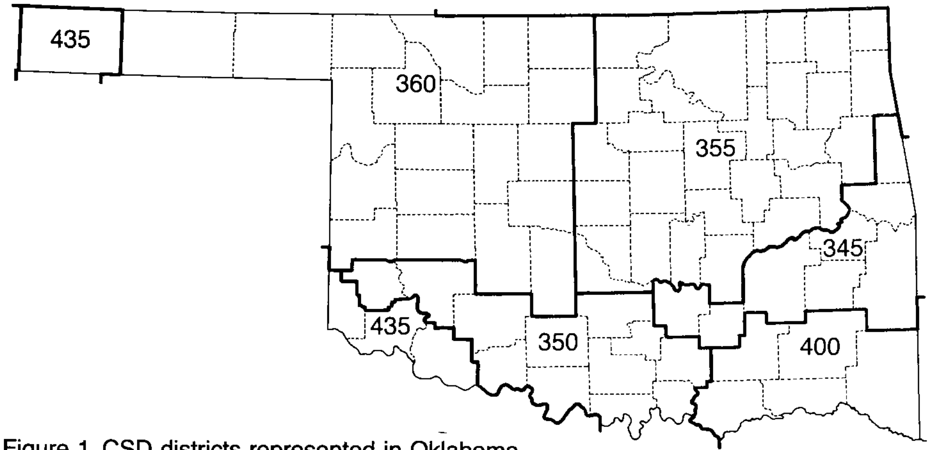

Figure 1. CSD districts represented in Oklahoma.

The only other county in which total drilling exceeded 1 million ft was Garvin County in CSD district 350.

Related to total drilling footage are the maximum depth and the average depth of drilling in a specified area or region. Average depth for each CSD district appears in Table 4. Average depths in individual counties are shown in Figure 3, and maximum depths attained in each county appear in Figure 4. All indicate that district 360 (approximately coextensive with the Anadarko Basin) was the site of deepest drilling, depth of drilling decreasing generally to the north, northeast, and southwest. The deepest drilling in eastern Oklahoma was in the Arkoma Basin and fringes of the Ouachita Mountains (CSD district 435); drilling was shallower to the north in CSD district 355, and to the southeast in CSD district 400.

The vigor of the drilling industry is also shown in the weekly count of active rigs made by Hughes Tool Company. The maximum number of rigs active in Oklahoma in any week during 1984 was 408, during the fourth week of January. By contrast, 418 active rigs were reported during the last week of December in 1983. The lowest rig count in 1983 was 232 in the fourth week of April, whereas the minimum weekly rig count in 1984 was 275 in the first week of August. Rig count in the last week of December 1984 was 309.

Completions

According to the API, the petroleum drilling industry completed 9,767 oil wells, gas wells, and dry holes in 1984, excluding old wells drilled deeper and service and core holes. This was a reduction of 1.7% from the total number of completions in 1983. It included reductions of 10.5%

TABLE 3.—COMPLETION DATA AND DEPTH INFORMATION FOR WELLS DRILLED IN OKLAHOMA, 1984

County	Total No. of wells drilled	Completions Oil	Completions Gas	% Completions Oil & Gas	Number of wells drilled in total-depth ranges (ft) 1–5,000	5,000–10,000	10,000–15,000	15,000–20,000	>20,000
Alfalfa	78	26	28	69	9	69			
Atoka	20	7	2	45	16	2	2		
Beaver	248	63	117	72	8	240			
Beckham	46	5	26	67	8	1	23	8	6
Blaine	104	29	51	76	1	78	25		
Bryan	4	3	75	2	1	1			
Caddo	96	33	34	69	11	7	44	33	1
Canadian	198	115	62	89		151	47		
Carter	189	151	14	87	133	46	8	2	
Cherokee	2				2				
Choctaw	1					1			
Cimarron	48	9	10	39	35	13			
Cleveland	97	50	1	52		95	2		
Coal	11	2	1	27	3	8			
Comanche	55	31	6	67	46	3	2	3	1
Cotton	94	49	8	60	94				
Craig	19	3	5	42	19				
Creek	631	395	88	76	630	1			
Custer	105	14	56	66		7	70	28	
Dewey	175	90	48	78	1	121	52	1	
Ellis	102	35	32	65	4	70	27	1	
Garfield	225	109	83	85	20	205			
Garvin	221	142	16	71	116	91	13	1	
Grady	112	43	37	71	12	41	48	11	
Grant	226	99	37	60	48	178			
Greer	11	2	1	27	8	3			
Harmon	14	4		28	6	8			
Harper	63	8	27	55		63			
Haskell	30		22	73	15	13	2		
Hughes	198	91	50	71	181	17			
Jackson	21	3	1	19	13	8			
Jefferson	77	63	1	83	11	56	10		
Johnston	3				1	2			
Kay	104	41	15	53	104				
Kingfisher	171	132	25	91		142	29		
Kiowa	124	85	13	79	123				1

Latimer	16		11	68		1	15		
Le Flore	11		5	45		11			
Lincoln	214	78	44	57	181	33			
Logan	217	118	20	63	44	173			
Love	51	35	1	70	8	38	4	1	
McClain	135	96	5	74	5	81	49		
McCurtain	3				3				
McIntosh	48	2	29	64	44	4			
Major	163	102	46	90	1	161	1		
Marshall	12	8	1	75	8	2	1	1	
Mayes	62	39	1	64	62				
Murray	19	6	1	36	17	1	1		
Muskogee	199	91	41	66	198		1		
Noble	269	194	8	75	175	94			
Nowata	250	166	40	82	250				
Okfuskee	158	62	29	57	158				
Oklahoma	141	68	35	73	4	137			
Okmulgee	476	241	109	73	476				
Osage	454	306	39	76	454				
Ottawa									
Pawnee	275	208	11	79	273	2			
Payne	163	81	7	53	143	20			
Pittsburg	72	1	54	76	31	27	14		
Pontotoc	196	134	17	77	194	2			
Pottawatomie	317	191	3	61	192	125			
Pushmataha									
Roger Mills	75	7	41	64	2	6	48	19	
Rogers	142	85	20	74	142				
Seminole	294	181	19	68	291	3			
Sequoyah	7		2	28	6	1			
Stephens	314	222	36	82	259	49	5	1	
Texas	119	42	30	60	15	104			
Tillman	25	6	1	28	14	11			
Tulsa	211	138	31	80	211				
Wagoner	116	43	33	65	116				
Washington	429	319	37	83	429				
Washita	60	13	30	71	1	3	35	21	
Woods	59	8	27	59		59			
Woodward	72	8	36	61	2	58	12		
State total	**9,767**	**5,231**	**1,817**	**72**	**6,089**	**2,947**	**591**	**131**	**9**

Source: American Petrolem Institute.

TABLE 4.—GROSS COMPLETIONS AND DRILLING FOOTAGE IN CSD DISTRICTS IN OKLAHOMA, 1984

CSD District	No. of Completions	Drilling footage (ft)	Average depth of drilling (ft)
345	343	1,447,427	4,219
350	1,115	4,227,111	3,791
355	5,621	17,665,946	3,142
360	2,552	21,887,318	8,576
400	28	94,136	3,362
435	108	534,531	4,949
Total:	**9,767**	**45,856,469**	

Source: American Petroleum Institute.

in dry holes completed, 3.7% in gas wells completed, and an increase of 4.4% in the number of oil wells completed. The number of development oil wells completed in 1984 was 4.6% greater than in 1983; completions of development gas wells decreased by 2%. Completions of exploratory oil wells in 1984 were down by 14.7% and those of exploratory gas wells were down 30.3% from completions in 1983. The distribution of completed successful wells by counties is shown in Figures 5 and 6, and Table 3.

Districts 350, 355, and 360 had 95.1% of the completions. Only districts 350 and 435 had more completions than in 1983. Net changes in each district appear in Table 5. Changes in the number of completions by commodity and well category in 1984 relative to 1983 appear in Table 6.

The total number of producing development wells completed in district 350 in 1984 exceeded those completed in 1983 by 154 (21.4%). The increase was due principally to a sharp rise in development drilling in Stephens County and significant increases in Cotton, Garvin, and Kiowa Counties.

The number of completions in CSD district 435 in 1984 was 108 (Table 5). Of these, 74 were dry holes. Forty-six of the dry holes were development projects and 26 of the dry development projects were in Cimarron County.

The number of completions was reduced in each of the other districts between 1983 and 1984. District 345 experienced the largest decline (129) in completions of any district. Ten counties that showed the greatest increase and 10 that showed the greatest decrease in the number of completions between 1983 and 1984 are listed in Table 7.

Crude Oil Production and Value

Output of crude oil, increasing for the fifth consecutive year, was 165.3 million bbl, the highest level of production since 1974. As a result, the total value of the output increased 0.3% from $4.76 billion in 1983 to

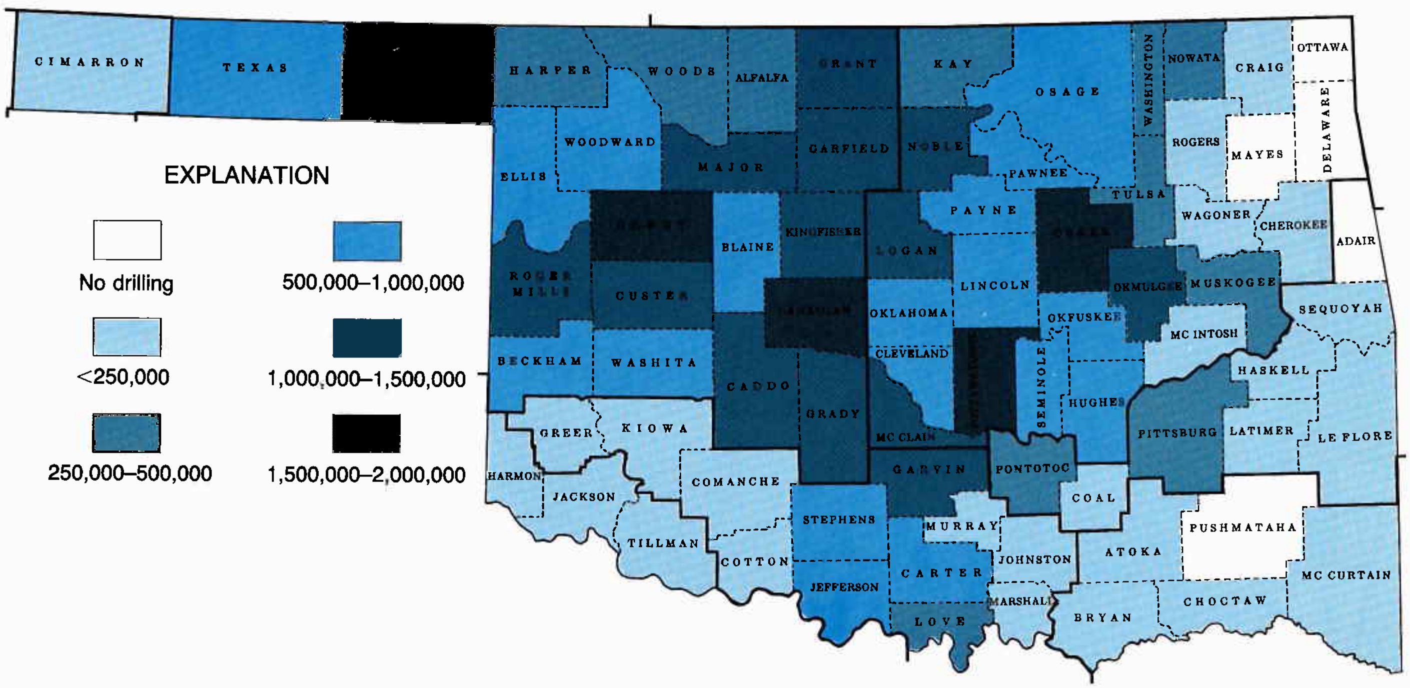

Figure 2. Total footage drilled in each county, 1984. Depth measured in feet.

