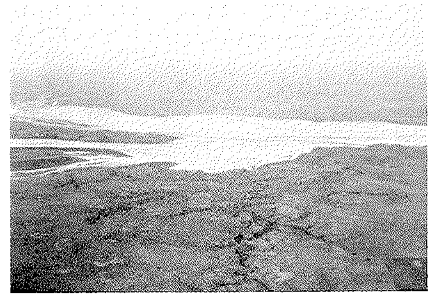
# Oklahoma Geology Notes

OKLAHOMA GEOLOGICAL SURVEY/VOL. 45, NO. 1—FEBRUARY 1985

*On the cover—*

## Natural Salt Deposits Formed at Western Oklahoma Localities



Big Salt Plain

At several localities in northwestern and southwestern Oklahoma, high-salinity brines escape to the surface through natural springs and create impressive salt plains or salt flats on the banks of rivers and streams. Layers of Permian rock salt in the Anadarko and Hollis Basins are being dissolved by fresh ground water at depths of 30 to 500 ft beneath the land surface. The resulting brine, which is nearly saturated with respect to sodium chloride, moves laterally and upward under hydrostatic pressure through small caverns, fractures, and clastic aquifers until it reaches the land surface.

Pictured on the cover is a crust of salt (white) built up on the floor of Salt Creek Canyon in Blaine County, west-central Oklahoma. The brine has been partially evaporated by the sun, leaving salt crystals incrusted on the surface adjacent to the springs and waterway. The field of view is about 5 ft wide.

Major salt plains include Great Salt Plains on the Salt Fork of the Arkansas River near Cherokee (Alfalfa County); Big Salt Plain and Little Salt Plain on the Cimarron River near Freedom (Woods County); Harmon County Salt Plains on the Elm Fork of the Red River near Erick; and Salt Creek Canyon Salt Plain just east of Southard (Blaine County).

These deposits have been a source of commercial salt to Indians, early-day settlers, and modern-day industry. Plants at which salt is produced by solar evaporation currently operate on Big Salt Plain and on the Harmon County Salt Plains.

Pictured in the inset above is an aerial view of Big Salt Plain at the confluence of the Cimarron River and Buffalo Creek, where Harper, Woods, and Woodward Counties meet. In this view, looking to the northwest, the salt plain extends 3 mi across the center of the photograph. Brine rising through the alluvium is evaporated by the sun and wind, leaving salt crystals as an incrustation on the alluvial plain. A salt crust up to several inches thick can be built up after one or two weeks of hot, dry weather.

*Kenneth S. Johnson*

*Cover photo by Tari Harrington*
*Inset photo, above, by Kenneth S. Johnson*


## Oklahoma Geology Notes

**Editor:** Connie Smith
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**Oklahoma Geology Notes**, ISSN 0030-1736, is published bimonthly by the Oklahoma Geological Survey. It contains short technical articles, mineral-industry and petroleum news and statistics, reviews, and announcements of general pertinence to Oklahoma geology. Single copies, $1.50; yearly subscription, $6. All subscription orders should be sent to the Survey at 830 Van Vleet Oval, Room 163, Norman, Oklahoma 73019.

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, 1982–83

Robert H. Arndt[1]

## Introduction

The biennium 1982–83 witnessed culmination of certain aspects of the petroleum boom that began in the late 1970's and continued into the early part of the 1980's. The total number of well completions, reflecting the intensity of drilling, reached a maximum in 1982 (table 1). The total value of produced oil and marketed natural gas similarly climaxed that year but fell in 1983 as a result of sharply reduced prices and a significant decrease in demand for natural gas (table 2). Contrastingly, the total annual production of oil grew continuously through 1983 to a level at 4.7 percent above that in 1981. The number of producing oil and gas wells also continued to increase (table 2). Oklahoma ranked fifth among those states that produced oil and third among those that produced natural gas by supplying 4.5 percent of the domestic output of oil and almost 10 percent of the domestic output of natural gas in 1982 and 1983.

## Drilling

The intensity of drilling is the most obvious evidence of oil- and gas-industry prosperity in producing states. Drilling footage was 63.5 million ft in 1982, an increase of 20 percent above that accomplished in 1981. Rapid erosion of the drilling industry in late 1982 and during 1983 reduced drilling footage in the latter year to 48.7 million ft, 8 percent below that of 1981 (table 1). About 91 percent of the footage was in development wells in 1982, and 90 percent in 1983. Completed wells ranged from depths of several hundred feet to more than 20,000 ft (table 3, a and b). About 88 percent of all wells drilled in 1982 were 10,000 ft or less in depth; 90 percent were in this depth range in 1983. The average depth of all completions was 5,324 ft in 1982. With an increase in the proportion of wells drilled to less than 5,000 ft in depth, the average footage dropped to 4,891 ft in 1983. Both of these average depths exceeded the average depth of 4,674 ft reported in 1981. Thirty-six wells exceeded a depth of 20,000 ft in 1982, and

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

TABLE 1.—DRILLING ACTIVITY IN OKLAHOMA, 1982, 1983

| | Oil | Gas | Dry | Total | 1981 Total |
|---|---|---|---|---|---|
| **All Wells** | | | | | |
| Number of wells | | | | | 11,300[1] |
| 1982 | 5,996 | 2,593 | 3,319 | 11,908[1] | |
| 1983 | 5,010 | 1,886 | 3,039 | 9,935[1] | |
| Total footage | | | | | 52,818,390 |
| 1982 | | | | 63,393,032 | |
| 1983 | | | | 48,590,456 | |
| Average footage | | | | | 4,674 |
| 1982 | | | | 5,324 | |
| 1983 | | | | 4,891 | |
| **Exploratory Wells** | | | | | |
| Number of completions | | | | | 651 |
| 1982 | 139 | 149 | 387 | 675 | |
| 1983 | 109 | 99 | 434 | 642 | |
| Percentage productive | | | | | 38 |
| 1982 | 20.6 | 22.1 | 57.3 | | |
| 1983 | 17.0 | 15.4 | 67.7 | | |
| Total footage | | | | | 4,685,481 |
| 1982 | | | | 5,711,608 | |
| 1983 | | | | 5,024,269 | |
| Average footage | | | | | 7,197 |
| 1982 | | | | 8,462 | |
| 1983 | | | | 7,826 | |
| **Development Wells** | | | | | |
| Number of completions | | | | | 10,649 |
| 1982 | 5,857 | 2,444 | 2,932 | 11,233 | |
| 1983 | 4,901 | 1,787 | 2,605 | 9,293 | |
| Percentage productive | | | | | 77 |
| 1982 | 52.1 | 21.8 | 26.1 | | |
| 1983 | 52.7 | 19.2 | 28.0 | | |
| Total footage | | | | | 48,132,909 |
| 1982 | | | | 57,681,424 | |
| 1983 | | | | 43,566,187 | |
| Average footage | | | | | 4,520 |
| 1982 | | | | 5,135 | |
| 1983 | | | | 4,688 | |

Source: American Petroleum Institute.
[1]Excludes service and stratigraphic test (core) boreholes and old wells drilled deeper.

50 wells reached similar depths in 1983. The greatest drilling depths were reached by both exploratory and development wells primarily in the Anadarko Basin (fig. 1, a and b). Beckham, Caddo, Comanche, Grady, Washita, and Blaine Counties each had several wells drilled to depths below 20,000 ft.

Kingfisher and Custer Counties each had more than 3 million ft of drilling, and drilling footage exceeded 2 million ft in Roger Mills, Caddo, Major, Dewey, and Garfield Counties in 1982. In total, these seven counties had 22.6 million ft or about 36 percent of the State's total footage. Drilling footage exceeded 2 million ft only in Caddo, Custer, and Roger Mills Counties in 1983. Creek, Dewey, Canadian, Grady, and Kingfisher Coun-

TABLE 2.—HYDROCARBON PRODUCTION IN OKLAHOMA, 1981–83

| | 1981 | 1982 | 1983 |
|---|---|---|---|
| **Crude Oil and Lease Condensate** | | | |
| Total annual production (1,000 bbl)[1] | 152,252 | 158,674 | 159,354 |
| Value ($1,000)[1] | 5,355,474 | 5,195,614 | 4,761,280[2] |
| Cumulative production[1] 1891–1983 (1,000 bbl) | 12,245,851 | 12,404,525 | 12,563,879 |
| Daily production (bbl)[1] | 417,129 | 434,723 | 436,586 |
| Total number of producing wells[3] | 82,639 | 91,745 | 95,868 |
| Daily average per well (bbl) | 5.1 | 4.7 | 4.6 |
| Oil wells on artificial lift[3] | 78,076(e) | 86,699 | 91,074 |
| **Natural Gas** | | | |
| Total annual marketed production (MMcf)[1] | 2,030,225 | 1,924,189 | 1,807,758 |
| Value ($1,000)[1] | 3,831,636 | 5,336,377 | 4,818,885 |
| Total number of gas or gas-condensate wells[3] | 16,994 | 20,742 | 22,135 |
| **Natural Gas Liquids** | | | |
| Total annual marketed production (1,000 bbl)[3] | 74,000 | 77,000 | 80,000 |
| Value ($1,000) | 2,020,200(e) | 2,521,288(e) | 2,390,723(e) |

[1]Oklahoma Tax Commission, tax-paid production.
[2]Includes $33,031,790 value of gas liquids not included elsewhere.
[3]Published: *World Oil*, v. 194, no. 3, Feb. 15, 1982; v. 196, no. 3, Feb. 15, 1983; v. 198, no. 3, Feb. 15, 1984; U.S. Department of Energy, various reports.
(e) = estimated.

ties each had between 1.5 and 2 million ft of drilling that year. Drill penetration in the eight counties was about 15.2 million ft or about 31 percent of all penetration in Oklahoma in 1983.

The weekly count of the number of rigs engaged in actual drilling operations within the State is the index of current drilling activity. Drilling was at a maximum for the year 1982 in the fourth week of January, when 882 rigs were operating. In the first week of June, the count had dropped to 694 rigs. It declined eventually to 336 rigs, the minimum for the year, in the first week in November. The first week in January of 1983 witnessed 368 active rigs. The lowest count in 1983 was 232 rigs, in the fourth week of April. An irregular increase in drilling activity brought the rig count in 1983 to the maximum of 418 in the last week of December.

## Well Completions

The American Petroleum Institute reported that oil- and gas-well completions in Oklahoma, excluding old wells drilled deeper and service wells, numbered 11,300 in 1981, 11,908 in 1982, and 9,935 in 1983. Exploration accounted for 4.6 percent of all wells drilled in 1981, 5.7 percent in 1982, and 6.5 percent in 1983. The remainder were development wells. Well

TABLE 3a.—COMPLETION DATA AND DEPTH INFORMATION FOR WELLS DRILLED IN OKLAHOMA, 1982

| County | Total no. of wells drilled | Completions: Oil | Completions: Gas | % Completions Oil & Gas | Number of wells drilled in following total-depth ranges (ft): 1-5,000 | 5,000-10,000 | 10,000-15,000 | 15,000-20,000 | >20,000 |
|---|---|---|---|---|---|---|---|---|---|
| Alfalfa | 95 | 48 | 21 | 73 | 4 | 91 | | | |
| Atoka | 7 | 1 | 2 | 43 | 3 | 1 | 3 | | |
| Beaver | 210 | 41 | 112 | 73 | 10 | 200 | | | |
| Beckham | 79 | 3 | 58 | 77 | 3 | 3 | 26 | 43 | 4 |
| Blaine | 125 | 37 | 52 | 71 | 1 | 74 | 50 | | |
| Bryan | 16 | 6 | | 37 | 11 | 4 | 1 | | |
| Caddo | 188 | 46 | 98 | 76 | 23 | 5 | 73 | 77 | 10 |
| Canadian | 302 | 193 | 87 | 93 | 2 | 223 | 77 | | |
| Carter | 192 | 148 | 9 | 82 | 105 | 63 | 21 | 3 | |
| Cherokee | 5 | | | | 5 | | | | |
| Choctaw | 5 | 3 | | 60 | 4 | 1 | | | |
| Cimarron | 40 | 4 | 7 | 27 | 22 | 18 | | | |
| Cleveland | 126 | 78 | 1 | 63 | | 122 | 4 | | |
| Coal | 16 | 6 | 6 | 75 | 2 | 13 | 1 | | |
| Comanche | 105 | 44 | 23 | 64 | 80 | 1 | 3 | 6 | 15 |
| Cotton | 93 | 43 | 14 | 61 | 92 | 1 | | | |
| Craig | 116 | 6 | 78 | 72 | 116 | | | | |
| Creek | 570 | 355 | 78 | 76 | 568 | 2 | | | |
| Custer | 233 | 18 | 155 | 74 | 4 | 5 | 164 | 60 | |
| Dewey | 232 | 126 | 46 | 74 | 1 | 156 | 70 | 5 | |
| Ellis | 105 | 18 | 54 | 68 | | 70 | 32 | 3 | |
| Garfield | 317 | 206 | 46 | 79 | 29 | 288 | | | |
| Garvin | 233 | 160 | 14 | 75 | 121 | 90 | 21 | 1 | |
| Grady | 162 | 51 | 58 | 67 | 15 | 29 | 70 | 47 | 1 |
| Grant | 186 | 93 | 27 | 64 | 55 | 131 | | | |
| Greer | 11 | 1 | 7 | 72 | 11 | | | | |
| Harmon | 6 | 1 | | 17 | 5 | 1 | | | |
| Harper | 75 | 5 | 34 | 52 | 2 | 73 | | | |
| Haskell | 83 | | 58 | 70 | 39 | 41 | 3 | | |
| Hughes | 215 | 76 | 62 | 64 | 196 | 19 | | | |
| Jackson | 14 | 3 | | 21 | 8 | 6 | | | |
| Jefferson | 51 | 37 | | 72 | 41 | 8 | 2 | | |
| Johnston | 4 | 1 | | 25 | 2 | 1 | 1 | | |
| Kay | 206 | 51 | 52 | 50 | 202 | 4 | | | |
| Kingfisher | 413 | 345 | 54 | 97 | | 383 | 30 | | |
| Kiowa | 97 | 63 | 1 | 66 | 96 | 1 | | | |
| Latimer | 22 | | 13 | 59 | | 7 | 15 | | |
| Le Flore | 33 | | 21 | 64 | 2 | 27 | 2 | 2 | |