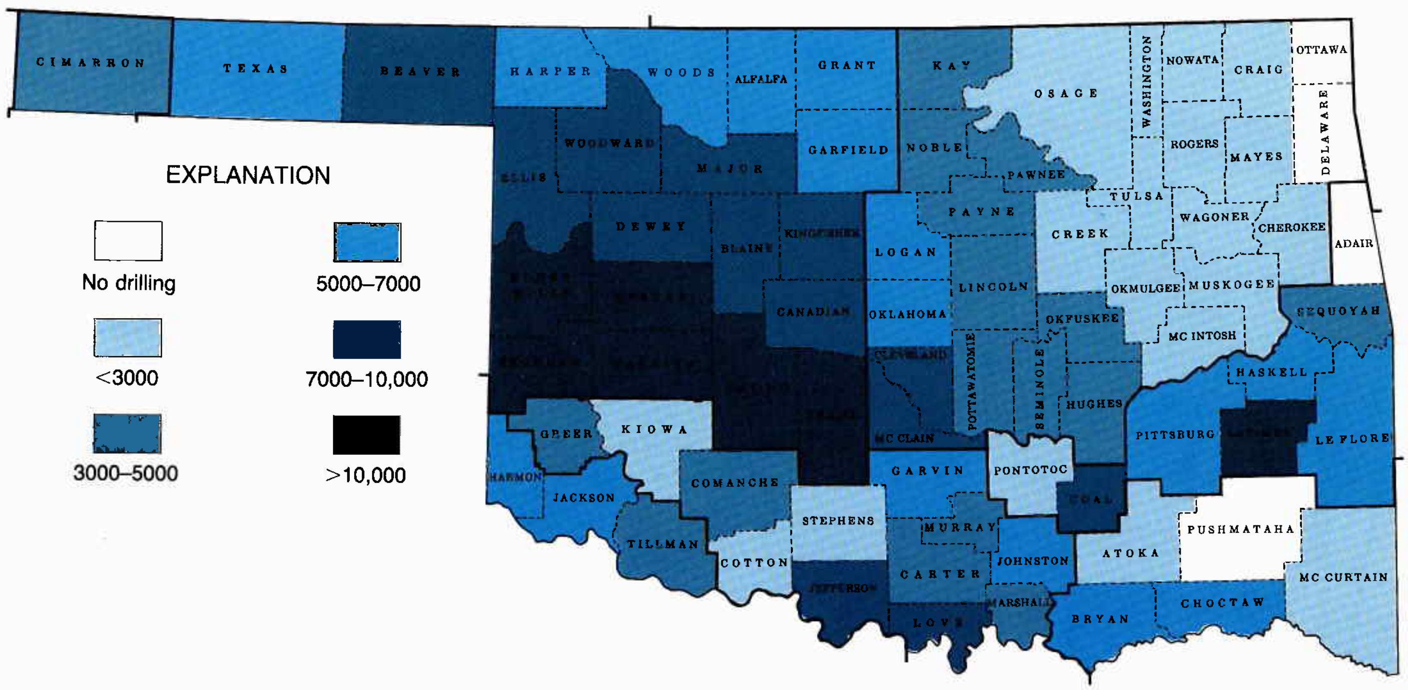

Figure 3. Average depth of drilling in each county, 1984. Depth measured in feet.

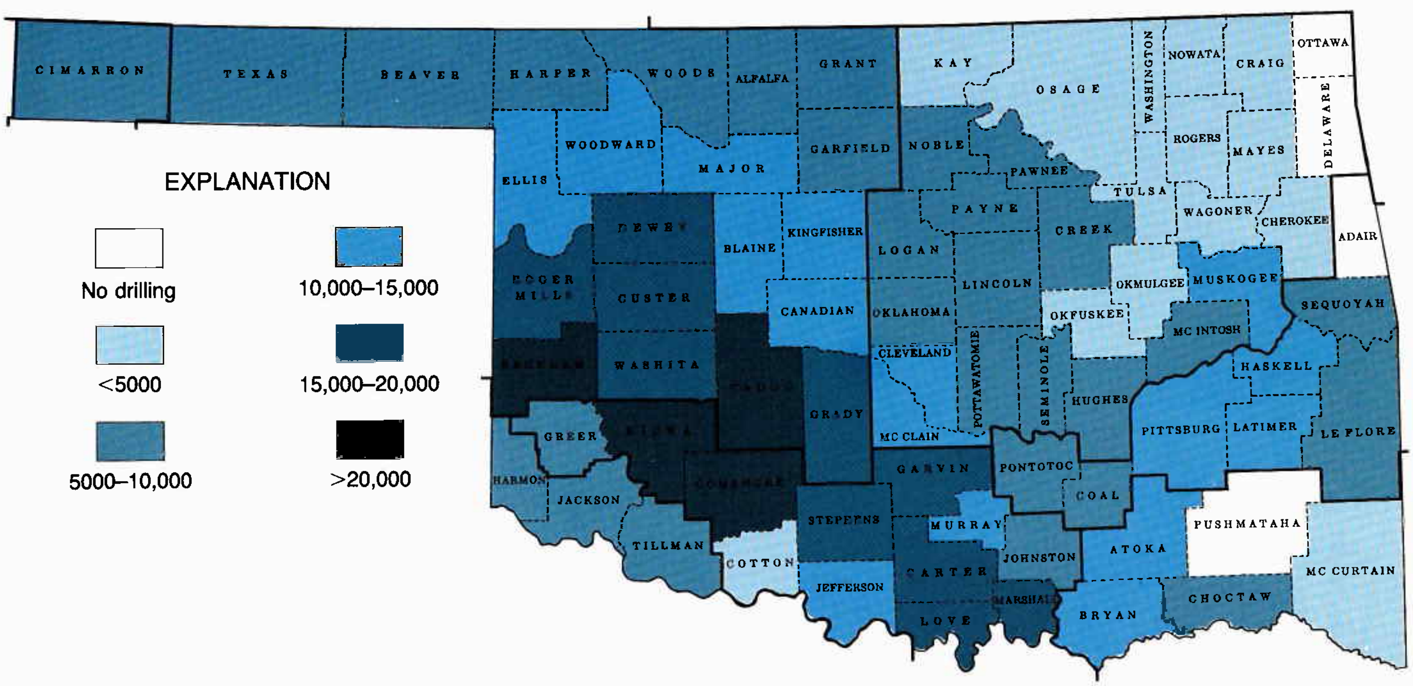

Figure 4. Maximum depth of drilling in each county, 1984. Depth measured in feet.

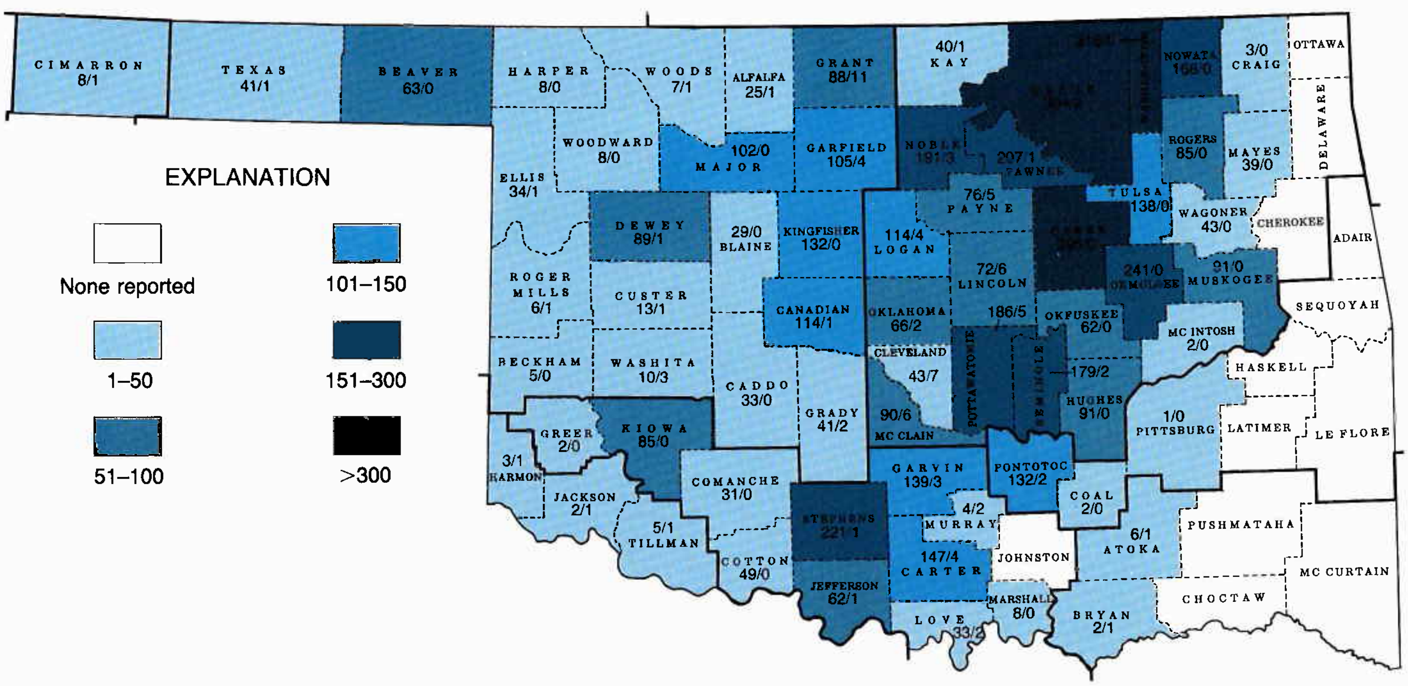

Figure 5. Number of oil wells completed in each county, 1984. Numbers to left on map signify development wells; numbers to right, exploratory wells.

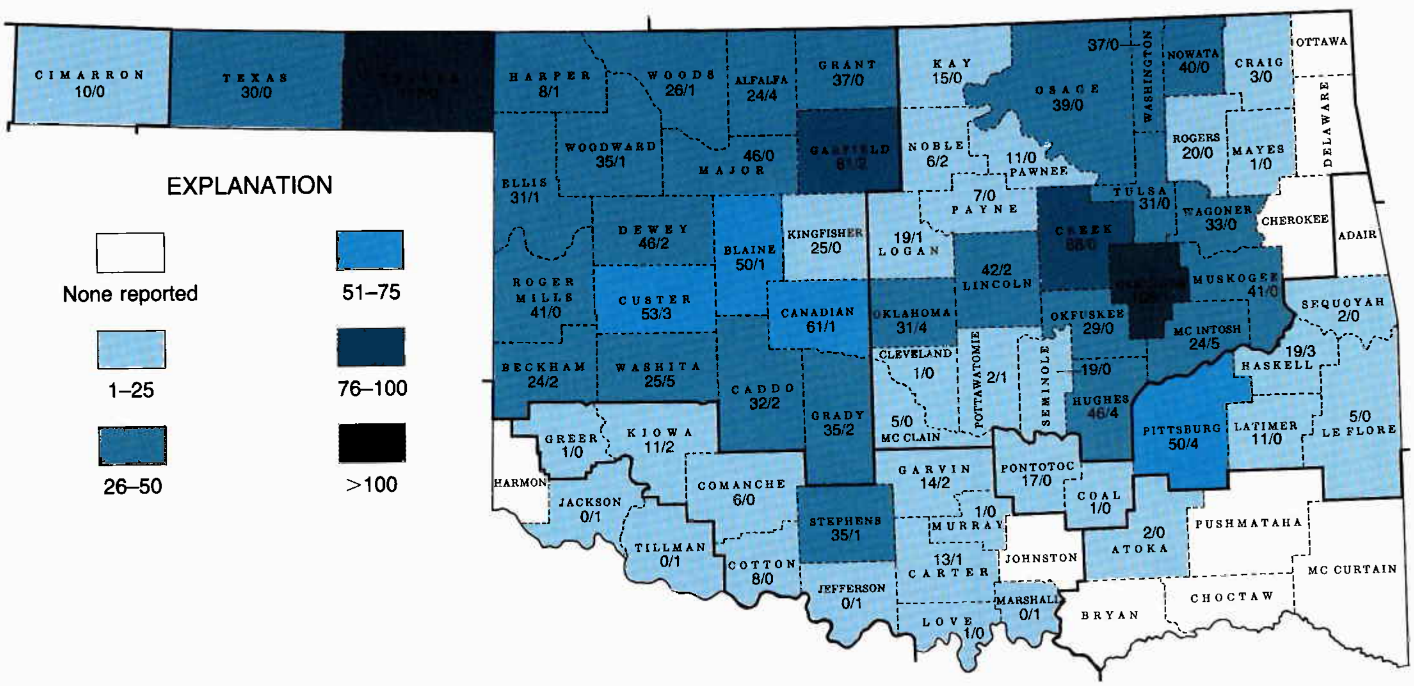

Figure 6. Number of gas wells completed in each county, 1984. Numbers to left on map signify development wells, numbers to right exploratory wells.

TABLE 5.—COMPARISON OF DRILLING COMPLETIONS IN CSD DISTRICTS, 1983, 1984

CSD District	1983 No. of completions	1983 % of state total	1984 No. of completions	1984 % of state total	Change 1983–1984 no. compl.	% Change 1983–1984 completions within district
345	472	4.8	343	3.5	−129	−27.3
350	1,079	10.9	1,170	12.0	+91	+8.4
355	5,742	57.8	5,621	57.5	−121	−2.1
360	2,539	25.6	2,497	25.6	−42	−1.6
400	29	0.3	28	0.3	−1	−3.4
435	74	0.7	108	1.1	+34	+45.9

$4.77 billion in 1984 (Table 2). The increase in total value was achieved in spite of a decrease in the average tax value of crude oil in Oklahoma from $29.88/bbl in 1983 to $28.89/bbl in 1984.