TABLE 3a.—CONTINUED

| County | Total no. of wells drilled | Completions: Oil | Completions: Gas | % Completions Oil & Gas | Number of wells drilled in following total-depth ranges (ft): 1-5,000 | 5,000-10,000 | 10,000-15,000 | 15,000-20,000 | >20,000 |
|---|---|---|---|---|---|---|---|---|---|
| Lincoln | 274 | 109 | 49 | 58 | 202 | 72 | | | |
| Logan | 275 | 166 | 32 | 72 | 19 | 256 | | | |
| Love | 131 | 107 | 1 | 82 | 16 | 71 | 42 | 2 | |
| McClain | 154 | 103 | 6 | 71 | 4 | 88 | 62 | | |
| McCurtain | 7 | | | | 7 | | | | |
| McIntosh | 36 | 1 | 21 | 61 | 34 | 2 | | | |
| Major | 285 | 208 | 58 | 93 | 4 | 268 | 12 | | 1 |
| Marshall | 17 | 7 | | 41 | 14 | 2 | | 1 | |
| Mayes | 57 | 33 | 5 | 67 | 56 | 1 | | | |
| Murray | 19 | 3 | 1 | 21 | 17 | 1 | | 1 | |
| Muskogee | 231 | 110 | 39 | 64 | 231 | | | | |
| Noble | 261 | 159 | 18 | 68 | 126 | 135 | | | |
| Nowata | 337 | 173 | 110 | 84 | 337 | | | | |
| Okfuskee | 218 | 79 | 53 | 60 | 218 | | | | |
| Oklahoma | 113 | 53 | 17 | 62 | 3 | 110 | | | |
| Okmulgee | 422 | 200 | 116 | 75 | 422 | | | | |
| Osage | 616 | 410 | 35 | 72 | 616 | | | | |
| Pawnee | 244 | 154 | 16 | 70 | 244 | | | | |
| Payne | 298 | 199 | 10 | 70 | 252 | 46 | | | |
| Pittsburg | 96 | 1 | 62 | 66 | 45 | 30 | 21 | | |
| Pontotoc | 329 | 219 | 33 | 76 | 326 | 3 | | | |
| Pottawatomie | 280 | 172 | 2 | 62 | 178 | 102 | | | |
| Pushmataha | 2 | | | | | | 2 | | |
| Roger Mills | 213 | 10 | 146 | 73 | 7 | 9 | 144 | 53 | |
| Rogers | 136 | 74 | 27 | 74 | 136 | | | | |
| Seminole | 304 | 183 | 22 | 67 | 295 | 9 | | | |
| Sequoyah | 5 | | 2 | 40 | 3 | 2 | | | |
| Stephens | 309 | 202 | 28 | 74 | 249 | 49 | 5 | 5 | 1 |
| Texas | 127 | 22 | 50 | 57 | 24 | 103 | | | |
| Tillman | 9 | | | | 9 | | | | |
| Tulsa | 293 | 180 | 42 | 76 | 293 | | | | |
| Wagoner | 101 | 34 | 27 | 60 | 100 | 1 | | | |
| Washington | 391 | 259 | 71 | 84 | 391 | | | | |
| Washita | 113 | 6 | 70 | 67 | 4 | 5 | 36 | 64 | 4 |
| Woods | 108 | 27 | 34 | 56 | 3 | 105 | | | |
| Woodward | 109 | 16 | 42 | 53 | 1 | 92 | 16 | | |
| **State total** | 11,908 | 5,996 | 2,593 | 72 | 6,766 | 3,724 | 1,009 | 373 | 36 |

Source: American Petroleum Institute.

## TABLE 3b.—COMPLETION DATA AND DEPTH INFORMATION FOR WELLS DRILLED IN OKLAHOMA, 1983

| County | Total no. of wells drilled | Completions | | % Completions Oil & Gas | Number of wells drilled in following total-depth ranges (ft) | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Oil | Gas | | 1-5,000 | 5,000-10,000 | 10,000-15,000 | 15,000-20,000 | >20,000 |
| Alfalfa | 66 | 25 | 18 | 65 | 1 | 65 | | | |
| Atoka | 10 | 2 | 2 | 40 | 5 | 3 | 1 | 1 | |
| Beaver | 175 | 47 | 82 | 74 | 4 | 171 | | | |
| Beckham | 58 | 2 | 28 | 52 | 2 | 2 | 16 | 30 | 8 |
| Blaine | 127 | 29 | 60 | 70 | | 99 | 27 | | 1 |
| Bryan | 11 | 5 | | 45 | 3 | 7 | 1 | | |
| Caddo | 185 | 56 | 71 | 69 | 26 | | 52 | 92 | 15 |
| Canadian | 195 | 127 | 50 | 91 | 5 | 161 | 29 | | |
| Carter | 195 | 150 | 3 | 78 | 139 | 41 | 13 | 2 | |
| Cherokee | 7 | | 2 | 28 | 7 | | | | |
| Choctaw | 4 | | | | 2 | 1 | 1 | | |
| Cimarron | 37 | 10 | 10 | 54 | 21 | 16 | | | |
| Cleveland | 79 | 38 | 6 | 56 | | 79 | | | |
| Coal | 10 | 2 | | 20 | 4 | 6 | | | |
| Comanche | 100 | 34 | 14 | 48 | 64 | 3 | 3 | 14 | 16 |
| Cotton | 59 | 23 | 6 | 49 | 58 | 1 | | | |
| Craig | 112 | 5 | 81 | 77 | 112 | | | | |
| Creek | 685 | 430 | 77 | 74 | 684 | 1 | | | |
| Custer | 151 | 15 | 80 | 63 | | 5 | 91 | 55 | |
| Dewey | 180 | 91 | 28 | 66 | | 123 | 55 | 2 | |
| Ellis | 85 | 27 | 25 | 61 | 3 | 51 | 30 | 1 | |
| Garfield | 168 | 90 | 37 | 75 | 28 | 140 | | | |
| Garvin | 192 | 110 | 10 | 62 | 113 | 68 | 10 | 1 | |
| Grady | 129 | 50 | 38 | 68 | 10 | 24 | 55 | 36 | 4 |
| Grant | 196 | 94 | 16 | 56 | 60 | 136 | | | |
| Greer | 5 | | | | 5 | | | | |
| Harmon | 14 | 8 | | 57 | 8 | 6 | | | |
| Harper | 58 | 6 | 14 | 34 | 1 | 57 | | | |
| Haskell | 56 | | 36 | 64 | 38 | 16 | 2 | | |
| Hughes | 184 | 78 | 34 | 61 | 166 | 17 | | | 1 |
| Jackson | 10 | | | | | 10 | | | |
| Jefferson | 132 | 113 | | 86 | 48 | 83 | 1 | | |
| Johnston | 2 | | | | 2 | | | | |
| Kay | 108 | 33 | 24 | 53 | 108 | | | | |
| Kingfisher | 171 | 129 | 33 | 95 | 1 | 148 | 22 | | |
| Kiowa | 96 | 62 | 3 | 68 | 95 | 1 | | | |
| Latimer | 22 | | 13 | 59 | 3 | 4 | 13 | 2 | |
| Le Flore | 18 | | 8 | 44 | 3 | 13 | 2 | | |

## TABLE 3b.—CONTINUED

| County | Total no. of wells drilled | Completions Oil | Completions Gas | % Completions Oil & Gas | Number of wells drilled in following total-depth ranges (ft) 1-5,000 | 5,000-10,000 | 10,000-15,000 | 15,000-20,000 | >20,000 |
|---|---|---|---|---|---|---|---|---|---|
| Lincoln | 215 | 102 | 44 | 68 | 167 | 48 | | | |
| Logan | 190 | 102 | 21 | 65 | 24 | 166 | | | |
| Love | 41 | 30 | | 73 | 8 | 26 | 7 | | |
| McClain | 92 | 56 | 6 | 67 | 7 | 46 | 39 | | |
| McCurtain | 2 | | | | 2 | | | | |
| McIntosh | 29 | | 21 | 72 | 29 | | | | |
| Major | 127 | 81 | 31 | 88 | | 127 | | | |
| Marshall | 18 | 9 | | 50 | 13 | 5 | | | |
| Mayes | 97 | 38 | 5 | 44 | 97 | | | | |
| Murray | 12 | 6 | 1 | 58 | 10 | 1 | 1 | | |
| Muskogee | 251 | 121 | 52 | 69 | 251 | | | | |
| Noble | 246 | 166 | 7 | 70 | 144 | 102 | | | |
| Nowata | 300 | 218 | 26 | 81 | 300 | | | | |
| Okfuskee | 187 | 59 | 52 | 59 | 187 | | | | |
| Oklahoma | 118 | 69 | 16 | 72 | 2 | 115 | 1 | | |
| Okmulgee | 450 | 232 | 104 | 75 | 450 | | | | |
| Osage | 588 | 425 | 18 | 75 | 588 | | | | |
| Ottawa | 1 | | | | 1 | | | | |
| Pawnee | 257 | 174 | 13 | 73 | 257 | | | | |
| Payne | 183 | 109 | 11 | 65 | 146 | 37 | | | |
| Pittsburg | 97 | 3 | 63 | 68 | 55 | 20 | 22 | | |
| Pontotoc | 261 | 173 | 28 | 77 | 260 | 1 | | | |
| Pottawatomie | 260 | 152 | | 58 | 156 | 104 | | | |
| Pushmataha | 2 | | 2 | 100 | 1 | 1 | | | |
| Roger Mills | 141 | 10 | 90 | 71 | | 3 | 87 | 50 | 1 |
| Rogers | 138 | 57 | 30 | 63 | 138 | | | | |
| Seminole | 239 | 140 | 18 | 66 | 237 | 2 | | | |
| Sequoyah | 8 | 1 | 2 | 37 | 6 | 2 | | | |
| Stephens | 227 | 138 | 29 | 73 | 168 | 43 | 12 | 3 | 1 |
| Texas | 112 | 42 | 27 | 62 | 28 | 84 | | | |
| Tillman | 13 | 5 | | 38 | 3 | 10 | | | |
| Tulsa | 226 | 123 | 43 | 73 | 226 | | | | |
| Wagoner | 148 | 37 | 63 | 67 | 147 | | 1 | | |
| Washington | 352 | 219 | 49 | 76 | 352 | | | | |
| Washita | 77 | 6 | 45 | 66 | 3 | 1 | 27 | 42 | 4 |
| Woods | 68 | 11 | 29 | 59 | 3 | 65 | | | |
| Woodward | 70 | 5 | 31 | 51 | 1 | 64 | 5 | | |
| **State total** | **9,935** | **5,010** | **1,886** | **69** | **6,296** | **2,631** | **626** | **331** | **51** |

Source: American Petroleum Institute.

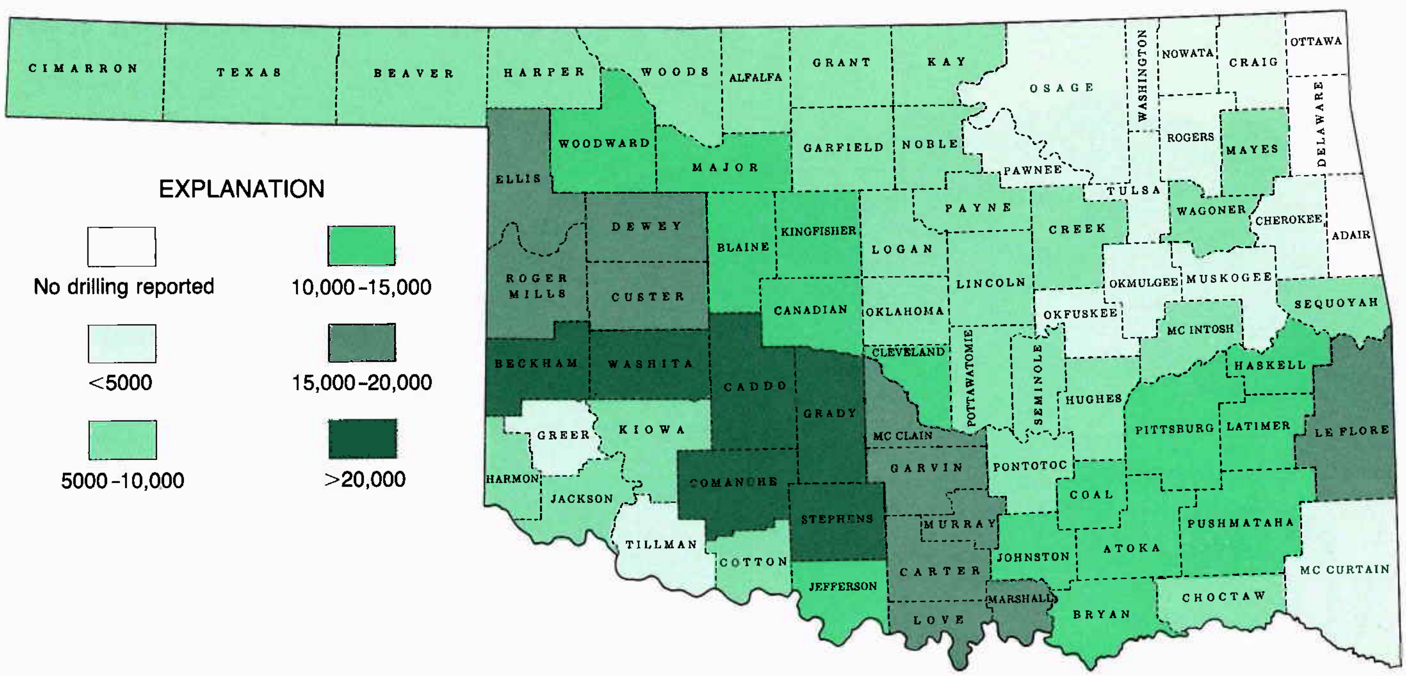


Figure 1a. Maximum drilling depth (in feet) for each county, 1982.

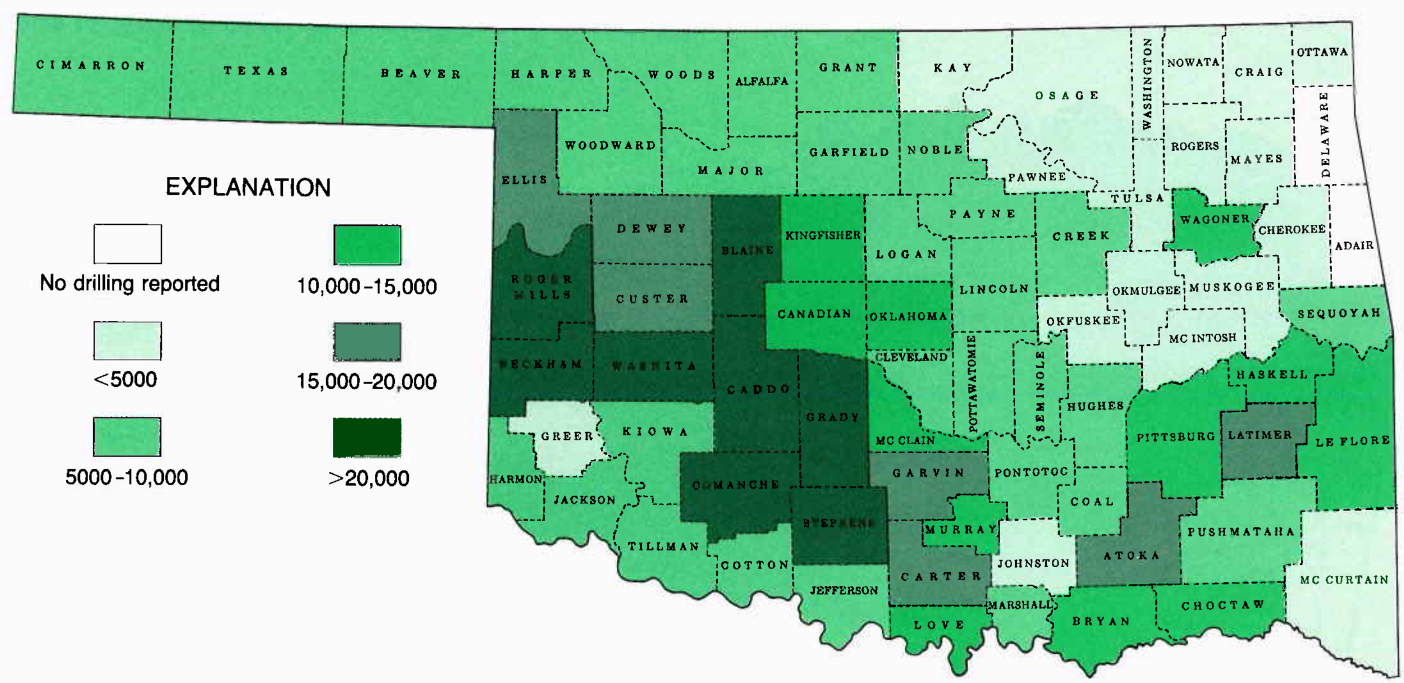


Figure 1b. Maximum drilling depth (in feet) for each county, 1983.

completions by type and county appear in table 3, a and b. Historical performance in well drilling since 1950 appears in figure 2.

The total number of completions of oil wells fell from 5,996 in 1982 to 5,010 in 1983. Figure 3, a and b, depicts the distribution of oil-well completions. In 1982, 19 counties each had more than 150 oil wells, with a total of 4,143 oil-well completions. The number of corresponding counties in 1983 was nine, with 2,189 oil-well completions. Osage, Creek, and adjacent counties in the northeast had the most completions both years, and Osage and Creek Counties are the only counties in which more than 300 oil-well completions were recorded in each of the years 1981 through 1983. The extensive oil-drilling activity of 1981 and 1982 that centered on Kingfisher County, as well as that in Stephens, Garvin, Pontotoc, and neighboring counties, subsided substantially in 1983. Ten counties along the eastern border of the State and Tillman County in the southwest had no successful oil-well completions in 1982. Fourteen counties in the same general areas had no oil-well completions in 1983.

Exploratory drilling for oil was greatest in the central part of the State from the Red River north to the Kansas border. The number of completions reported as exploratory oil wells was similar to those for natural

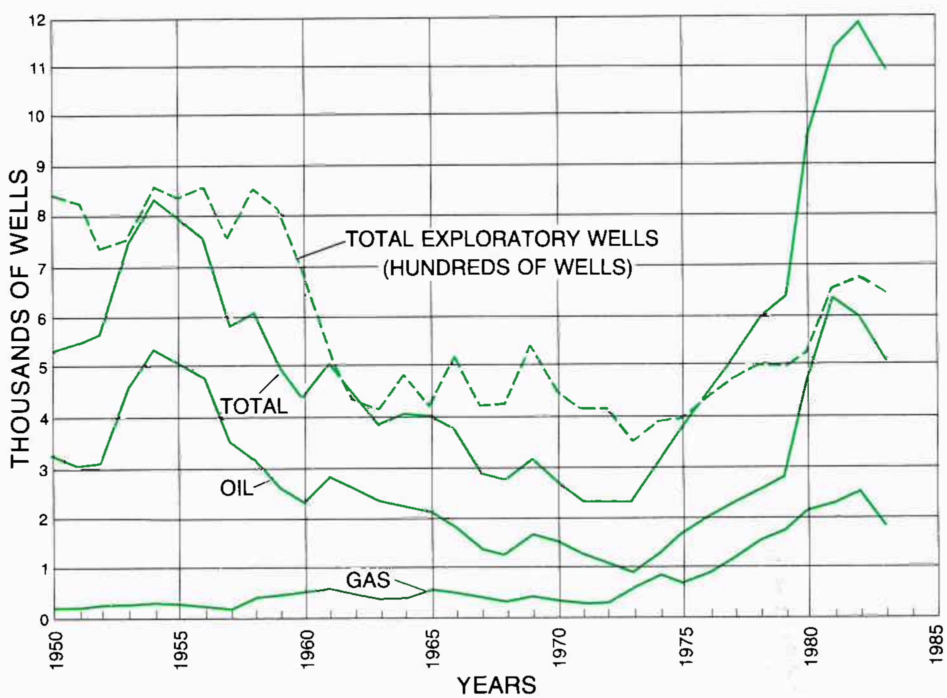


Figure 2. Graph of total wells drilled, oil wells completed, and gas wells completed, 1950–83.

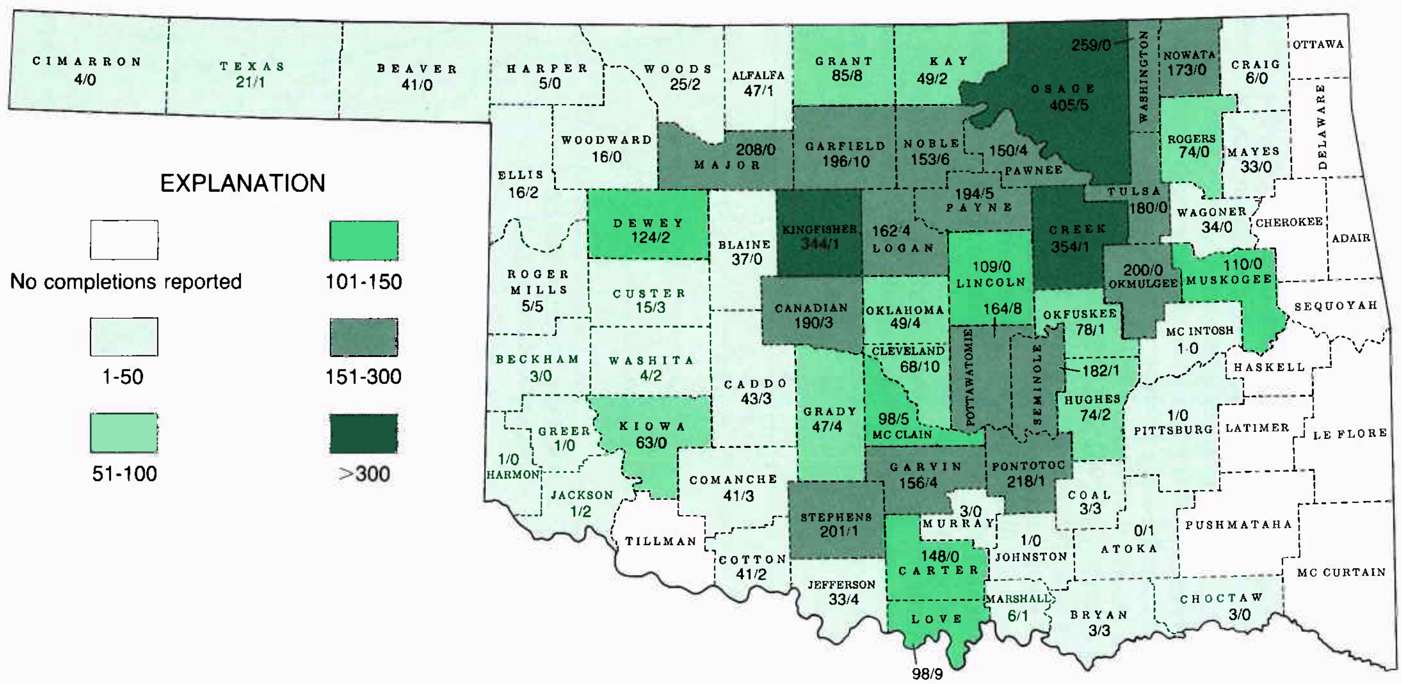


Figure 3a. Number of oil wells completed in each county, 1982. Numbers to left on map signify development wells; numbers to right, exploratory wells.