As in 1983, Carter and Stephens Counties ranked first and second respectively among the 67 oil-producing counties. Their combined output of 26.9 million bbl of oil (Carter 14.1 million bbl and Stephens 12.8 million bbl) was 16.3% of Oklahoma's total output. Osage, Grady, Garvin, Creek, Kingfisher, Pottawatomie, Pontotoc, and Texas Counties—ranked in order of decreasing output—individually yielded between 5 and 10 million bbl of oil and accounted for an additional 32.2% of the state's production. Figure 7 demonstrates that the most productive counties, excepting Texas and Beaver, were in a central zone that extends from Carter County in the south to Osage County in the north. No production was reported in eight counties along the eastern border of the state and two counties in the southwest. Oil production in each county is shown on Figure 7.

Figure 8 displays Oklahoma's total production of oil and relative share of production in each CSD district after 1954. Annual state production also is shown. Trends by district are shown in relation to data points established at 5-yr intervals from 1955 to 1970, at 2-yr intervals from 1971 to 1979, and yearly intervals from 1979 to 1984. Districts 355 and 360 clearly led all others in production in 1984.

The average tax value at the wellhead for crude oil produced in Oklahoma in 1984 was $28.89/bbl. In terms of 1967 constant dollars, the value would be $4.32/bbl of crude oil. The wide divergence between the values of crude oil in current dollars and in constant dollars for the period 1965 to 1984, shown in Figure 9, reflects the degree of monetary inflation experienced in the value of petroleum.

TABLE 6.—CHANGES IN THE NUMBER OF COMPLETED WELLS IN EACH CSD DISTRICT FROM 1983 TO 1984

CSD District	Oil Wells		Gas Wells	
	Development	Exploratory	Development	Exploratory
345	−41	−1	−39	+1
350	+123	−4	+31	+1
355	+117	−13	−103	
360	+37	+1	+75	−35
400	+5	−2	+1	−3
435	−4	+3		+2

TABLE 7.—COUNTIES WITH GREATEST CHANGES IN DRILLING COMPLETIONS BETWEEN 1983–1984

County	Completion 1983	Completion 1984	Absolute change	Percent change
Stephens	227	314	+87	38.3
Washington	352	429	+77	21.8
Beaver	175	248	+73	41.7
Garfield	168	225	+57	33.9
Pottawatomie	260	317	+57	21.9
Seminole	239	294	+55	23.0
McClain	92	135	+43	46.7
Major	127	163	+36	28.3
Cotton	59	94	+35	59.3
Grant	196	226	+30	15.3
Craig	112	19	−93	−83.0
Caddo	185	96	−89	−48.1
Roger Mills	141	75	−66	−46.8
Pontotoc	261	196	−65	−24.9
Creek	685	631	−54	− 7.8
Muskogee	251	199	−52	−20.7
Nowata	300	250	−50	−16.6
Custer	151	105	−46	−30.4
Comanche	100	55	−45	−45.0
Mayes	97	62	−35	−36.0

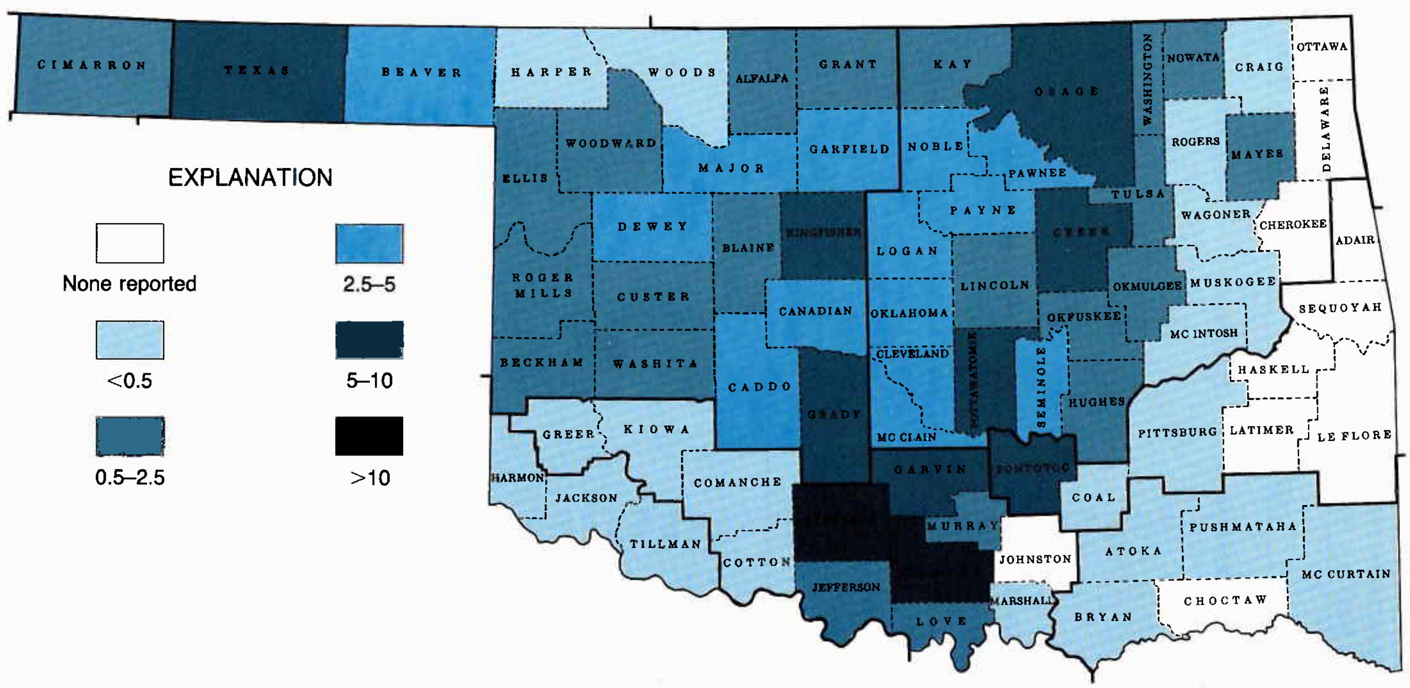

Figure 7. Output of crude oil in each county, 1984. Production shown in millions of barrels.

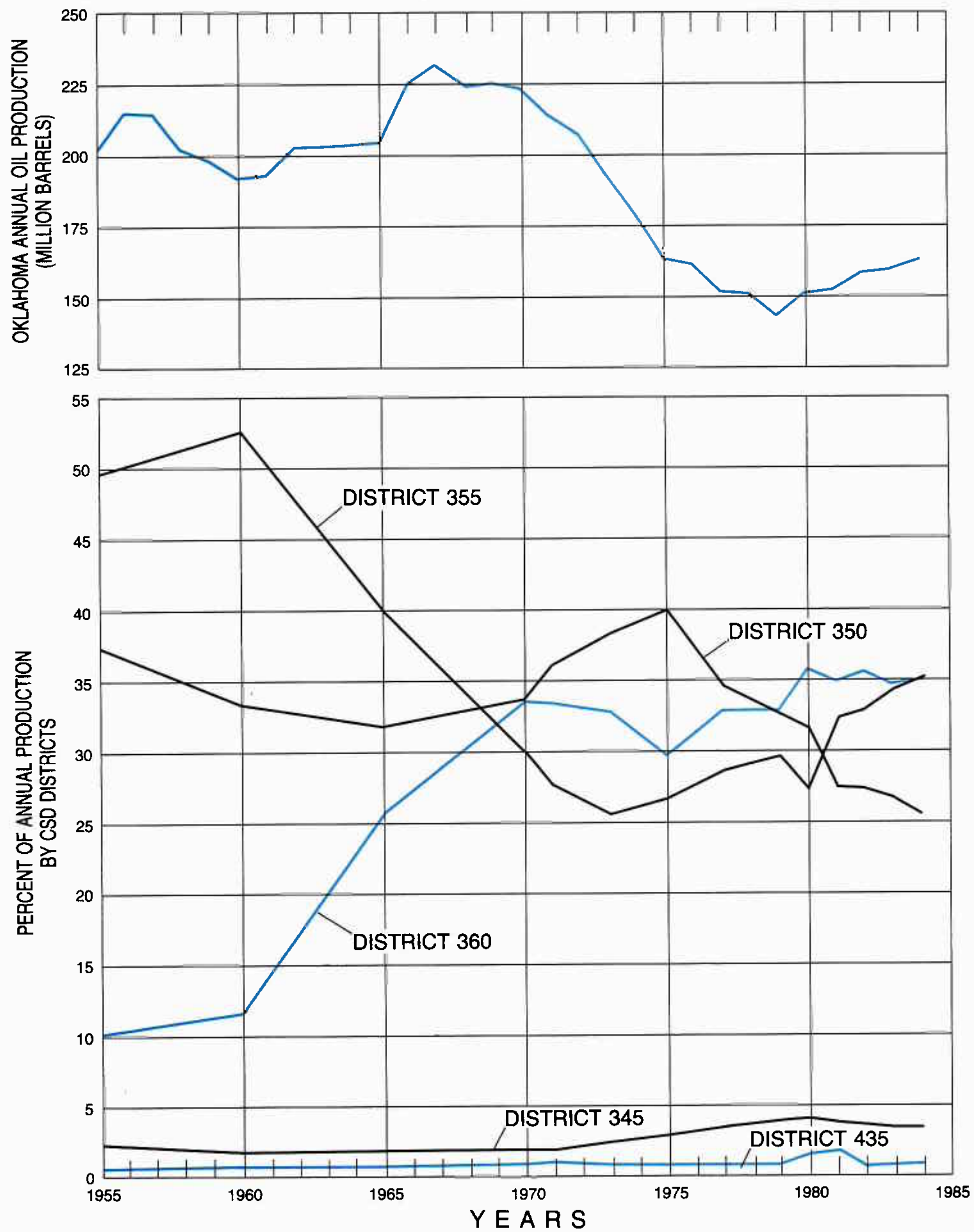

Figure 8. Annual production of oil in Oklahoma. Percent of total production originating in each CSD district shown at 5-year intervals, 1955–70; 2-year intervals 1971–1979; annually 1979–1984. District 400 not shown, because all production is less than 0.35%.

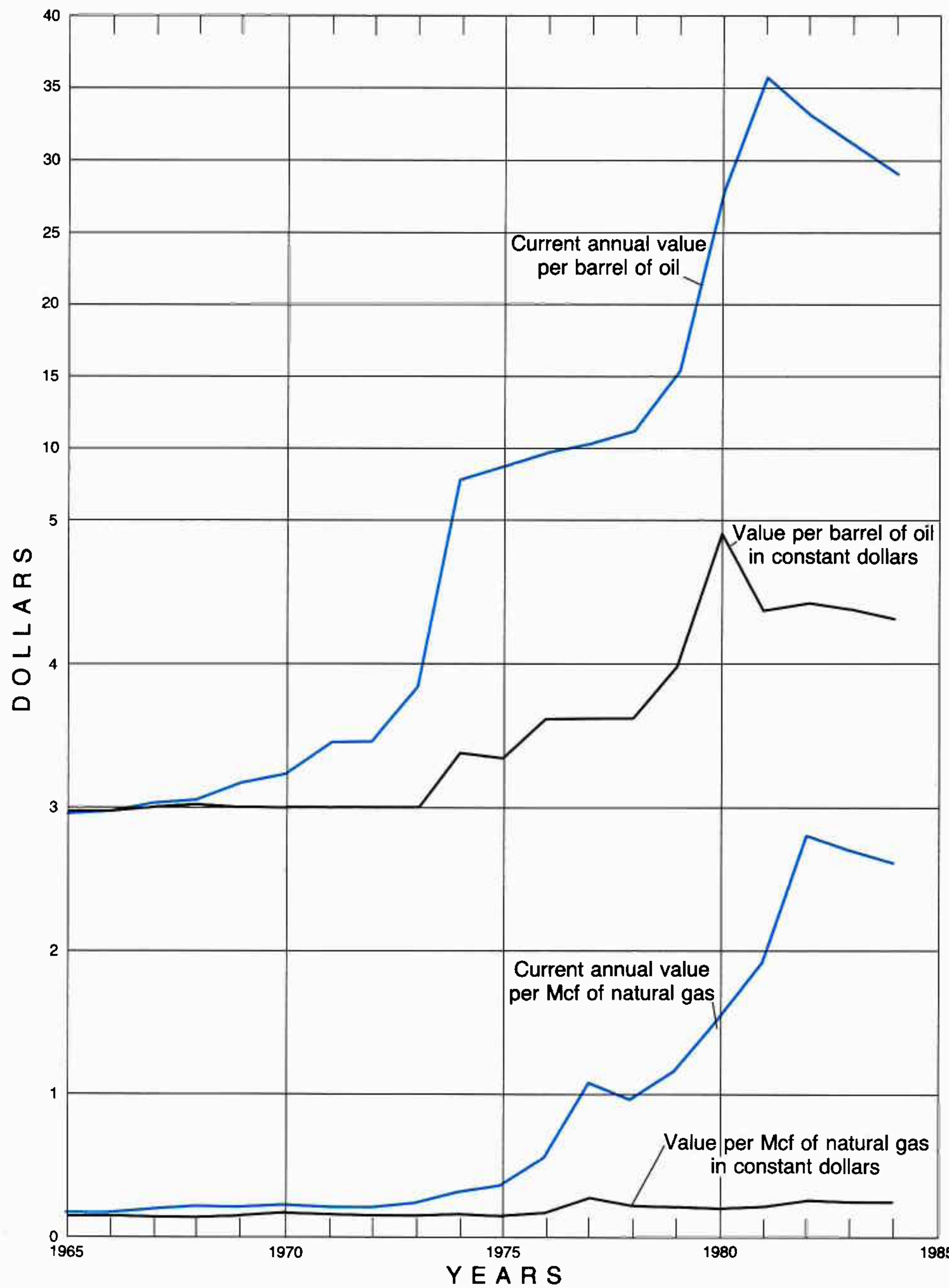

Figure 9. Average tax value of oil and natural gas at the wellhead in Oklahoma, expressed in annual current dollars and in 1967 constant dollars, calculated from producers price index.