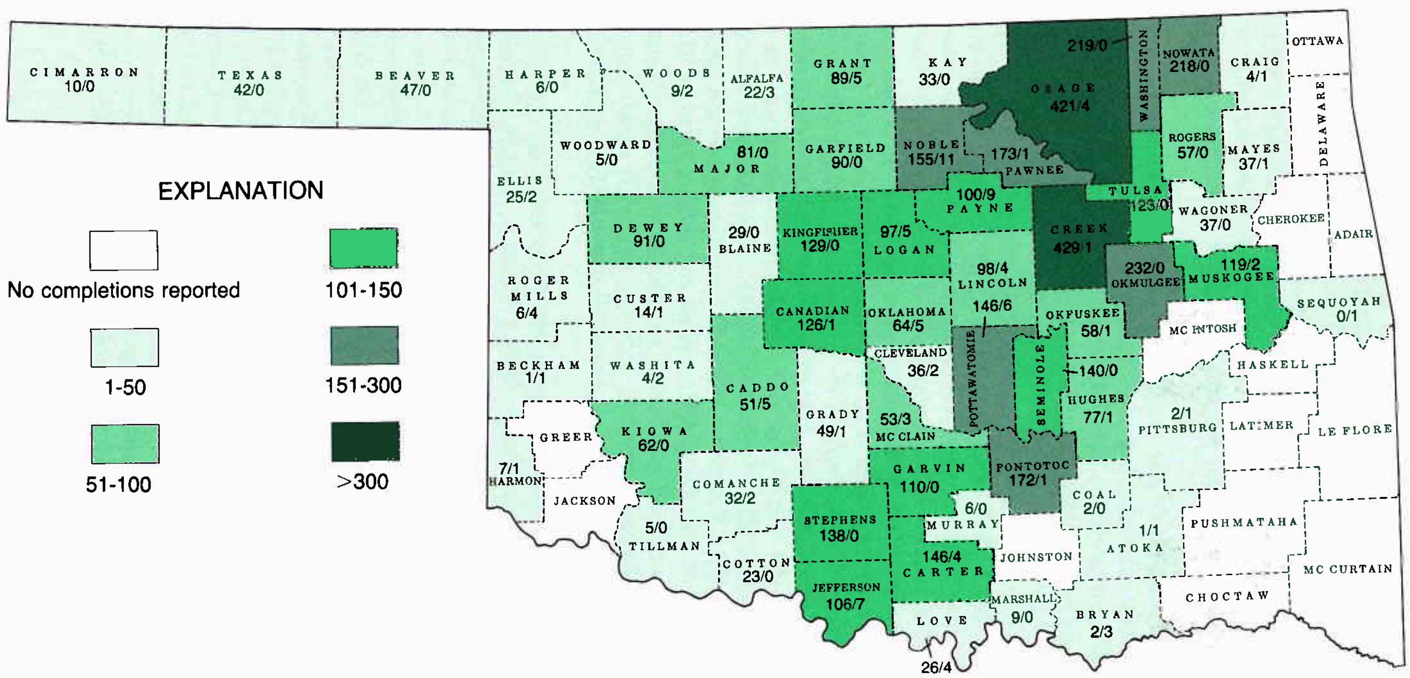


Figure 3b. Number of oil wells completed in each county, 1983. Numbers to left on map signify development wells; numbers to right, exploratory wells.

gas. In 1982, oil-well completions numbered 139, and in 1983 there were 109. Counties in which five or more completions were recorded either in 1982 or 1983, or both, listed from western Oklahoma eastward, are Roger Mills, Caddo, Grant, Garfield, Jefferson, Love, McClain, Cleveland, Oklahoma, Logan, Noble, Osage, Payne, and Pottawatomie. Counties in which a total of 10 or more exploratory oil wells were completed during the biennium are Grant, Garfield, Noble, Payne, Cleveland, Pottawatomie, Jefferson, and Love.

The contrasting numbers of gas wells completed in Oklahoma in 1981, 1982, and 1983 amply illustrate the vicissitudes of the gas-well-drilling industry. From 2,182 gas wells in 1981, the number of completions rose to 2,593 in 1982 and subsequently dropped to 1,886 in 1983. Completed gas wells made up 22.9 percent of all wells completed in the State in 1982, and 19 percent in 1983. Changes in the number and geographic distribution of completions from 1982 to 1983 are shown in figure 4, a and b. Six counties individually had more than 75 gas-well completions in 1981. Gas-well completions exceeded 75 in nine counties in 1982. The 980 gas wells completed in those counties represented 37.8 percent of all gas wells completed that year. Among these nine counties, five recorded more than 100 completions, led by Custer County with 155, followed by Roger Mills, Beaver, Nowata, and Okmulgee Counties. Figure 4a shows the heavy concentration of completions in the vicinity of the Anadarko Basin as well as prominent activity in the Panhandle, northeastern, east-central, and Arkoma Basin–Ouachita areas. By 1983 the number of counties in which gas-well completions exceeded 75 had been reduced to six, with a total of 514 wells representing 27.3 percent of all gas wells completed. Okmulgee County, with 104 gas-well completions, was the only county with more than 100. Areas with relatively high densities of gas-well completions remained the same as in 1982.

The Anadarko Basin had by far the greatest number of completed exploratory gas wells in 1982. Custer, Roger Mills, Washita, Caddo, Beckham, Ellis, and Dewey Counties collectively had 97 of the State's 149 completed exploratory gas wells. Exploratory drilling also occurred in the Arkoma Basin and on the northern flank of the Ouachita Mountains, where a total of 13 exploratory gas wells were completed in Atoka, Coal, Pittsburg, Hughes, and McIntosh Counties. In the south-central part of the State, Garvin and Stephens Counties each had three completed exploratory gas wells. The completion rate of exploratory gas wells in 1983 remained relatively high in the Anadarko Basin, where Custer County led with 10 wells, and the total number of completed exploratory gas wells in Custer, Dewey, Roger Mills, Beckham, Washita, Caddo, Canadian, and Grady Counties was 48. In the east-central part of the State, Creek County had two exploratory gas-well completions reported; several others had one each. Exploration continued active in the Arkoma Basin–Ouachita Mountains area, where six exploratory gas wells were completed in Pittsburg County, two in Atoka County, and at least one in several others.

## Production and Value

Petroleum production continued to increase for the fourth consecutive year in 1983, when the State's output reached 159.4 million bbl of oil (table 2). Although the taxed value of the crude oil at the wellhead reached a maximum of $5.2 billion in 1982, it declined to $4.7 billion in 1983, according to the Oklahoma Tax Commission. By contrast, the output of natural gas fell from the recorded all-time high of 2 trillion cu ft in 1981 to 1.9 trillion cu ft in 1982 to 1.8 trillion cu ft in 1983. The value of natural gas at the wellhead reached its maximum, $5.3 billion, in 1982 and then dropped to $4.8 billion in 1983.

Almost half (48 percent) of the State's total output of crude oil (158.7 million bbl) in 1982 came from nine counties in which annual production exceeded 5 million bbl. These counties were, in order of decreasing output, Carter (15.2 million bbl), Stephens (13.7 million bbl), Osage (8.1 million bbl), Kingfisher (7.9 million bbl), Grady (7.2 million bbl), Garvin (7 million bbl), Creek (6.7 million bbl), Pontotoc (5.5 million bbl), and Major (5.4 million bbl). Production in eight counties exceeded 5 million bbl in 1983 and accounted for 44.2 percent of the State's total output of oil. The counties were, in order of decreasing production, Carter (14.4 million bbl), Stephens (12.9 million bbl), Osage (9.9 million bbl), Grady (7.7 million bbl), Creek (7.1 million bbl), Garvin (6.8 million bbl), Kingfisher (6.2 million bbl), and Pontotoc (5.3 million bbl). Figure 5, a and b, shows that major oil production was concentrated both years in the south-central, northeastern, and central parts of the State. In general, counties along the eastern border of the State were unproductive. Among these counties, in one or both years of the biennium, were Ottawa, Delaware, Cherokee, Adair, Sequoyah, Haskell, Le Flore, Latimer, and Choctaw. The National Stripper Well Association indicated that about 59 percent of the State's crude-oil output was recovered from stripper wells in both 1982 and 1983, an increase from the 54.6 percent of the State's total output credited to stripper wells by the association in 1981.

The output of natural gas declined in both 1982 and 1983. In the latter year output was 11 percent less than in 1981. Almost 75 percent of the State's total produced natural gas was obtained from 16 counties in the western part of the State, each of which yielded more than 50 billion cu ft in 1982 (fig. 6a). Harper, Roger Mills, Garfield, Kingfisher, Canadian, and Grady Counties individually provided more than 100 billion cu ft. Pittsburg County was the only eastern county in which production exceeded 50 billion cu ft. The increment from highly productive western counties had shrunk to 63.3 percent of the State total in 1983, when only 14 counties yielded more than 50 billion cu ft of natural gas, and Roger Mills and Canadian Counties were the only counties that accounted for more than 100 billion cu ft (fig. 6b). Pittsburg County remained the sole eastern county that yielded more than 50 billion cu ft in 1983. Unproductive counties were concentrated in the northeast, southeast, and southwest corners of

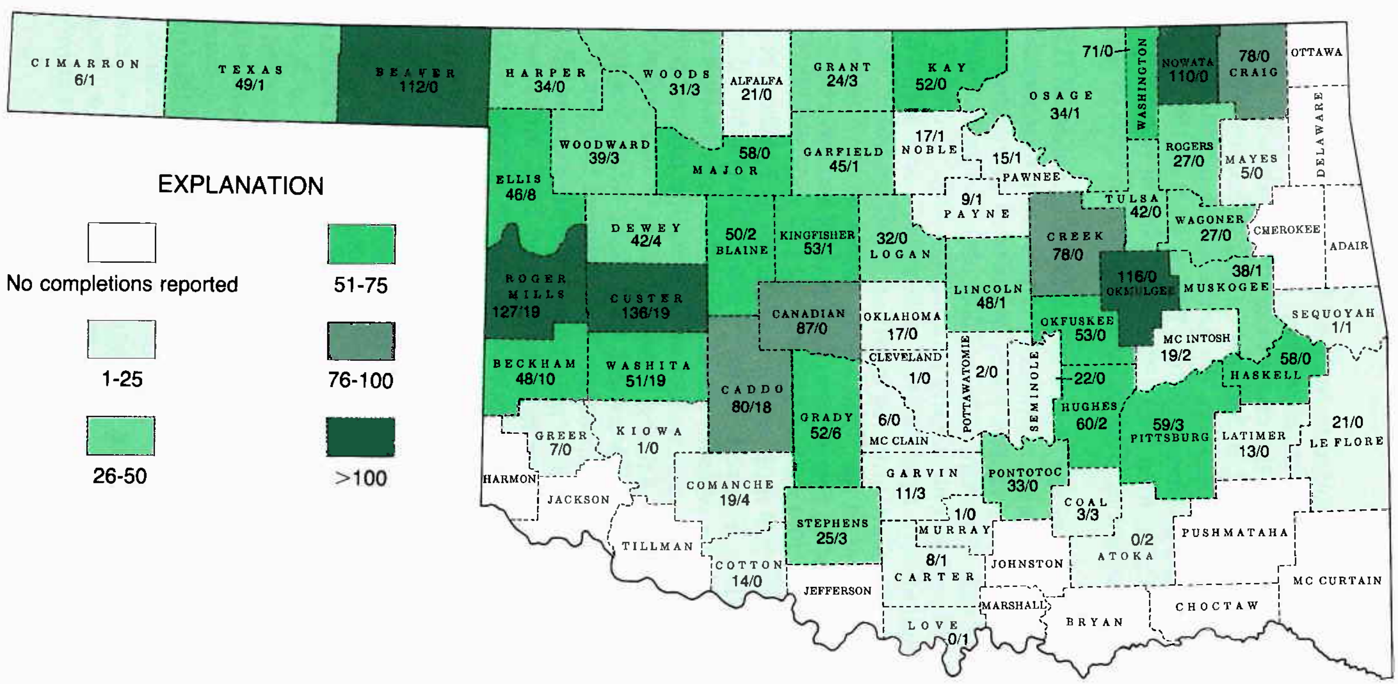


Figure 4a. Number of gas wells completed in each county, 1982. Numbers to left on map signify development wells; numbers to right, exploratory wells.