Production of Oklahoma oil from stripper wells (a well that has an average production of 10 bbl/day or less) was 94,045,552 bbl in 1984, according to the National Well Survey made by the Interstate Oil Compact Commission and the National Stripper Well Association. This was 56.9% of Oklahoma's total oil output reported by the Oklahoma Tax Commission. The 82,431 active stripper wells had an average oil production of 3.12 bbl/day. Despite abandonment of 1,491 stripper wells during the year the number of active stripper wells in the state increased by 6% from the number active in 1983. Production from stripper wells was, however, 10% less than in 1983.

Traditionally oil production is reported in respect to giant oil fields (those fields that have yielded or are expected ultimately to yield more than 100 million bbl of oil) as well as by counties. The practice allows a measurement of productivity in areas of stratigraphic, structural, and reservoir continuity that cannot be discerned readily on the basis of county tabulations. Giant oil fields involve the environment of oil and thus they commonly extend across county boundaries. Eleven of the giant fields of Oklahoma are listed in Table 8. Of these only Hewitt (Carter County), and Postle (Texas County) are contained completely in one county. By contrast, the areal giant is Sooner Trend which extends over large parts of Logan, Kingfisher, Garfield, and Major Counties.

TABLE 8.—GIANT OIL FIELDS OF OKLAHOMA, 1983, 1984

Field	1983 Production (1,000 bbl)	1983 Number of wells[e]	1984 Production (1,000 bbl)	1984 Number of wells[e]	Cumulative production 1/1/85 (1,000 bbl)	Remaining reserves[e] (1,000 bbl)
Burbank	2,201	1,057	1,961	1,058	529,565	13,950
Eola-Robberson	1,377	594	1,219	601	128,281	12,000
Fitts	3,318	597	3,272	601	181,748	9,400
Glenpool	1,223	1,121	1,109	1,118	323,183	7,402
Golden Trend	3,721	1,245	4,319	1,301	438,697	25,331
Healdton	2,087	1,425	1,987	1,237	333,271	16,622
Hewitt	2,627	1,276	2,633	1,276	263,080	23,607
Oklahoma City	763	204	597	174	740,973	8,500
Postle	1,665	316	1,548	318	101,039	20,039
Sho-Vel-Tum	19,575	8,571	19,292	8,506	NA	101,000
Sooner Trend	7,288	5,320	6,534	5,314	266,164	28,935
Totals	**45,845**	**21,726**	**44,471**	**21,504**	**3,306,001**	**266,786**

Source: *Oil and Gas Journal*, v. 83, no. 5, Jan. 28, 1985.
[e] = Estimated.
NA = Not available.

Production from giant oil fields declined from levels of 1983 during 1984. Rates of decline ranged from 1.4% in Fitts and Sho-Vel-Tum to 21.8% in Oklahoma City. An infinitesimal increase in production occurred in Hewitt field and an increase of 16.1% occurred in Golden Trend (Garvin, Grady, and McClain Counties).

Reduced production from year to year is normal in oil fields of mature to old age unless some incident in field management occurs, such as application of secondary or enhanced oil-recovery methods or the drilling of a series of in-fill wells. The number of producing wells in Golden Trend was 56 greater in 1984 than in 1983. Contrastingly, reduced production from Oklahoma City was accompanied by a reduction of 30 in the number of producing wells.

Cumulative production from the fields (excepting Sho-Vel-Tum) from the time of discovery of Glenn Pool in 1905 to 1984 was 3.3 billion bbl of oil according to the *Oil and Gas Journal*. In 1984 the 11 fields yielded 44.5 million bbl of oil, which was about 2.9% less than in 1983. Production was from 21,504 wells, 222 less than in the previous year. Estimated reserves remaining in the 11 giant fields were 266.8 million bbl of oil at the end of 1984.

Natural Gas Production and Value

After declining in 1982 and 1983, natural-gas production rose sharply in 1984 to 2.007 billion mcf, thus closely approaching the all-time high output of 2.03 billion mcf attained in 1981. Value of output in 1984 was $5.2 billion, which in turn approached the record value of $5.3 billion established in 1982.

Average tax value of natural gas at the wellhead was $2.59/mcf. The equivalent value expressed in 1967 constant dollars would be $0.24/mcf.

Natural gas was produced in 66 of the state's 77 counties. The bulk of the output came from counties in the western half of the state. Roger Mills, Canadian, Custer, Texas, Grady, Caddo, and Beaver Counties each yielded more than 100 million mcf of natural gas and collectively provided 39.7% of the state's entire output in 1980. In 1983 only Roger Mills and Canadian counties produced more than 100 million mcf of natural gas individually. In addition, Beckham, Blaine, Dewey, Garfield, Harper, Kingfisher, Major, Pittsburg, and Washita Counties each had production of more than 50 million mcf of natural gas. Their total output in conjunction with that from counties previously listed constituted 71.8% of Oklahoma's total output of natural gas in 1984. Of these counties, only Pittsburg is in the eastern half of the state. No production was reported from 11 counties clustered in the northeast, southeast, and southwest corners of the state (Fig. 10).

CSD district 360 was the most productive district, having a yield of 1,505 million mcf of natural and casing-head gases. Following successively, but far behind in production, are districts 355 (191.7 million mcf), 345 (174.2 million mcf), and 400 (2.4 million mcf).

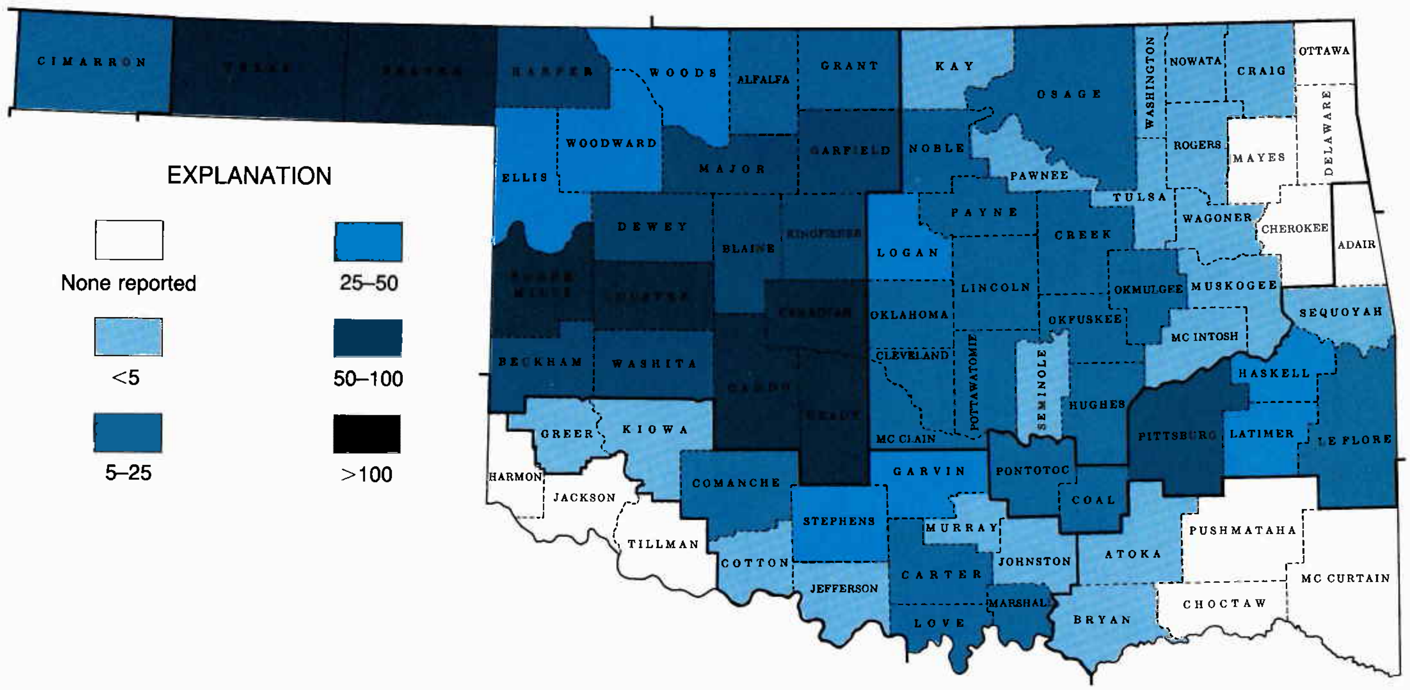

Figure 10. Output of natural gas in each county, 1984. Production shown in billions of cubic feet.

Reserves

Estimated reserves of crude oil were 940 million bbl on December 31, 1984. In combination with 769 million bbl of natural-gas liquids, Oklahoma had a total of 1.7 billion bbl of reserves of liquid hydrocarbons according to the Department of Energy (DOE). In arriving at the total, DOE also recorded 122 million bbl of liquid hydrocarbons in extensions and revisions, and 30 million bbl in new discoveries. Total production of liquids was estimated at 244 million bbl (Fig. 11).

Reserves of dry natural gas were 16.13 billion mcf at year end, about 0.5% less than on December 31, 1983. During the year, extensions and revisions were 1.65 billion mcf of gas while discoveries were 0.38 billion mcf. Production of dry natural gas was 1.78 billion mcf.

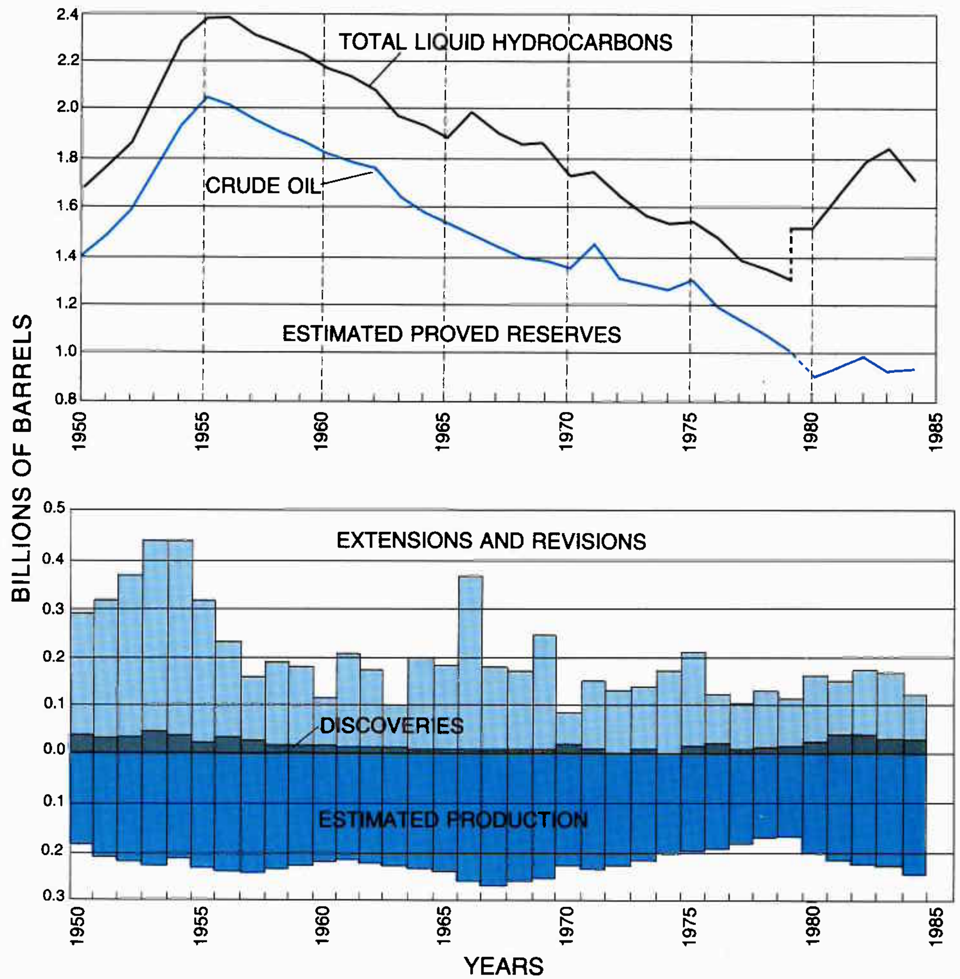

Figure 11. Liquid-hydrocarbon reserves, extensions and revisions, discoveries, and production in Oklahoma, 1950–84. Source: U.S. Department of Energy, annual reports.

Historical Review

Oil and gas produced in 1984 raised Oklahoma's cumulative output to 12.7 billion bbl of oil, 55.2 billion mcf of natural gas, and 1.7 billion bbl of liquefied petroleum gases. Total cumulative value of crude oil and natural gas produced in Oklahoma through 1984 was $90.02 billion. Table 9 is a historical presentation of these statistics in data categories used by the U.S. Department of Energy.

Figure 12 illustrates that CSD districts 350, 355, and 365 have been the principal sources of crude oil since 1955. Each district has had its period

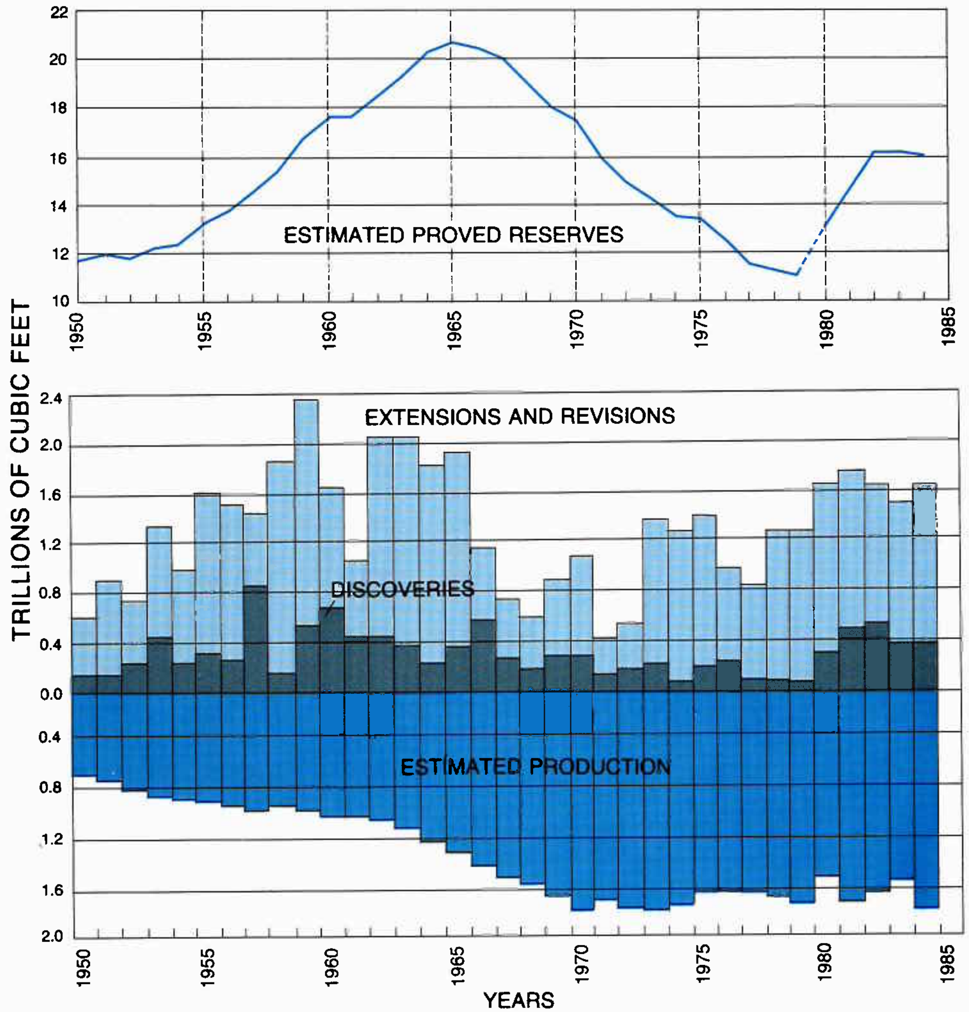

Figure 12. Natural-gas reserves, extensions and revisions, discoveries, and production in Oklahoma, 1950–84. Source: U.S. Department of Energy, annual reports.

TABLE 9.—CUMULATIVE (THROUGH 1955) AND YEARLY (1956–84) MARKETED PRODUCTION AND VALUE OF PETROLEUM, NATURAL GAS, AND LIQUEFIED NATURAL GAS IN OKLAHOMA[1]

	Petroleum		Natural Gas		Liquefied natural gas[2]	
Year through	Volume (1,000 bbl)	Value ($1,000)	Volume (MMcf)	Value ($1,000)	Volume (1,000 bbl)	Value ($1,000)
1955	7,230,010	11,443,269	12,977,332	1,378,370	430,806	1,010,826
1956	215,862	600,096	678,603	54,288	25,454	49,970
1957	214,661	650,423	719,794	59,743	24,947	47,153
1958	200,699	594,069	696,504	70,347	26,141	51,851
1959	198,090	578,423	811,508	81,151	26,767	56,513
1960	192,913	563,306	824,266	98,088	30,816	65,483
1961	193,081	561,866	892,697	108,016	31,865	63,499
1962	202,732	591,977	1,060,717	135,772	33,136	60,987
1963	201,962	587,709	1,233,883	160,405	32,532	64,112
1964	202,524	587,320	1,323,390	166,747	34,163	62,066
1965	203,441	587,944	1,320,995	182,297	34,876	66,769
1966	224,839	654,281	1,351,225	189,172	36,771	80,046
1967	230,749	676,095	1,412,952	202,052	37,489	85,122
1968	223,623	668,202	1,390,884	197,506	39,402	78,349
1969	224,729	701,155	1,523,715	223,128	41,925	73,334
1970	223,574	712,419	1,594,943	248,811	42,842	92,908
1971	213,312	725,610	1,684,260	273,945	41,727	97,588
1972	207,633	709,033	1,806,887	294,523	41,707	99,810
1973	191,204	723,273	1,770,980	334,110	43,718	144,334
1974	177,785	1,277,076	1,638,492	458,904	43,812	251,099
1975	163,123	1,389,164	1,605,410	513,731	40,025	203,535
1976	161,426	1,484,297	1,726,513	866,710	42,514	254,018
1977	151,390	1,504,817	1,824,710	1,452,683	42,350	317,625
1978	150,456	1,640,595	1,773,582	1,599,771	44,369	488,059
1979	143,641	2,158,526	1,845,389	2,062,868	50,752	762,662
1980	150,140	4,110,515	1,902,157	2,856,457	70,000	1,917,000
1981	152,252	5,355,474	2,030,225	3,831,636	74,000	2,020,200
1982	158,674	5,195,614	1,924,189	5,336,377	77,000	2,521,288
1983	159,354	4,761,280	1,807,758	4,818,885	80,000	2,390,723
1984	165,257	4,773,570	2,007,388	5,193,223	86,000	2,483,680
Totals:	**12,729,136**	**56,567,398**	**55,161,348**	**33,449,716**	**1,707,906**	**15,960,609**

[1]Oklahoma Tax Commission.
[2]Production for 1980–84 from U.S. Department of Energy.

of dominant production starting with the northeast (355) since before 1955 until the period 1965–70. In the latter period, production in districts 350 (south central) and 360 (Anadarko equivalent) surpassed that of district 355. Production in district 350 peaked about 1975, after which it diminished continuously to the 1984 level. Production in district 360 generally leveled between 1970 and 1979. In 1980 district 360 became the most productive in Oklahoma and held that position until 1984. During the same interval a strong surge in production in district 355 restored it to the lead by a very narrow margin in 1984.

UPCOMING MEETINGS

Friends of the Pleistocene, Midwest Cell, August 15–17, 1986, Lawrence, Kansas. Information: W. C. Johnson, Department of Geography, University of Kansas, Lawrence, KS 66045; (913) 864-5143.

AAPG, Rocky Mountain Section, Annual Meeting, September 7–10, 1986, Casper, Wyoming. Information: Nancy or Mark Doelger, Barlow & Haun, Inc., 214 East 13th St., Casper, WY 82601; (307) 234-1574.

GSA Penrose Conference, "Synsedimentary Tectonics," September 7–12, 1986, Durango, Colorado. Information: William A. Thomas, Department of Geology, Box 1945, University of Alabama, University, AL 35486.

International Gas Research Conference, September 8–11, 1986, Toronto, Ontario. Information: 1986 International Gas Research Conference, c/o Gas Research Institute, 8600 West Bryn Mawr Ave., Chicago, IL 60631; (312) 399-8300.

AAPG, Eastern Section, Annual Meeting, October 2–4, 1986, Ann Arbor, Michigan. Information: Paul A. Catacosinos, Department of Geology, Delta College, University Center, MI 48710; (517) 686-9000.

AAPG, Gulf Coast Section, Annual Meeting, October 22–25, 1986, Baton Rouge, Louisiana. Information: Harry L. Roland, Jr., Louisiana Geological Survey, P.O. Box G, University Station, Baton Rouge, LA 70893; (504) 342-6754.

American Association of Stratigraphic Palynologists Annual Meeting (with Congrès Internationale du Microflore Paléozoïque), October 29–31, 1986, New York, New York. Information: Dan Habib, Graduate School of City University of New York, 33 West 42nd St., New York, NY 10036; (212) 790-4218.

SEPM, Mid-Continent Section, Annual Field Conference, October 30–November 1, 1986, Ponca City, Oklahoma. Information: William A. Morgan, Conoco, Inc., 1000 S. Pine, Ponca City, OK 74603; (405) 767-2853.

Geological Society of America Annual Meeting, November 10–13, 1986, San Antonio, Texas. Information: GSA, Meetings Department, P.O.

Box 9140, Boulder, CO 80301; (303) 447-2020.

SEPM, Gulf Coast Section, Annual Research Conference, "Shelf Sedimentation, Shelf Sequences, and Related Hydrocarbon Accumulation," December 7–10, 1986, Corpus Christi, Texas. Information: Susan J. Conger Morris, 11422 Hornbrook Drive, Houston, TX 77099; (713) 495-6071.

AAPG, Southwest Section, Annual Meeting, March 22–24, 1987, Dallas, Texas. Information: James A. Gibbs, 1106 One Energy Square, 4925 Greenville Ave., Dallas, TX 75206; (214) 363-3008.

GSA Penrose Conference, "Coastal Sediments '87," May 12–14, 1987, New Orleans, Louisiana. Information: Nicholas C. Kraus, USAE Waterways Experiment Station, Coastal Engineering Research Center, P.O. Box 631, Attn: WESCR-P, Vicksburg, MS 39180-0631.

GEOLOGIC MAP OF OKLAHOMA AVAILABLE ON OGS POSTCARD

A miniaturized map showing the geology of Oklahoma in full color on a postcard has been issued by the Oklahoma Geological Survey.

In addition to generalized surface geology, the card contains two cross sections that show the subsurface structure along two transects, one extending from the Hollis Basin in southwestern Oklahoma through the Wichita Mountains and the Anadarko Basin, the other from the Ouachita Mountains of southeastern Oklahoma through the Arkoma Basin and the Ozark Uplift.

What is still the most comprehensive geologic map of Oklahoma was compiled under the supervision of former U.S. Geological Survey geologist Hugh D. Miser with cooperation from the Oklahoma Geological Survey and was published by the USGS in 1954 at a scale of 1:500,000 (1 in. = approximately 8 mi). This map was modified and reduced for publication as OGS Educational Series Map 1, under the direction of former OGS director Carl C. Branson.

This small 8- by 16-in. map was further modified by Branson and the present OGS associate director Kenneth S. Johnson for publication in 1972 as part of OGS Educational Publication 1. It is this map that has been modified by OGS cartographic manager T. Wayne Furr for printing on the postcard. Cartography on the new map is by Massoud Safavi, cartographic technician with OGS.

The new OGS postcard geologic map can be obtained from the Survey at the address given inside the front cover. The price is 15¢ each, or two for 25¢.

The previous versions of the Geologic Map of Oklahoma are also available from the Oklahoma Geological Survey. The large 1954 map, issued in two sheets, is $8.80. Educational Publication 1, which contains seven pages of maps and cross sections, is $2 (or individual maps 40¢).