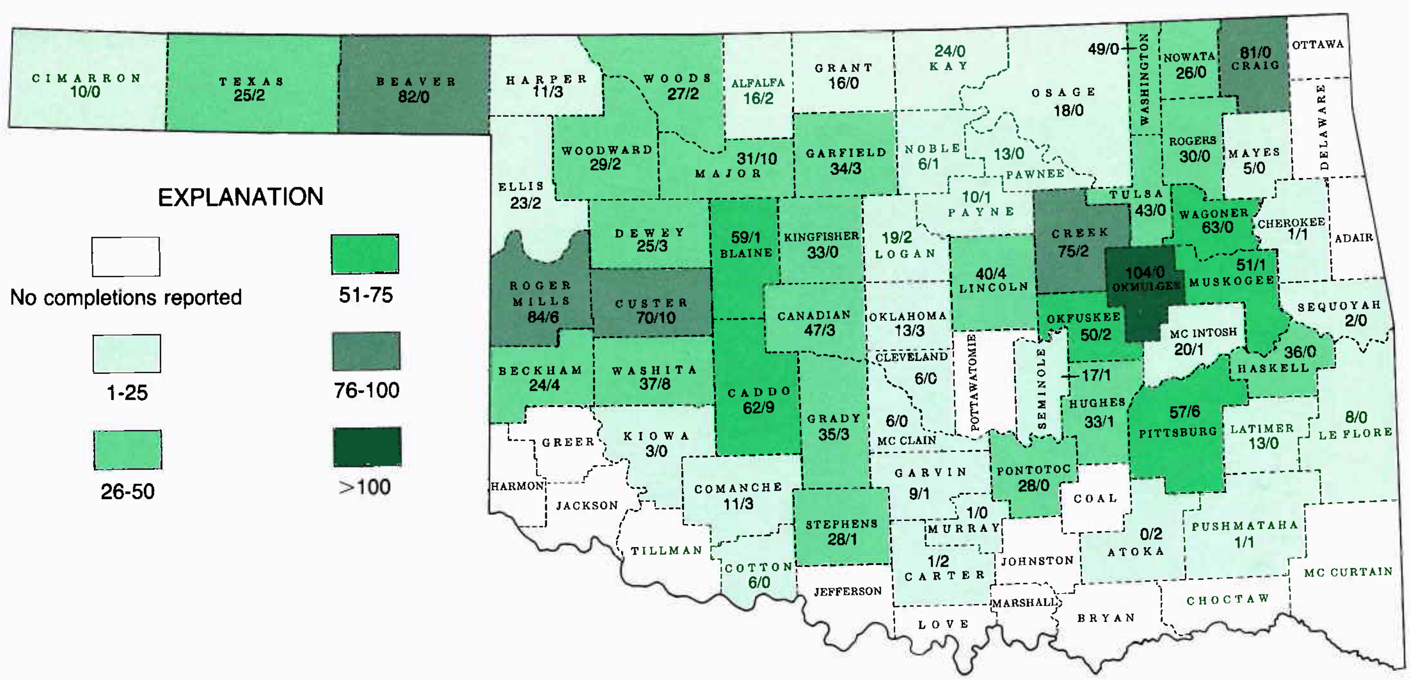


Figure 4b. Number of gas wells completed in each county, 1983. Numbers to left on map signify development wells; numbers to right, exploratory wells.

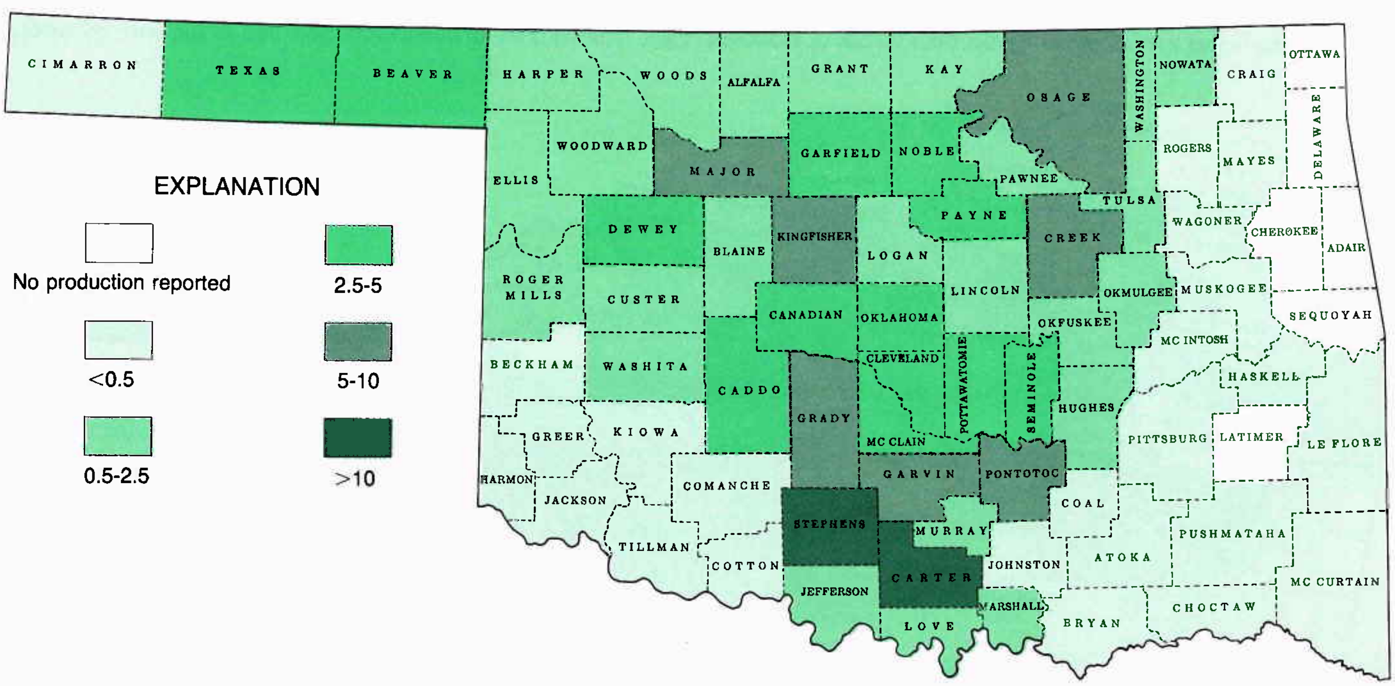


Figure 5a. Output of crude oil per county, 1982. Production shown in millions of barrels.

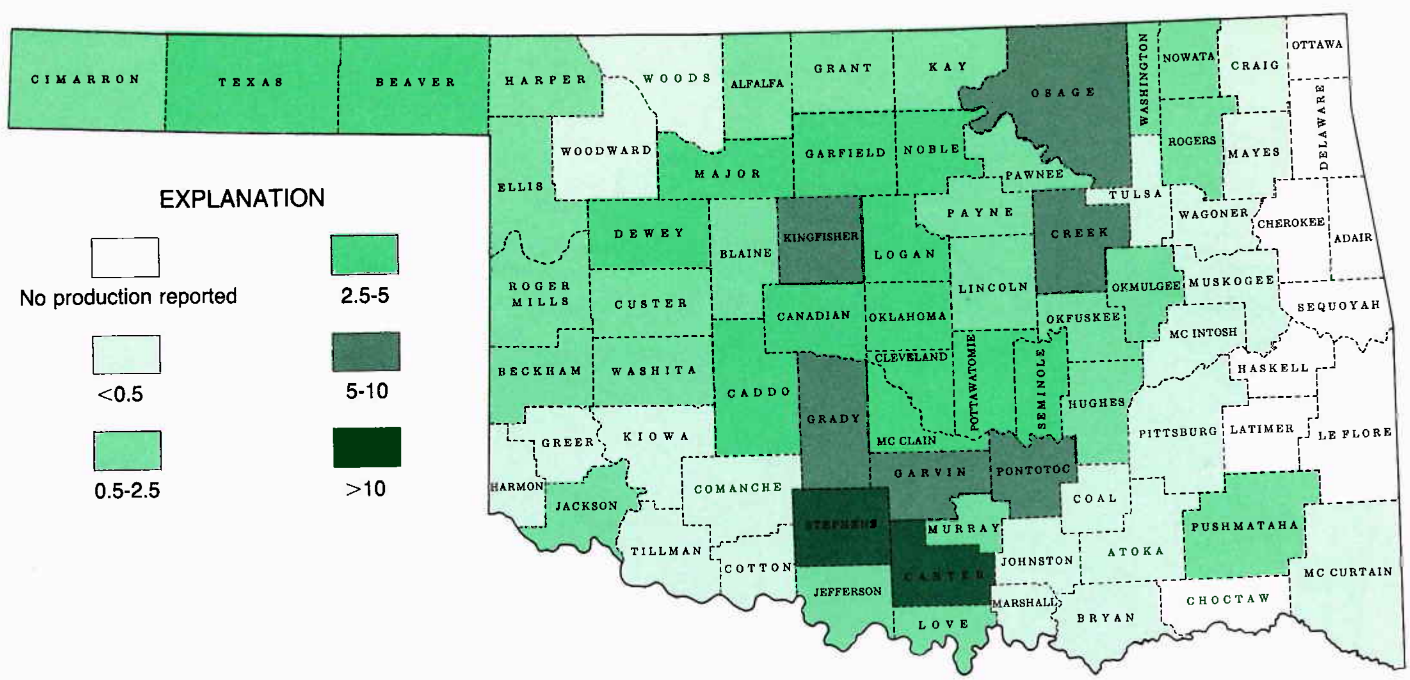


Figure 5b. Output of crude oil per county, 1983. Production shown in millions of barrels.

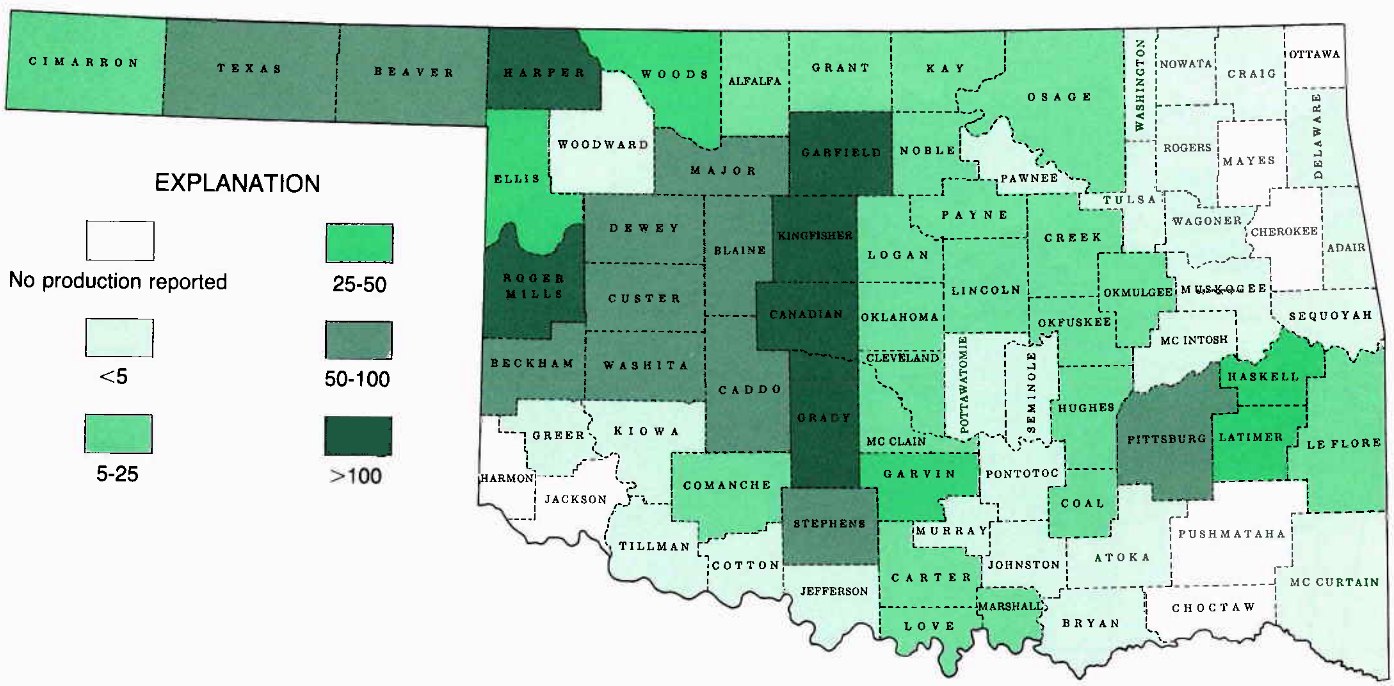


Figure 6a. Output of natural gas per county, 1982. Production shown in billions of cubic feet.

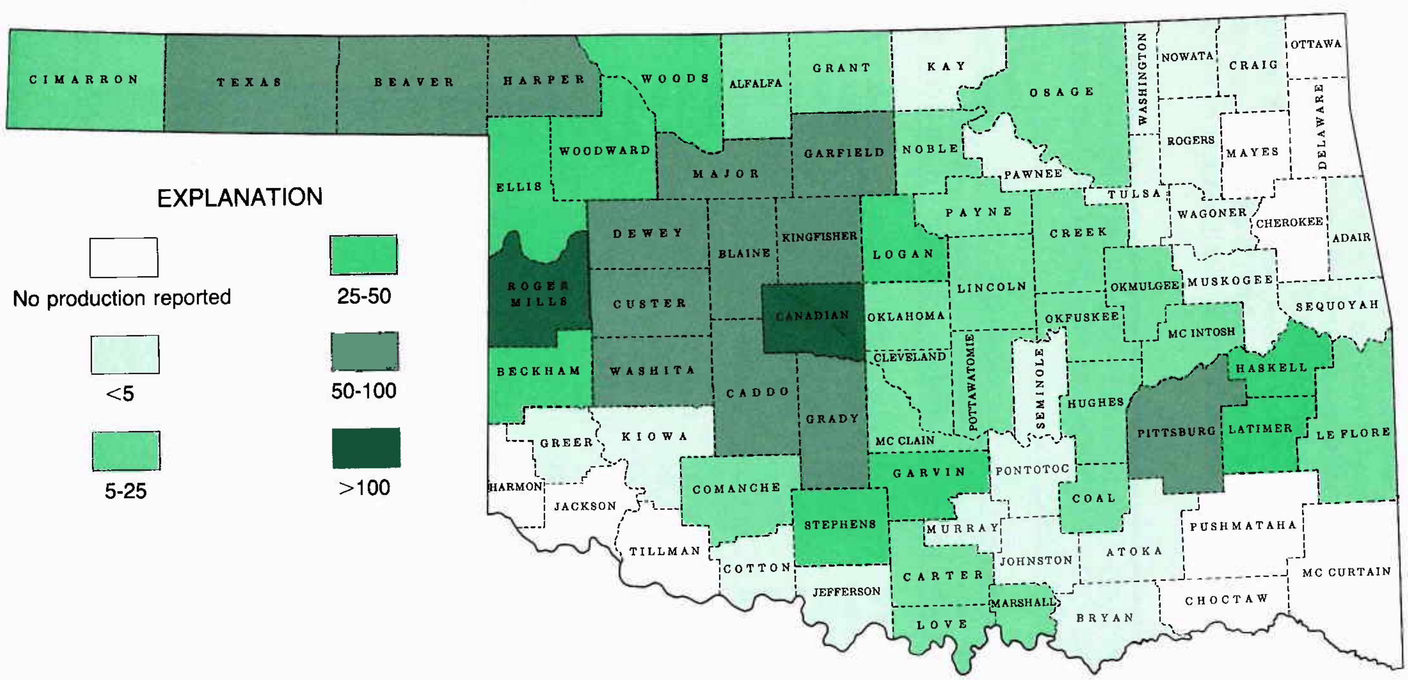


Figure 6b. Output of natural gas per county, 1983. Production shown in billions of cubic feet.

the State: Ottawa, Mayes, Cherokee, Pushmataha, Choctaw, Jackson, and Harmon Counties were without production in both years.

The output of petroleum, natural gas, and natural-gas liquids in 1982 and 1983 is shown in historical perspective in table 4. By the end of 1983 the State's total cumulative output of these commodities had reached 12.6 billion bbl of oil, 53.2 trillion cu ft of gas, and 1.6 billion bbl of liquefied petroleum gases. The cumulative value of all the products is estimated to

TABLE 4.—CUMULATIVE (THROUGH 1955) AND YEARLY (1956–83) MARKETED PRODUCTION AND VALUE OF PETROLEUM, NATURAL GAS, AND LIQUEFIED NATURAL GAS IN OKLAHOMA[1]

| Year through | Petroleum Volume (1,000 bbl) | Petroleum Value ($1,000) | Natural Gas Volume (MMcf) | Natural Gas Value ($1,000) | Liquefied natural gas[2] Volume (1,000 bbl) | Liquefied natural gas[2] 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(e) |
| 1979 | 143,641 | 2,158,526 | 1,845,389 | 2,062,868 | 50,752 | 762,662(e) |
| 1980 | 150,140 | 4,110,515 | 1,902,157 | 2,856,457 | 70,000 | 1,917,000(e) |
| 1981 | 152,252 | 5,355,474 | 2,030,225 | 3,831,636 | 74,000 | 2,020,200(e) |
| 1982 | 158,674 | 5,195,614 | 1,924,189 | 5,336,377 | 77,000 | 2,521,288(e) |
| 1983 | 159,354 | 4,761,280 | 1,807,758 | 4,818,885 | 80,000 | 2,390,723(e) |
| **Totals** | **12,563,879** | **51,793,828** | **53,153,960** | **28,256,493** | **1,621,906** | **13,476,929** |

[1]Oklahoma Tax Commission.

[2]Production for 1980–83 from U.S. Department of Energy.

be $93.5 billion. Presentation of historical data in table 4 conforms to data categories provided by the U.S. Department of Energy.

The average tax value of produced crude oil at the wellhead in 1982 was $32.74 per barrel, and that of marketed natural gas $2.77 per thousand cubic feet. In 1983 the tax value of crude oil dropped to $29.88 per barrel, and that of natural gas to $2.67 per thousand cubic feet. Expressed in terms of 1967 dollars, calculated from the producers' price index to show the effects of inflation, the average tax value of crude oil in 1982 would be $11.66 per barrel and that of natural gas $0.95 per thousand cubic feet. Similarly, the price of crude oil in 1983 would be $10.40 per barrel, and that of natural gas $0.94 per thousand cubic feet.

## Reserves

The combined effects of the discoveries of new sources of oil and gas, extension and revision of estimated oil and gas reserves in existing fields, and withdrawals by production are summarized in figures 7 and 8. Whereas crude-oil reserves rose from 950 million bbl in 1981 to about 971 million bbl in 1982, the U.S. Department of Energy estimates that they were reduced to 931 million bbl by the end of 1983. Contrastingly, the reserves of natural-gas liquids increased from 631 million bbl on December 31, 1981, to 745 million bbl in 1982 and 829 million bbl on December 31, 1983. Thus, total liquid hydrocarbons rose from 1,581 million bbl in 1981 to 1,760 mil-

TABLE 5.—GIANT OIL FIELDS OF OKLAHOMA, 1982, 1983

| | 1982 | | 1983 | | | |
|---|---|---|---|---|---|---|
| **Field** | **Production (1,000 bbl)** | **Number of wells (e)** | **Production (1,000 bbl)** | **Number of wells (e)** | **Cumulative production 1/1/84 (1,000 bbl)** | **Remaining reserves (e) (1,000 bbl)** |
| Burbank | 2,268 | 1,047 | 2,201 | 1,057 | 526,854 | 15,551 |
| Eola-Robberson | 1,400 | 585 | 1,377 | 594 | 127,062 | 12,939 |
| Fitts | 3,500 | 625 | 3,318 | 597 | 178,476 | 9,766 |
| Glenpool | 1,067 | 1,101 | 1,223 | 1,121 | 322,488 | 7,512 |
| Golden Trend | 3,800 | 1,196 | 3,721 | 1,245 | 434,378 | 29,650 |
| Healdton | 2,260 | 1,417 | 2,087 | 1,425 | 331,284 | 18,609 |
| Hewitt | 3,285 | 1,279 | 2,627 | 1,276 | 259,979 | 26,240 |
| Oklahoma City | 796 | 204 | 763 | 204 | 740,376 | 8,393 |
| Postle | 1,927 | 316 | 1,665 | 316 | 98,246 | 21,587 |
| Sho-Vel-Tum | 19,868 | 8,708 | 19,575 | 8,571 | NA | 105,423 |
| Sooner Trend | 8,600 | 5,156 | 7,288 | 5,320 | 259,630 | 35,469 |
| **Totals** | **48,771** | **21,634** | **45,845** | **21,726** | **3,278,773** | **291,139** |

Source: *Oil and Gas Journal*, v. 81, no. 5, Jan. 31, 1983; v. 82, no. 5, Jan. 30, 1984.
(e) = estimate.
NA = Not Available.

lion bbl at the end of 1983. Natural-gas reserves (dry) rose from the 14.7 trillion cu ft reported in 1981 to 16.2 trillion cu ft in 1982 and remained essentially at that level at the end of 1983.

## Giant Oil Fields

Production of oil from Oklahoma's giant oil fields was 48.8 million bbl in 1982 and 45.8 million bbl in 1983, according to the *Oil and Gas Journal* (table 5). These quantities represent 31.7 and 28.8 percent of Oklahoma's total

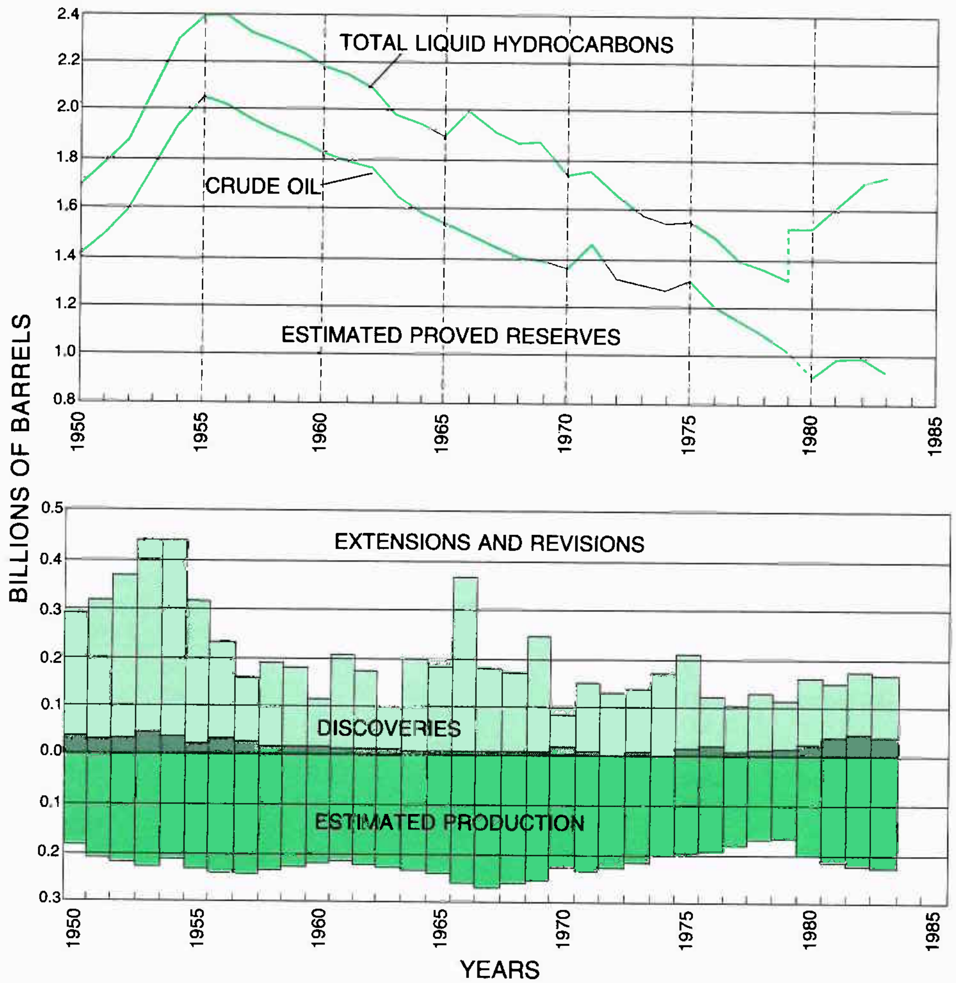


Figure 7. Graphs showing liquid-hydrocarbon reserves, extensions and revisions, discoveries, and production in Oklahoma, 1950–83. Source: U.S. Department of Energy, annual reports.