MAP OF OKLAHOMA OIL AND GAS FIELDS IS ONE OF SURVEY'S BEST SELLERS

The recently released *Map of Oklahoma Oil and Gas Fields* has become a best seller at the OGS. The 63- by 40-in. map, issued as OGS Map GM-28, is in color at a scale of 1:500,000 (1 in. = approximately 8 mi). It delineates and gives the type of production for 3,083 active fields and 35 abandoned fields in the state. The fields are cross indexed for ease of location.

OGS petroleum geologist Margaret R. Burchfield, compiler of the map, said that field outlines were taken from official field descriptions as documented by the Oklahoma–Kansas Division of the Midcontinent Oil and Gas Association. The field outlines on this map are intended to show actual field boundaries as defined by well locations.

In compiling this map, Burchfield worked with the Nomenclature Committee of the Midcontinent Oil and Gas Association in naming new fields. She has extended and redescribed fields in several western Oklahoma counties and has corrected situations where fields overlap, are incomplete, or are contained within larger fields.

Production types (oil, gas, or combination) for each field were determined by calculating gas-oil ratios. Fields designated as oil fields have a gas-oil ratio of less than 5,000; gas fields have a gas-oil ratio greater than 20,000; and in combination fields this ratio falls between 5,000 and 20,000. On the map, fields are color-coded on this basis.

Burchfield said current field records are being maintained at the OGS in order to update future editions of the map. The OGS is participating in an ongoing effort to redescribe the field boundaries on a county-by-county basis. When this is completed, the Survey plans to digitize the map for computer generation of future versions.

GM-28 can be obtained from the Oklahoma Geological Survey at the address given inside the front cover. The price is $5.

SHORT COURSE SET FOR SME–AIME MEETING

The short course *Permit Requirements for Subsidence Control Plans* will immediately precede the 1986 Society of Mining Engineers Fall Meeting that will take place at the Clarion Hotel, St. Louis, Missouri, September 7–10. The short course will be conducted September 6–7.

The course discusses how to prepare the subsidence aspects of mine permits and to control or mitigate the effects of mine subsidence. The course is intended to introduce mine subsidence to mine operators and to help them assess the amount of subsidence that may be expected, and examine the steps that might be taken for prevention or control.

The course fee is $325 for AIME members and $450 for nonmembers. For more information, contact Meetings Department, Society of Mining Engineers of AIME, Caller No. D, Littleton, CO 80127; (303) 973-9550.

L. Joy Hampton

DID YOU EVER DRILL A DISCOVERY?

The Oklahoma Geological Survey is engaged in a project to develop an Oil- and Gas-Field Production File for the state. The file will contain the following information on each field: location and outline by section-township-range, year of discovery, county, county code, former name or consolidated history, producing formation(s), product code, and monthly production since 1983. In addition, information on the discovery well for each field will be included.

Work has proceeded on this project for the past two years and much of the information required for the file is now in place. However, collection and verification of several important data elements are still under way. An important component of the continuing work is the identification of the discovery well for each field. This activity is being conducted by Joy Hampton, petroleum geologist with the Survey. She would greatly appreciate any assistance in identifying field discovery wells.— Charles J. Mankin, director, OGS.

Did you ever drill a discovery? I really need to hear about it, from you old-timers (that's anybody my age). I've decided that the only way I'm going to find all of them is by swabbing old-timers and I started that at the AIPG meeting in Tulsa, March 7th. I sat down with Bill Decker, and he gave me the names of five discoveries he drilled.

I'm working right now on old fields in Payne County. I think I have run down New Cushing, Norfolk, and West Norfolk by searching the files and accepting the first producing well in the area as the discovery. West Norfolk, it turns out, has been utilized as a waterflood—and I found a comprehensive report on the flood with a direct reference to the discovery well.

I checked the 1936 list of pools from the nomenclature committee, the 1938 list, then mapped the current boundaries of the pool. I found sec. 2, T18N, R5E to be listed on each of these reports and called the discovery for the Norfolk field, the C. B. Shaffer, N. J. Laughlin, NE NE NE of sec. 2. The well was completed December 30, 1916, at a total depth of 3,030 ft and had an initial production of 16,500 mcfgpd. The New Cushing field was combined with Norfolk field March 19, 1959, and Norfolk now covers most of the eastern half of T18N, R5E and spills over into T19N, R5E and T18N, R6E.

If you drilled a discovery or know who did, I'd love to hear from you. Payne County is just the first county I'll need help with.

L. Joy Hampton

NEW THESES ADDED TO OU GEOLOGY LIBRARY

The following M.S. theses and Ph.D. dissertation have been added to the University of Oklahoma Geology and Geophysics Library:

Multicomponent Trace Analysis and Seismic Reflection Studies in the Great Salt Lake Desert, Utah, by Prentice Mark Forsyth. 200 p., 71 figs., 1 table, 7 appendixes, 1985.

Seismic Studies Near Crater Island in the Great Salt Lake Desert, Utah, by Ki Young Kim. 73 p., 31 figs., 1 table, appendix, 1985.

Lithostratigraphy and Depositional History of the Upper Dornick Hills Group (Early Desmoinesian, Pennsylvanian) of the Ardmore Basin, Oklahoma, by David Thomas McGee. 348 p., 25 figs., 8 pls., 2 appendixes, 1985.

Investigation of Paleotemperatures in the Vicinity of the Washita Valley Fault, Southern Oklahoma, by William James Metcalf III. 94 p., 18 figs., 6 tables, 2 appendixes, 1985.

A Sedimentological and Geochemical Study of the Bigfork Chert in the Ouachita Mountains and the Viola Limestone in the Arbuckle Mountains, by Atiqullah Sediqi. 155 p., 25 figs., 8 tables, 2 appendixes, 1985 (Ph.D. dissertation).

Petrology and Geochemistry of Mid-Tertiary Volcanic Rocks, La Perla, Chihuahua, Mexico, by Karen Lee Spaulding. 83 p., 21 figs., 1 pl., 8 tables, 2 appendixes, 1985.

The Geology of the Parguera Area and Insular Shelf, Southwest Puerto Rico, by Gary C. Stewart. 137 p., 31 figs., 7 pls., 4 exhibits, 1985.

Paleomagnetism and Diagenesis of the Triassic Chugwater Group, Wyoming, by Alexander Jules Zdzinski. 149 p., 14 figs., 2 tables, 1985.

DNAG PROJECT BEGINS PUBLICATION

The first publications were issued recently from the Decade of North American Geology (DNAG), a project sponsored by the Geological Society of America in celebration of its centennial decade, 1979–88.

DNAG's goal is publication of a modern synthesis of the geology and geophysics of North America and the adjacent oceanic regions. The complete series will include 40 volumes, 23 continent-ocean transects, and seven continent-scale geologic or geophysical maps of North America. The 40 volumes include a 19-volume set of the Geology of North America (United States and Mexico), a nine-volume set of the Geology of Canada, six Centennial Field Guides for the United States and Canada, and four special topical titles.

Among the U.S. volumes, *Sedimentary Cover of the Craton: U.S.* was edited by L. L. Sloss, P. R. Vail, and Charles J. Mankin, director of the Oklahoma Geological Survey. This volume is expected to be available in December 1986. Other publications of the DNAG series will be issued periodically during the next three years.

The publications are a unique earth-science series produced in honor of the 100th anniversary of the founding of the Society. The DNAG project spans 10 years of planning, development, and printing. More than a thousand editors, authors, and contributors have collaborated on the project.

For further information, contact the Geological Society of America, Marketing Department, P.O. Box 9140, Boulder, CO 80301.

NOTES ON NEW PUBLICATIONS

Index Maps for High-Altitude Photographs

An index map showing areas of the United States covered by the second National High Altitude Photography (NHAP II) program is now available, as well as an updated version of the NHAP I index map. Aerial photographs for the NHAP II program, taken during the leaf-on growing season to show maximum foliage, are typically used for soil and vegetation studies, agricultural-resources surveys, and crop analyses. Photos for the NHAP I program, taken during leaf-off seasons, are used for mapping, scientific research, natural-resources surveys, and land-use planning. Each NHAP index map sheet shows available black-and-white aerial photographs on one side and available color-infrared photos on the other side.

Order from: U.S. Geological Survey, Western Distribution Branch, Box 25286, Federal Center, Denver, CO 80225. Single copies of NHAP II and NHAP I indexes are free.

Directory of Principal Crushed-Stone Producers in the United States in 1983

A total of 863 million tons of crushed stone valued at $3.3 billion, f.o.b. plant, was reported produced in the United States in 1983 by 1,809 companies with 3,791 active quarries. Most of the crushed stone produced in 1983 came from quarries with an annual output larger than 300,000 tons; 387 quarries, representing 22% of the total number of active quarries, produced 75% of the total tonnage. The directory reports that the leading states, listed in descending order of tonnage, were Texas, Florida, Pennsylvania, Illinois, Georgia, Missouri, Virginia, California, North Carolina, and Kentucky, which accounted for 52% of the total output.

Order from: U.S. Bureau of Mines, 2401 E St., N.W., Washington, DC 20241. Single copies of the directory are free.

Maps in the Geoscience Community

Papers included in this volume concern geoscience map production, acquisition, bibliographic control, storage, and utilization. Edited by Claren M. Kidd, this is the proceedings of the 19th annual meeting of the Geoscience Information Society.

Order from: Publication Manager, Geoscience Information Society, c/o American Geological Institute, 4220 King St., Alexandria, VA 22302. The price is $20.

OKLAHOMA ABSTRACTS

GSA, Northeastern Section, Annual Meeting
Kiamesha Lake, New York, March 12–14, 1986

The following abstract is reprinted as published in *Abstracts with Programs, 1986* of the Geological Society of America, v. 18, no. 1. The page number is given in brackets below the abstract. Permission of the author and of the GSA to reproduce the abstract is gratefully acknowledged.

Sedimentary Structures from Borehole Images: Attempts to Model Their Three-Dimensional Geometry

STEFAN M. LUTHI, Schlumberger-Doll Research, Old Quarry Road, Ridgefield, CT 06877-4108

Borehole images contain information on the sedimentary structures in clastic sequences, and are of great value for the interpretation of depositional environments. Different borehole imaging techniques produce different types of information, borehole coverage, and degree of lateral as well as vertical resolution.

The digitized form of data facilitates computer processing using image analyses techniques. Since borehole images are recorded on a cylindrical surface, and since their lateral extent is considerably restrained, the three-dimensional reconstruction of sedimentary structures from borehole images becomes a prime issue. Several steps are proposed, the first of which is numerical quantification of the images with geologically relevant variables such as orientation and dip of directional structures, density of laminations, thickness of depositional units, etc. Subsequently, a comparison with type structures contained in a data bank has to be performed. These may be obtained using geometric and kinematic models already published or to be developed. Finally, the resulting reconstructed sedimentary features may be presented in oriented block diagrams for easier further interpretation.

OKLAHOMA ABSTRACTS is intended to present abstracts of recent papers relating to the geology of Oklahoma and adjacent areas of interest. The editors are therefore interested in obtaining abstracts of formally presented or approved documents, such as dissertations, theses, and papers presented at professional meetings.

Examples include a cross-bedded aeolian sequence, where dune shapes and palaeocurrents have been analyzed, and a fluvio-deltaic deposit, in which the onset of tidal influence is recognized through current reversals, herringbone cross-bedding and sand waves. [32]

GSA, Cordilleran Section, Annual Meeting
Los Angeles, California, March 25–28, 1986

The following abstract is reprinted as published in *Abstracts with Programs, 1986* of the Geological Society of America, v. 18, no. 2. The page number is given in brackets below the abstract. Permission of the author and of the GSA to reproduce the abstract is gratefully acknowledged.

Gas Phase Transport of Contaminants to Ground Water

MONTE E. RAY, LeRoy Crandall and Associates, 711 N. Alvarado St., Los Angeles, CA 90026

State of the art and regulations concerning contamination of ground water typically view contaminants as spreading in the form of a simplistically defined "plume." This case history entails landfill contaminants consisting of volatile organic gases such as vinyl chloride, TCE, PCE, benzene, and 1,1 and 1,2 dichloroethanes showing up in ground water in Tertiary bedrock without evidence of heavy metals, chlorides or other contaminants typical of liquid contact (such as leachate) contamination. The presence of these contaminants without diagnostic liquid contaminants suggests gas transport and gas solubility under various pressures as a significant mode of transport to the ground water from the vadose zone where gases come in contact with the ground water surface. Alternatively, cooling gases disseminating outwardly from a landfill may condense on rock and grain surfaces and then migrate into the surface of the ground water. Complexity of the transport mechanisms may be attributed in part to bedrock lithologies and structures. Several instances of wells containing contaminants of volatile organics associated with probable gas transport mechanism(s) have been recognized. Gas extraction systems may prove to be the desired mitigating measure. [174]

GSA, Southeastern and South-Central Sections, Annual Meeting
Memphis, Tennessee, April 2–4, 1986

The following abstracts are reprinted as published in *Abstracts with Programs, 1986* of the Geological Society of America, v. 18, no. 3. Page numbers are given in brackets below the abstracts. Permission of the authors and of the GSA to reproduce the abstracts is gratefully acknowledged.