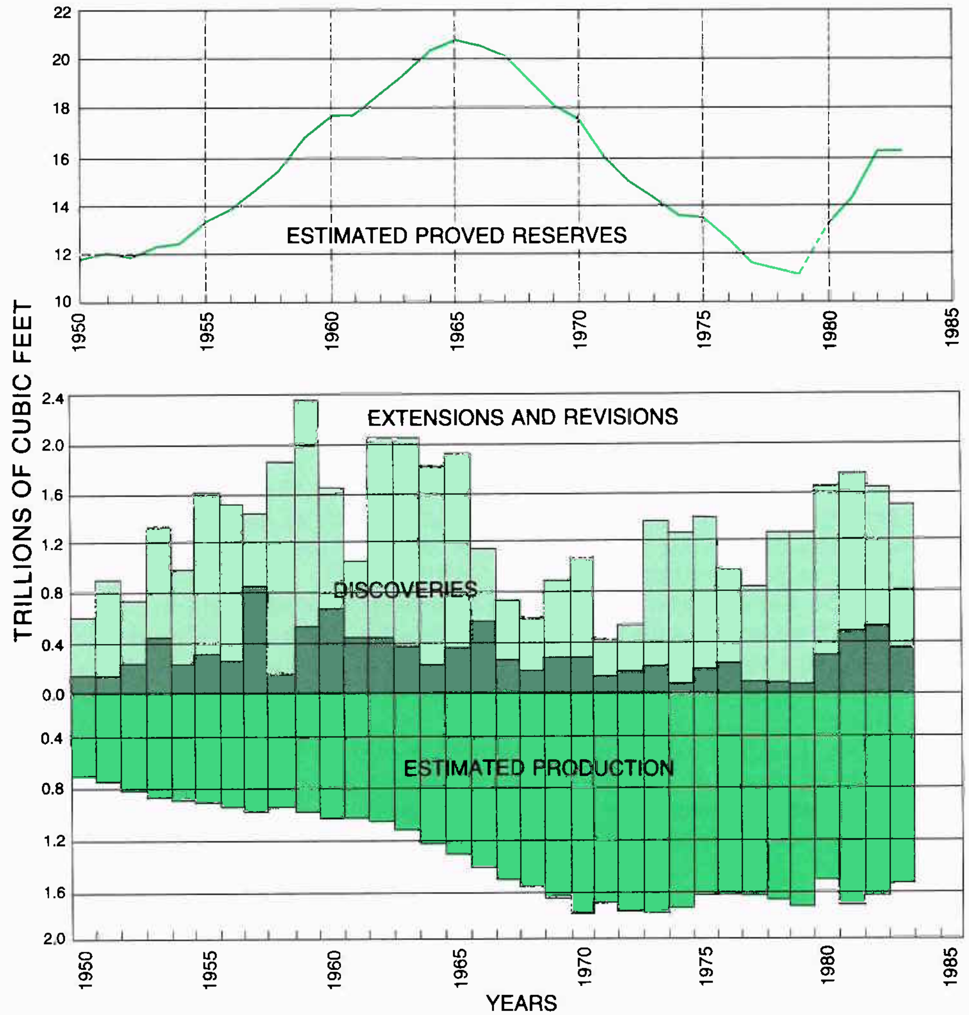


Figure 8. Graphs showing natural-gas reserves, extensions and revisions, discoveries, and production in Oklahoma, 1950–83. Source: U.S. Department of Energy, annual reports.

output of crude oil in the respective years. Increases in output occurred in Burbank, Hewitt, Postle, and Sooner Trend Fields in 1982 and in Glenpool Field in 1983. Cumulative output was 3.28 billion bbl of oil, reserves were 291.1 million bbl of oil, and the estimated number of wells was 21,726 by the end of December 1983.

# OKLAHOMAN NAMED TO AIPG EXECUTIVE COMMITTEE

Robert A. Northcutt, an independent from Oklahoma City, Oklahoma, will be serving on the 1985 Executive Committee of the American Institute of Professional Geologists. Northcutt was elected at the October meeting of the AIPG Advisory Board in Orlando, Florida. Elected along with Northcutt to one-year terms were John B. Gustavson, Bobby J. Timmons, and Ross L. Shipman.

Gustavson, who heads the geologic consulting firm of Gustavson Associates, Inc., in Boulder, Colorado, will be serving on the Institute's executive committee for the third straight year, as will Timmons, a consultant in Jacksonville Beach, Florida. Shipman, with the Bureau of Economic Geology, University of Texas, Austin, Texas, has served on past AIPG executive committees.

Other results of the AIPG elections include Travis H. Hughes, a consulting geologist and vice president of P. E. LaMoreaux & Associates, Tuscaloosa, Alabama, having been voted 1985 president elect of the group. He will serve as president of the institute in 1986.

Susan M. Landon was voted 1985 vice president of the institute. She is a senior staff geologist with Amoco Production Co., Denver, Colorado.

Elected to a two-year term as 1985–86 editor of the institute was Gary B. Glass, State geologist/director of the Wyoming Geological Survey, Laramie, Wyoming.

Hughes, Landon, and Glass, along with president Ernest K. Lehmann, president of Ernest K. Lehmann and Associates, Inc., Minneapolis, Minnesota, and secretary-treasurer Richard J. Anderson, a consulting geologist from Columbus, Ohio, will constitute the institute's officers for this year.

# STATE GEOTHERMAL MAP RELEASED

A new map issued by the Oklahoma Geological Survey offers information on Oklahoma's geothermal resources as determined from bottom-hole temperatures in many of the non-producing wells drilled over the years in the State. The map was compiled by Kenneth V. Luza, William E. Harrison, and George A. Laguros, of the OGS; M. Lynn Prater, formerly with OGS and now with E-Systems of Greenville, Texas; and Paul K. Cheung, Tangram Resources, Inc., Calgary, Canada.

The map, *Geothermal Resources and Temperature Gradients of Oklahoma*, OGS Map GM–27, was published at a scale of 1:500,000 (1 in. = approximately 8 mi), and provides information not only on temperatures but also on high-pressure zones and water quality and delineates zones most favorable for development of low-temperature geothermal gradients in the State.

The map, produced by the National Geophysical Data Center of the National Oceanic and Atmospheric Administration, represents the culmination of a project undertaken in 1980 in cooperation between the Oklahoma Geological Survey and the U.S. Department of Energy. A report on this project in three counties was issued in 1983 as OGS Special Publication 83–1.

The investigation was undertaken to gather information to evaluate the possibility of using natural heat from hot water trapped deep beneath the surface of the earth as an alternative energy source. Results of the study classify the geothermal resources of Oklahoma as low-temperature waters. According to the U.S. Geological Survey, such resources can be used for space heating, ethanol production, grain drying, and greenhouse heating, with the use depending on the characteristics of the water. Some of these resources in Oklahoma are now used for heat pumps and for space heating and cooling of residences and small businesses.

It would be uneconomical to drill only for the use of this natural heat, but with the wells already having been drilled for oil or gas, the possibility of using the available wells is more realistic.

GM–27 can be ordered from the Oklahoma Geological Survey at the address given inside the front cover of this issue. The price is $2.

## SUTHERLAND EDITS "COMPTE RENDU" VOLUME

Patrick K. Sutherland, professor in the OU School of Geology and Geophysics, is co-editor with Walter L. Manger, of the University of Arkansas, of a 629-page publication recently released by the Southern Illinois University Press. The substantial book is the second proceedings volume of the Ninth International Congress of Carboniferous Stratigraphy and Geology, which met on the campus of the University of Illinois in Champaign–Urbana in the spring of 1979.

This was the first meeting of the Congress to be held in the United States, and more than 900 geologists from 29 countries attended. It was also the first time the People's Republic of China was represented at the Congress. The proceedings, known as the "Compte Rendu," contain papers that were presented by these geologists at the week-long gathering of the Congress. Sutherland and Manger's volume, entitled *Biostratigraphy*, is a collection of 61 of these studies that discuss in detail various plant and animal fossils as indicators of stratigraphic zones and relationships of Carboniferous rocks (about 280–350 million years old) in this country and others.

Also, James R. Chaplin, geologist with the Oklahoma Geological Survey, is the author of a paper on "Conodont Biostratigraphy of Lower Carboniferous Strata in the Southern Appalachians" that also appears in the volume.

*Compte Rendu: Ninth International Congress of Carboniferous Stratigraphy and Geology, Volume 2: Biostratigraphy* can be obtained from the Southern Illinois University Press, P.O. Box 3697, Carbondale, Illinois 62901. The price is $75.

# NOTES ON NEW PUBLICATIONS

*Changes in Stratigraphic Nomenclature by the U.S. Geological Survey*

G.V. Cohee and W. B. Wright are authors of this 84-page Bulletin.

Order B 1422-A from: Eastern Distribution Branch, Text Products Section, 604 S. Pickett St., Alexandria, VA 22304. The price is $2.50.

*Assessment of Undiscovered Conventionally Recovered Petroleum Resources of the Northwest European Region*

The report, by C. D. Masters of the U.S. Geological Survey and H. D. Klemme of Weeks Exploration Co., is a product of the World Energy Resources Program's investigations of major oil- and gas-producing regions of the world. The basic elements of geology responsible for petroleum occurrence, or absence thereof, in the northwest European region (including the North Sea and Norwegian Sea extensions) are described, and the area is assessed for petroleum potential, region by region.

Order Circular C 0922-A from: Eastern Distribution Branch, Text Products Section, 604 S. Pickett St., Alexandria, VA 22304. The circular is free in limited quantities.

*Preliminary Appraisal of the Hydrology of the Red Oak Area, Latimer County, Oklahoma*

The 44-page Water-Resources Investigations Report 83-4166 by Melvin V. Marcher and others contains 11 figures, 3 plates, and 17 tables.

Order from: Open-file Services Section, Western Distribution Branch, U.S. Geological Survey, Box 25425, Federal Center, Lakewood, CO 80225.

*Northern Plains Highway Map*

Highway map no. 12, the Northern Great Plains Region map, is a geological map of North Dakota, South Dakota, Iowa, Nebraska, and Minnesota, and is overlain by a standard highway map. Map sections include: stratigraphic columns, a physiographic map, a pre-Pleistocene bedrock geologic and tectonic map, area cross sections, places of geological interest, a reference section, and a highway mileage chart. Scale is 1 in. = 30 mi.

Order from: AAPG Bookstore, P.O. Box 979, Tulsa, OK 74101. The price is $4.50. The maps are also available from the Oklahoma Geological Survey at the address given inside the front cover of this issue.

*Generalized Structural, Lithologic and Physiographic Provinces in the Fold and Thrust Belts of the United States*

Kenneth G. Bayer's new geologic map outlines the locations of the three major fold and thrust-fault belts of the conterminous United States. The 2-sheet map set was designed to provide the earth scientist and layperson with a composite map that helps to visualize the relative positions of selected specific structural, lithologic, and physiographic provinces on the standard (1:2,500,000-scale) U.S. Geological Survey geologic map of the United States. Also included is a 32 × 52-in. explanation sheet.

Order from: Eastern Distribution Branch, USGS, 1200 S. Eads St., Arlington, VA 22202. The price is $8.80 per set, plus $1 postage for orders less than $10.

*Introduction to Correlation of Precambrian Rock Sequences*

Authors J. E. Harrison and Z. E. Peterman generalize correlation of Precambrian rocks of the United States and Mexico on a single chronometric correlation chart in this new 7-page Professional Paper. The length of the Precambrian record in various areas is related to the North American craton and fragments welded to it at various times. Problems of deriving a regional or worldwide time scale for the Precambrian are illustrated by application of the chart to possible methods based on stratotypes, tectonomagmatic events, and direct division of geologic time.

Order P 1241-A from: Eastern Distribution Branch, Text Products Section, 604 S. Pickett St., Alexandria, VA 22304. The price is $1.50.

*Annual Review of Energy, Volume 8*

Editor Jack M. Hollander has included the writing of 16 authors prominent in the field of energy in his new 541-page review. Among the authors is Oklahoma Geological Survey director Charles J. Mankin, who has written a chapter on "Unconventional Sources of Natural Gas."

Also among the articles are: "The Evolution in U.S. Electric Utility Rate Design," by Hethie S. Parmesano and Catherine S. Martin: "Oil Sands: The Canadian Experience," by James J. Heron and Elma K. Spady; "Future Energy Savings in U.S. Housing," Robert H. Williams, Gautam S. Dutt, and Howard S. Geller; "The Price of World Oil," by S. Fred Singer; and "The Development of Breeder Reactors in the United States," by Herbert Kouts.