Paleoecologic Comparison of Henryhouse and Haragan Faunas, South-Central Oklahoma

ROBERT M. ABERNETHY and JERRY W. VINCENT, Department of Geology, Stephen F. Austin State University, Nacogdoches, TX 75962

The Henryhouse and Haragan formations of south-central Oklahoma were deposited in an epeiric sea during a period of increasing faunal provincialism. They consist of marly limestones containing diverse, brachiopod-dominated fossil assemblages of the Silurian North Atlantic Region and the Devonian Appohimichi Subprovince, respectively.

The essentially identical lithology and similar faunal composition of the formations suggest an unchanging environment both within and between them, yet they are separated by an unconformity of some magnitude. Though they are taxonomically similar to coeval communities of their respective faunal realms, there is substantial variation in faunal density and dominance diversity characteristics among the assemblages of these two formations.

Where the Henryhouse is highly fossiliferous, assemblages range from diverse, low equitability *Atrypa* dominated communities to high diversity, high equitability *Dicaelosia*-Rhipidomellid communities. The Haragan Formation is more consistently fossiliferous with assemblages ranging from diverse, low equitability communities dominated by *Orthostrophia* and *Dicaelosia*-Rhipidomellid to more equitable *Leptaena-Meristella* and *Dicaelosia-Rhynchospirina* communities.

The high variability of faunal density and dominance diversity characteristics belie the consistently homogenous environment indicated by sedimentary parameters and taxonomic composition. Thus, controls for community variations likely involved fluctuations in trophic resources and unrecorded physical parameters. [209]

Middle Ordovician (Whiterockian-Mohawkian) Evolution of *Phragmodus* and *Plectodina*

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Middle Ordovician rocks of the North American Midcontinent are extremely difficult to correlate with precision. Conodonts offer a viable means of correlation but Middle Ordovician evolutionary lineages are imprecisely known at present. Following the Sauk regression, Midcontinent conodont faunas are highly restructured with the dominant forms including species of *Phragmodus* and *Plectodina* which are abundant in variety of shallow-water deposits.

The upper Simpson Group of southern Oklahoma contains abundant *Phragmodus* and *Plectodina* and appears to represent a more continuous record in comparison with other Midcontinent deposits. At least four species of *Phragmodus* can be recognized in the Simpson collections, two of which have been previously grouped together in *P. flexuosus*. Three of those species can be arranged in a lineage that qualitatively offers support for gradualistic evolution. The fourth species is coeval with *P. inflexus* and probably represents an unsuccessful branch of the lineage.

The *Plectodina* lineage is not clearly discerned from upper Simpson collections. The oldest species, *P. joachimensis*, is succeeded by a new species in the lower part of the sequence but their ranges overlap with no obvious transitional forms represented. *P. aculeata* along with transitions between it and the older *P.* n.sp. are recognized in the uppermost Simpson. [211]

Depositional Systems and Sandstone Diagenesis in the McAlester Formation (Surface and Subsurface) of East-Central Oklahoma

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The McAlester Formation (Desmoinesian Series) of the western Arkoma Basin and adjacent shelf contains five major deltaic sandstone units, whose subsurface equivalents are termed the Booch Sands. Evidence from 550 well logs, 2 core, 5 sets of well cuttings, and 12 measured sections demonstrates that the productive Lower Booch (Warner) in the Lake Eufaula area is dominated by two high constructive lobate delta lobes that prograded south-southeastward from eastern Kansas. Upper and lower delta plain facies, including distributary channels, crevasse splays, and delta plain sheet sand bodies were identified both in outcrop and from individual electric log curves. Isopach

and isolith maps of the Lower Booch, as well as an isopach map of the total McAlester Formation, indicate that the deltaic facies prograded to the shelf edge.

All sandstone units in the formation should be classified as sublitharenites. Monocrystalline quartz is the most prominent grain type, with lesser quantities of sedimentary rock fragments, metamorphic rock fragments, and feldspar (plagioclase and orthoclase) also being present. Authigenic cements include siderite, an important indicator of delta plain sedimentation, calcite, hematite, and chlorite. Illite is present as detrital matrix and kaolinite is the predominant authigenic clay mineral. Productive porosity in the Lower Booch is hybrid intergranular and represents more than one stage of precipitation and dissolution of authigenic cements. Dissolution of detrital constituents such as feldspar and clay clasts also enhanced the overall porosity, which ranges from 8 to 15 percent. [212]

Ground-Water Lakes—Modern and Pleistocene Examples from New Mexico and Texas[1]

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Quaternary deposits in the western Rolling Plains, northwestern Texas, include thick lenticular lithosomes of highly fossiliferous calcareous clay. These deposits accumulated in lakes very different from existing, small, ephemeral, pluvial lakes (playas) on the adjacent Southern High Plains. Better modern analogs are the perennial Bottomless Lakes in the semiarid Pecos River valley, Chaves County, New Mexico, on the opposite (western) side of the buried Palo Duro Paleozoic evaporite basin. The Bottomless Lakes are "cenotes": deep, steep-walled sinkholes extending below water table. Lake levels are maintained by artesian underflow from the Permian San Andres Limestone at depth. Geochemically unsaturated ground water rises through leaky confining beds of the Artesia Group and overlying Permian units that crop out on the eastern side of the Pecos River. The resulting dissolution of halite and gypsum within this section causes upward propagation of collapse chimneys like the karstic breccia pipes in nearby Delaware and western Anadarko evaporite basins. If a collapse structure reaches the surface it may become a ground-water lake. These lakes have small surface areas and negligible overland inflow, so that they receive little coarse-clastic sediment. Instead, they accumulate horizontally bedded clastic mud and both biogenic and authigenic carbonates. Continued subsidence causes tensional fracturing and

[1]Study funded by the U.S. Department of Energy, Contract No. DE-AC97-83WM46651.

downwarping of the lake sediment. Deposits within the Bottomless Lakes are almost identical to Pleistocene lacustrine strata in the western Rolling Plains. Fossil ostracodes, mollusks, and calcareous macrophytic algae in the Pleistocene units indicate limnological conditions similar to those in the Bottomless Lakes. [214]

Paleoecology of Middle-Upper Ordovician Graptolites, Ouachitas and Appalachians

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During the Middle-Upper Ordovician, the Ouachita geosyncline was tectonically tranquil, while the Appalachians were in the throes of the Taconic orogeny. In the N. Appalachians, major allochthons, composed in large part of graptolite shales deposited on the slope and rise, were emplaced in a foreland basin that was also a site of graptolite shale deposition. Such a foreland basin also developed in the S. Appalachians. Graptolite shales deposited in this basin range from the upper *tentaculatus* Zone to the *gracilis* Zone. The fauna of the S. Appalachians was cosmopolitan with markedly similar species assemblages being found in the N. Appalachians, the Ouachita geosyncline, and other continents. However, in the S. Appalachians, there are distinct differences in species assemblages over small geographic distances that appear to be due to local environmental controls. Distinct biofacies encompassing large geographic areas are developed in post-*gracilis* Zone strata. In the *amplexicaulis* Zone, one biofacies (biofacies A) is represented in the Marathon region of the Ouachitas, the western Cordillera, and the Arbuckle Mountains of Oklahoma (S. Oklahoma aulacogen). Biofacies B is represented in the Taconic foreland basin of New York and Quebec and in the Ouachita Mountains. Higher, in the *tubuliferus* Zone, biofacies A is replaced by biofacies B in the Arbuckles, and biofacies B is replaced by biofacies A in the Ouachitas. In the *amplexicaulis* and *tubuliferus* Zones, the N. Appalachian basin was isolated far from the Ouachita geosyncline. Still its distinct biofacies extends to the Arbuckles and Ouachitas. Depth in the water column is one possible control on the distribution of the biofacies, but it cannot explain some aspects. In the highest Orodvician (*complanatus* Zone) faunas are again cosmopolitan but of low diversity. [220–221]

***Declinognathodus noduliferus* Zone: Mississippian or Pennsylvanian?**

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Grayson and others (1985) documented a previously unknown conodont zonal succession from an exceptionally complete sequence of the Rhoda Creek Formation. The older *Adetognathus unicornis* Zone was considered latest Mississippian (Chesterian) and the younger *Declinognathodus noduliferous* Zone was regarded as "Pennsylvanian" but pretype Morrowan (Pennsylvanian) in age. In Oklahoma, the top of the *D. noduliferus* Zone is concealed and strata above the covered interval contain early Morrowan *Neognathodus symmetricus* Zone conodonts.

An occurrence of *D. noduliferus* Zone conodonts has also been discovered in Central Texas from a thin unit between the Barnett Shale (Mississippian) and the Marble Falls Limestone (Pennsylvanian). The upper Barnett Shale yields a low diversity fauna dominated by the platform species *Paragnathodus commutatus* and *Gnathodus bilineatus*. In Texas, the *D. noduliferus* Zone is succeeded above a disconformity by middle Morrowan *Idiognathodus sinuosis* Zone conodonts.

In Oklahoma and Texas, assignment of the *D. noduliferus* Zone to either Mississippian or Pennsylvanian is without a material basis. Nonetheless, the appearance of *D. noduliferus* zonal conodonts represents an abrupt evolutionary event that could serve as a possible horizon to locate a Mississippian-Pennsylvanian boundary stratotype. This horizon would also have the advantage of being readily recognizable on an intercontinental basis. In Europe the zone can be equated with the ammonoid cephalopod *Homoceras* (H_1-H_2) Stage although it succeeds a depauperate conodont fauna from the highest *Eamorphoceras* (E_{2c}) Stage. [224]

Conodont Color Alteration Above 300°C: Calibration Experiments and Geologic Applications

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Conodont color alteration (CAI) has become a widely used index of organic metamorphism. Experimental studies of Epstein and others (1977) established geologic temperature ranges for CAI 1–5; approximate temperature ranges for higher CAI values were based on occurrences of high CAI conodonts with metamorphic mineral indices. We undertook experimental calibration of CAI >5 because of increasing use of conodonts to date and thermally characterize metamorphic rocks. We used open-air, anhydrous pyrolysis of unaltered conodonts to induce color alteration. These experiments show that: (1) CAI 6–8 in conodonts from regionally metamorphosed, contact metamorphic, and hydrothermally altered rocks can be reproduced by heating alone and are time/temperature dependent and (2) the temperature ranges for CAI's >5, for 500 million to 1,000 years, determined from an Arrhenius plot of the experimental data are: CAI 5 = 360°–550°C; CAI 6 = 440°–610°C; CAI 7 = 490°–720°C; CAI 8 = >600°C.

Anhydrous pyrolysis at 1 kb neither retards nor accelerates conodont color alteration, but under the same conditions, the addition of water considerably retards it. We tried to calibrate thermally induced color alteration in a water-methane, oxygen-buffered system at ½ kb. These experiments show that: (1) CAI is retarded by about 50%; (2) above CAI 2 or 3, conodonts show a mixture of CAI values because color alteration processes change from predominantly carbonization to predominantly oxidation of organic matter; (3) conodonts have CAI values and textures most like those from hydrothermally altered and contact metamorphic rocks.

Field and laboratory data indicate that uniformity or variability of CAI values within a sample or from sample to sample within a small area, together with the texture of conodonts, helps differentiate kinds of metamorphism. Although CAI 6–8 values may not indicate temperatures of hydrothermally altered rocks, they may be valuable indicators of potential mineralization. [225]

The New Madrid Earthquake Hazard: A Strategy for Geologic Education in the South-Central U.S.

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Recently public attention has been focused on the New Madrid Seismic Zone and the potential hazard presents an unusual opportunity for academic geologists and earth science teachers to address various aspects of this risk in introducing such traditionally treated geologic topics as mass wasting, subsidence, soils, flooding, groundwater, geologic structure, faulting, tectonics and seismology. Mass wasting may be treated by first discussing the slope stability problems along the valley walls of the Mississippi Valley and Crowley's Ridge. Subsidence may be introduced in the context of sunken lands and raised lands produced in 1811 and 1812. Soils could be addressed from the view of predicted liquefaction problems and such phenomena as sand blows. Flooding and other aspects of stream flow could lead from the flooding predicted from breached levees and failed locks and dams. Ground water could be discussed starting from disruption of aquifers and water wells, and ground water behavior prior to an earthquake. Examples of geologic structures may easily be given using the Reelfoot rift as a focal point. Change of structural style with time is also possible using the rift as a case history. Of course, seismology, earthquake prediction and intraplate seismology and related topics are easily initiated discussing the seismic risk in the Mississippi Valley. This geologic approach is recommended in earth science courses in our middle and secondary schools and where appropriate, in our introductory and upper level geology courses. [249]

Metagabbros of the Ouachit Core, Arkansas and Oklahoma[1]

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Two occurrences of deformed, greenschist facies metagabbro have been documented in the core of the Ouachita Mountains, one at Hominy Hill in the Benton uplift near Alexander, Arkansas, and the other, previously reported by Honess (1923) near Broken Bow, Oklahoma. Their structural and stratigraphic setting is similar to the metamorphosed ultramafics ("soapstones"), and these rocks may all be related to a similar source. The age obtained by K-Ar whole-rock methods on the Hominy Hill metagabbro is 1025 +/− 48 Ma (Precambrian). Actual age of the rock may be slightly younger (700–1000 Ma) due to low K abundances and small amounts of excess Ar (40* Ar/Total Ar = 0.494–0.580), but is almost certainly Late Precambrian.

The Hominy Hill metagabbro extends as boudins or 25 m-wide en echelon pods approximately 2 km along a NW–SE trend, and is enclosed in Ordovician Womble shale near the overlying Bigfork Chert. Contacts with the host Womble shale appear sheared. The Hominy Hill metagabbro contains titanaugite with an average of 2.3 wt% TiO_2 and high Al_2O_3, indicating a mildly alkaline nature. REE are 30 × chondrite, and have a flat pattern. These and other low-mobility geochemical discriminants (TiO_2, Zr, P_2O_5, Y) indicate a slightly LIL-enriched oceanic character, similar to EMORB. Possible settings for the origin of this rock include back-arc basin or transform fault.

The Honess gabbro from the Broken Bow uplift is an extremely sheared rock which occurs in separated pods 3 to 10 m in width along a 1 km NE–SW trend in the southern-most Ouachita core. It is also enclosed in Womble shale near the contact with the Bigfork Chert. The host Womble is a coarser grained rock than at Hominy Hill and is metamorphosed to lower-most greenschist facies. Limestone pods in the Womble adjacent to the Honess gabbro contain a typical Womble conodont assemblage with a CCI suggesting temperatures above 350°C. Major-element abundances of the Honess gabbro may not accurately reflect its original nature due to the extreme deformation and alteration, but suggest that it is (was) a slightly more silicic rock than that of Hominy Hill. No relict minerals have been found to date.

The metagabbros of the Ouachita core may define a significant trend related to early rifting or transform activity in the Ouachita trough. The deformed and metamorphosed character of these gabbros and the related ultramafic pods suggest diapiric emplacement of these igneous rocks in an extensional tectonic environment long before the Ouachita orogeny.

[256–257]

[1]This is a revised abstract submitted by the authors.

Multistage Deformation and Variable Strain Axes for the Arbuckle Mountains, Oklahoma

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While extensive attention has been given to the regional structural setting of the Arbuckle Mountains, limited detailed work has been published analyzing critical age relationships. Three areas have been remapped at a scale of 1:12,000. These areas are the East Timbered Hills, the Doughtery anticline, and the Wapanucka area in the eastern Arbuckle Mountains. From these studies the three stages of deformation are best observed in the East Timbered Hills. (1) Initial northeast-southwest shortening places the Colbert Rhyolite in fault contact with the Arbuckle Group. Folding associated with this southwest dipping fault zone appears to correlate to the larger Arbuckle anticline. (2) Cross cutting these early structures are north-south trending faults and folds. Just west of highway I-35, rotated folds of the Arbuckle anticline plunge about vertically along the westerly dipping (~ 70°) fault. Just south of Turner Falls, north-south trending faults reorient early folds such that they plunge steeply towards the northwest. At the southern end of the Timbered Hills a large scale fold hinge plunges ~ 35° due south. (3) The third stage can be seen in the synorogenic conglomerates, the Collings Ranch Conglomerate. Folds within this conglomerate trend east-west, and faults within the conglomerate have sub-horizontal slickensides. Analysis of calcite twins in limestones near the Reagan and Sulphur fault zones reveal an east-west compression direction followed by a north-south compression axis (Islam, 1985). These data suggest that the stress associated with initial folding was not high enough for calcite twin formation. The extension axes are also horizontal indicating left-lateral slip within the existing fault zones (east-west compression) and then right-lateral slip (north-south compression). The dominant southeast trend of the fold system is apparent in high altitude photographs; but then so is a well developed south-trending set of younger "cross folds."
[258]

A Structural Analysis of a Portion of the Seneca Fault in Mayes County, Oklahoma

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The Seneca fault is a prominent northeast-trending wrench fault that cuts Paleozoic strata on the southwestern margin of the Ozark uplift in northeastern Oklahoma and southwestern Missouri. The age of faulting suggests that the Seneca fault may be a continental effect of Ouachita collisional events.

Evidence for wrench faulting includes nearly horizontal slickensides, mixed stratigraphic offsets, propeller blade fault planes, and a flower

structure. Strike-slip faults parallel to the overall trend of the Seneca fault (approximately N50E), right-lateral faults oriented at N60E to N80E, left-lateral faults oriented at N60W to N80W, veins and normal faults in an east-west direction, and folds and a thrust fault oriented in a north-northwest direction indicate that the Seneca fault is a right-lateral wrench fault system. A discontinuous structural sag associated with the zone of faulting may have a pull-apart origin due to either overlapping en echelon faults, or bends in the trend of the fault zone. [259]

Collings Ranch Conglomerate: An Example of Syndepositional Deformation in an Extensional Strike-Slip Basin at the Arbuckle Mountains, Oklahoma

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An approximately 200 ft (61 m) thick limestone boulder-cobble conglomerate which unconformably overlies the steeply dipping limestone units of the Arbuckle Group on the northeastern flank of the Arbuckle anticline is exposed at the vicinity of the Turner Falls area, Arbuckle Mountains, Oklahoma. Ham (1954) observed many characteristics of the unit, named it as the Collings Ranch Conglomerate, and determined its age as Middle Virgilian (Late Pennsylvanian). The conglomerate consists of mostly angular and poorly sorted limestone clasts of the Arbuckle Group (Lower Ordovician) imbedded in a clay to sand matrix. Subordinate to the limestone clasts are a few Reagan sandstone (Cambrian) fragments. The angularity of the clasts, their derivation from the underlying formations, the poor sorting, and the presence of fine grained matrix indicate that the conglomerate is an alluvial fan deposit. When present, channel deposits show well developed imbricate structure.

The conglomerate is deposited in an extensional strike-slip basin formed in response to left-stepping along the left-lateral Washita Valley strike-slip fault zone of the Arbuckle Mountains. A northwest trending syncline, well exposed along I-35, lies close to the structural axis of the basin. The syncline is a flexural-slip fold showing (1) well developed shear zones and (2) slickensides perpendicular to the strike of the bedding. The fault surfaces with slickensides do not truncate the clasts and are restricted to the matrix. These suggest to us that the syncline was formed prior to cementation of the conglomerate and contemporaneous with deposition. [260–261]

Late Devonian–Early Mississippian Phosphorite-Bearing Shales, Arbuckle Mountain Region, Oklahoma

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Variations in phosphorite development across the Arbuckle Mountain region of southern Oklahoma reflect hydrographic and topographic conditions during late Famennian–early Kinderhookian time. Formation of marine apatite was controlled by upwelling circulation and concurrent development of a prolific pelagic biota. Release of phosphorous occurred as organic matter decayed near the boundary of the oxygen minimum layer, and phosphate subsequently accumulated below the sediment/water interface.

In the central Arbuckle Mountain region, phosphorites formed at shallow bathyal depths and occur as discrete spheroidal to lenticular nodules in black siliceous shales and cherts of the Woodford Shale. X-ray diffraction analysis reveals no phosphate within the sediments except that within the nodules. Nodules formed as a result of physicochemical mobilization of syndepositional phosphate by differential compaction. Various stages of fluorapatite crystal development occurred as a result of phosphate mobilization.

On the Lawrence Uplift, 35 miles to the northeast, phosphorites accumulated on a current agitated platform and occur as irregular laminae interbedded with dark clay shales and black siliceous shales of the Woodford. Phosphate formed as discrete, sand-sized collaphonous micronodules. Most micronodules lack internal structure, although some are concentrically laminated and others resemble grapestones. Reworking of phosphate by winnowing currents concentrated the micronodules into packstone laminae, and ultimately into irregular nodules. Discrete nodules accumulated in the overlying green shales of the pre-Welden horizon due to reworking of packstone laminae. [266]

The Impact of Recently Enacted Federal Legislation on Demand for Geoscientists

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Cycles of demand for scientists are familiar. We are on the edge of a long-range demand for some types of geoscientists; this is driven by legislation for management of radioactive and hazardous wastes. The result is a mandated job market for at least a decade for many types of geoscientists.

Legislation dealing with disposal of radioactive wastes, especially high-level wastes, has created demand for hundreds of geoscientists, especially hydrologists and geochemists. Increased employment for such disciplines as we seek sites for mined repositories will continue. The greatest impact, however, will be seen from the legislation (RCRA, CERCLA) that deals with disposal of hazardous wastes. Regulatory time bombs have been created that require intensive study of sites to assess and to minimize contaminant migration. It is estimated that as much as $15 to $20 billion will be needed annually for the RCRA, which covers such areas as municipal landfills, of which some 18,000 may exist nationwide, and development and application of new standards for land disposal systems for wastes. The superfund sites (CERCLA) are being identified from 21,000 potential sites; as many as 10,000 may end up on the National Priority List for full characterization and cleanup.

Hydrology leads the list of needed geoscience disciplines, but others cannot be overlooked. Aqueous geochemistry (inorganic and organic) and its link to transport processes through modeling will be crucial. Flow through fractured media must be quantified and represents a link between structural geology and hydrology. The list could be expanded. The community must provide needed expertise. While perceptions of a dismal job market apply to many geoscience areas, they do not apply to waste-management. Trends of graduate enrollment and degrees granted do not indicate that the scientists in demand are geing produced. [267]

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Geochemistry of Germanium in Coal—A Review

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A review of the geochemistry of Germanium (Ge) in coals is presented. Emphasis on the origin, source, occurrence, distribution within the bed, chemical affinity, and physicochemical extraction are discussed.

There is a rising demand for Germanium (Ge) due to its widespread use in metallurgy, chemotherapy, polymer chemistry, optical instrumentation and the manufacture of transistors and solar cells. In addition, organocomplexes of the type R_3GeX possess marked antimicrobial activity with low toxicity. The potential uses of this element are legion; however, Ge does not form one distinctive binary mineral compound, but instead crystallizes with many other elements and is highly dispersed as a trace element in nature.

Most of the world production is derived from smelting of Ge-rich zinc sulfides that are enriched (160 ppm) in the flue dust. Review of the industry indicates that the Ge content in coal can economically compete with this source. For example, high concentrations of Ge (2500 ppm) are known to occur in the lower 4½" and upper 2" of the L. Kittanning (No. 5) coalbeds of Ohio. The best model which explains this dual occurrence was proposed by Quick (1983). He employed the concepts of Hubbert (1949) who related groundwater flow to equipotential lines. The Ge was transported by convective diffusion into the coal where the COOH (carboxyl) functional groups in humic acids chemisorbed or organically complexed the Ge. Possible sources for the Ge are from *Equisetales* flora which can metabolically concentrate the Ge and on decomposition can release the enriched Ge to groundwater or from deltaic sands which were permeated by groundwater.

Selective mining of each bed and use of electrostatic precipitators, with a cyclone burner and a chain-grate type furnace could beneficiate the Ge concentration in coal for greater than those occurring in flue dust of zinc sulfide ores. [313]

A Methodology for Identification of Aquifer Contamination by Oil/Gas Brines

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Shallow water wells in highly permeable sediments are particularly susceptible to contamination. The high hydraulic conductivity of such sediments allows the advection of contaminants with relative speed and ease. One of the most common sources of the shallow aquifer contamination is associated with oil/gas drilling operations.

Contamination of ground water by oil/gas brine results in high salinity. However, an elevated salinity in ground water may also be caused by other factors, such as road de-icing agents. The use of Stiff's "shape" and Piper's trilinear diagrams in conjunction with factor analysis of ionic ratios provide an objective methodology to identify oil/gas brines and to distinguish this source of contamination from other agents.

Oil brines, contaminated water well and non-contaminated water well samples were collected in Perry Township, Lake County, Ohio. Piper and Stiff diagrams and chemical analyses are presented for the brines and water well samples. Stiff diagrams of contaminated water wells show a distinctly similar shape to those of the brines, while the unaffected wells show a very different shape. Similarly, waters of the contaminated wells plot in the same vicinity on the Piper diagrams as do the brines, while the unaffected wells plot in a different area. The relative percentage of magnesium, calcium, sodium and chloride are similar between the brines and contaminated wells. This method is suggested as a standard procedure to identify contamination of aquifers by oil/gas brines. [317]