The review also contains a subject index and a cumulative index of contributing authors and chapter titles for volumes 1 through 8.

Order from: Annual Reviews Inc., 4139 El Camino Way, Palo Alto, CA 94306. The price is $56 U.S., $59 elsewhere.

# OKLAHOMA ABSTRACTS

The following abstracts are reprinted from *Abstracts with Programs* of the Geological Society of America, v. 16, no. 6. Page numbers are given in brackets below the abstracts. Permission of the authors and of the GSA to reproduce the abstracts is gratefully acknowledged.

## GSA Annual Meeting
## Reno, Nevada, November 5–8, 1984

### Depositional Facies of Pennsylvanian Red Fork and Skinner Sandstones, Pottawatomie Co., Central Oklahoma

TRENA BLACKSTOCK DALE and CHARLES F. MANSFIELD, Geoscience Department, University of Tulsa, 600 S. College Ave., Tulsa, OK 74101

Ten full-diameter cores, 6 in 1 $km^2$, from the NW Tecumseh Field, detail depositional relations in this shoestring sandstone complex that is 7 km long, 1.4 km wide and up to 60 m thick. An overlying coal marks original horizontality and provided the correlation datum. Core to core correlation along and across the deposit, cross sections, and a fence diagram show a sequence of at least 13 channel-fill sandstones, each less than 600 m wide, that cut one another and grade laterally from channel-center sands to finer, channel-margin sand and silt into levee mud. The complex truncates underlying prodelta shale and is gradationally overlain by terrestrial shale and coal. Regionally, limestone encloses these units.

The complex comprises low sinuosity channels of light gray brown, fine- to very fine-grained sandstone with mud-pebble lag concentrates. Channel-center sandstones are either cross-bedded or structureless with very angular, shale rip-up clasts that decrease in abundance upward. Ripples are common in upper parts of channels and on channel margins. Channel-margin and levee deposits are texturally bimodal, light gray, very fine-grained sand and black mud. Very thin laminae, ripples, small load structures and microfaults are common. Channel-margin mud locally slumped

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OKLAHOMA ABSTRACTS is intended to present abstracts of recent unpublished 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, that have not yet been published.

into channels. Abandoned channel-fill deposits are thinly laminated, very fine-grained sand and mud. Burrows are common; microfaults are present; ripples are rare. Overlying siltstones and shales are dark gray brown to black, thinly laminated and interlayered like varves.

Sandstones contain 88 to 94% quartz, up to 8% feldspar, mostly plagioclase, and a few percent metasedimentary lithic fragments. Edge-to-edge grains, quartz overgrowths and diagenetically sutured grains are common. Carbonate replacement and subsequent dissolution resulted in secondary, oversized pores and leached feldspars; porosity reaches 20% and permeability 400 millidarcies. [482]

**Holocene Paleoenvironments, Geology and Archaeology of the McGee Creek Area, Western Ouachitas, Oklahoma**

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Interdisciplinary investigations in the McGee Creek Area, western Ouachitas, Oklahoma, have defined a series of Holocene deposits containing abundant archaeological materials. The study of Ferndale Bog has [yielded] a 12,000 year record of pollen from the project area. Initial analyses indicate an early Holocene vegetation dominated by grasses, suggesting an open prairie environment. A poor middle Holocene pollen record is followed by a series of late Holocene samples indicating [establishment] of the oak–hickory–pine communities during the last 3,000 years.

Holocene geologic deposits containing archaeological materials include alluvial and aeolian units. The major valley fills are massive aeolian silts; these are devoid of archaeological materials, and although undated at present, are thought to be of late Pleistocene age. Late Paleoindian through middle Archaic archaeological occupations occur in younger aeolian deposits, or in buried alluvial sediments. Extensive erosion of early Holocene alluvia appears to have taken place during middle Holocene times.

Several distinct episodes of aggradation and floodplain abandonment during late Holocene times is indicated by extensive terrace deposits, containing abundant, deeply stratified archaeological sites. These sites indicate increasing occupational intensity during late Archaic and Woodland periods, with declining use of the area in the last 1,000 years. [508]

**Isotopic and Geochemical Composition of Deep-Basin Brines, Palo Duro Basin, Texas [1,2]**

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Permian evaporites in the Palo Duro Basin are being evaluated for long-term disposal of high-level nuclear waste. Nineteen water samples from six

DOE test wells and three samples from nearby oil wells that penetrate the subsalt formations have been analyzed to determine their hydrologic and geochemical history.

Oxygen isotopic compositions of samples from the interior and eastern portion of the basin (−1.7 to 2.2 ‰) approach equilibrium with carbonate minerals at sample depth and temperature. In the northern part of the basin, brines have oxygen isotopic compositions (−5.1 to −7.3 ‰) similar to those of meteoric water in the overlying Cenozoic aquifers. Waters from the north central part of the basin have oxygen isotopic compositions (−2.0 to −5.4 ‰) that appear to be a mix of deep basinal and meteoric waters.

Salinities as high as 290 g/l are the result of evaporite dissolution; however, the fluids are presently undersaturated with respect to halite, gypsum and anhydrite. Na:Cl ratios are greatest in the formations immediately below the evaporite section. Waters having high Cl:Br ratios (800–1700) are typically isotopically depleted whereas waters with low Cl:Br ratios (200–400) are isotopically enriched.

The chemical and isotopic compositions imply the mixing of a fluid which has been within the basin long enough for oxygen isotopic equilibration with a non-equilibrated fluid. Chemical compositions and high Cl:Br ratios of non-equilibrated waters suggest leakage through the overlying evaporite section. Hydrologic modeling also indicates leakage through the evaporite section into the deep-basin brine aquifer.

[1] Publication authorized by director, Bureau of Economic Geology, University of Texas at Austin.
[2] Study funded by U.S. Dept. Energy, Contract No. DE-AC97-83WM46651. [509]

## Phases of Middle Permian Structural Activity in the Texas Panhandle—Evidence from Cyclic Deposits of the San Andres and Blaine Formations[1,2]

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Cycles composed primarily of carbonate and evaporite facies comprise three genetic sequences in the San Andres and equivalent Blaine Formations of the Palo Duro Basin area, Texas Panhandle. In each sequence, cycles extend over the entire basin and display similar vertical facies successions, relative facies thicknesses, and lateral changes in thickness of non-halite facies. Vertical facies sequence and relative thickness are functions of regional basin subsidence rates. Lateral thickness changes of non-halite facies probably reflect salinity gradients induced by small-scale paleotopographic features. Paleotopography resulted from differential subsidence over reactivated, fault-bounded basement structures. Differences in facies relations among the three genetic sequences probably reflect systematic changes in rates of regional and local basin subsidence.

Lower San Andres cycles in the basin interior exhibit a complete vertical sequence of black mudstone, carbonate, anhydrite and halite facies, are relatively thick, and display marked thickness changes of non-halite facies over short distances. These relations imply a relatively high overall basin subsidence rate, modified by local differential subsidence. Middle San Andres cycles are incomplete (halite missing), are relatively thin and nearly uniform in thickness, implying a reduced basin subsidence rate and limited local structural activity. Cycles of the upper San Andres are complete, relatively thin, and display lateral thickness variations of non-halite facies, implying accelerated basin subsidence and increased local structural activity. The Palo Duro Basin is bounded to the northeast by the Amarillo Uplift, which was structurally active throughout San Andres/Blaine deposition and hence does not display the episodic pattern of structural activity evident in the basin interior.

[1] Publication authorized by the director, Bur. Econ. Geol., UT–Austin.
[2] Study funded by U.S. Dept. Energy, Contract No. DE-AC97-83WM46651. [511]

## Constructing a Crustal Model for the Craton

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**Approach:** The COCORP program and advent of the Scientific Drilling Program stimulate more thinking on the character of the deeper crust. Igneous petrology of surface and/or basement surface rocks can be used to develop petrological/structural models of the subjacent crust. This is particularly true where the following assumptions can be made:

1) Silicic melt forms in the crust.
2) Composition of this melt is a function of pressure (depth).
3) This melt requires an associated large volume of mafic melt.

Generation of silicic partial melt tends to destroy pre-existing stratigraphic horizons. New crustal levels are formed from intrusion of mafic liquid. Regional tectonic analysis is necessary to determine the [likelihood] of decollement zones.

**Application:** The Southern Oklahoma Aulacogen in the southern Midcontinent provides a useful case study where model crustal levels may ultimately be matched against seismically observed ones. Surface rocks are dominantly Pennsylvanian–Permian clastics; basement surface is a Lower to Mid-Cambrian bimodal unmetamorphosed igneous complex including rhyolites and shallow-seated granites, 1.2by(?) mildly metamorphosed graywackes, and 1.3–1.4by shallow-seated granites and volcanics. Plate collisional features older than the Cambrian rifting are not identified.

The proposed model includes ten crustal "horizons" including the Moho, six of which ought to have sufficient density contrast for reflections. Four levels should be zones of disruption or of change in layering character that will take more subtle seismic analysis. The Cambrian silicics may be partially melted from a depth of 12–15 km. The idealized crustal profile, COCORP seismics, and regional geophysics are generally compatible. [518]

### Rare Earth Element Distributions in Carbonate Rocks and Minerals from the Tri-State District, Missouri–Kansas–Oklahoma

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The lead–zinc ore deposits of the Tri-State district were formed as replacements and breccia fillings in carbonate rocks of the Mississippian Warsaw and Keokuk Formations. The host rocks to the deposits consist of limestones and cherty limestones. Within and around ore bodies, the limestones were altered to or replaced by gray gangue dolomite and jasperoid. Cavities in breccia zones are lined with pink dolomite, calcite, sulfide minerals, and sometimes quartz. A REE study was made of carbonate rocks and minerals and cherty material outside and within the ore bodies. The purpose of the study was to determine whether there are changes in REE patterns that can be attributed to mineralization, as there are in the lead–zinc deposits of southeast Missouri where carbonate rocks and minerals affected by ore solutions have significantly lower La/Sm ratios than those of host rocks.

Analytical results to date indicate that there is no difference in the shape of REE patterns, as measured by La/Sm, Sm/Lu, and Eu/Sm values, that can be related to mineralization. La/Sm ratios, unlike those in southeast Missouri, are constant from group to group in the Tri-State district. Ranges of La/Sm values are 3.1 to 5.8 for unmineralized host rocks, 3.5 to 3.8 for cherts, 3.2 to 4.3 for gray gangue dolomites, 2.3 to 4.3 for pink dolomites, and 2.8 to 5.2 for calcites. Sm/Lu and Eu/Sm show similar behavior and all samples have negative Eu anomalies.

The similar shapes of REE patterns within and outside the ore zones suggest that either interaction between host rocks and ore solutions was so intense that host rock REE dominated the ore-forming system or that the ore solution's history was such that it acquired a REE pattern shaped like that of the host rocks. [522]

### Mississippian–Pennsylvanian Boundary Conodonts From the Rhoda Creek Formation, Oklahoma

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A unique exposure of basinal shale assigned to the Rhoda Creek Formation contains the latest Mississippian and earliest Pennsylvanian conodont faunas known in North America. Two zones are recognized: (1) The older *Adetognathus unicornis* Zone of Collinson and others (1971) indicates a latest Mississippian (Chesterian) age. (2) The succeeding *Declinognathodus noduliferus–Streptognathodus lateralis* Zone of Higgins (1975) is earliest Pennsylvanian but pre-type Morrowan in age. The platform conodont fauna diagnostic of Higgins' zone include *Gnathodus* n. sp. (= *Neognathodus bassleri* of Higgins, 1975), *Adetognathus* sp. cf *A. gigantus*, and the zonal indices. This fauna has not been previously recognized in North America shelf sequences presumably due to the Mississippian–Pennsylvanian boundary unconformity. Recognition of this boundary conodont zone has significant implications for intercontinental correlation and phylogenetic interpretation of Pennsylvanian conodonts. [524]

### Paleoenvironmental and Diagenetic Analysis of the Wichita Group, Palo Duro Basin, Texas

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The carbonate–evaporite sequence of the Wichita Group in the Palo Duro basin is transitional with a carbonate sequence of Wolfcampian age and an evaporite–red bed sequence of Leonardian age. [Superjacent] evaporites and hypersaline brines contributed to epi- and mesogenetic emplacement of evaporites and diagenetic masking of the Wichita depositional framework.

Wichita deposition occurred in a shallow restricted marine setting in which depositional parameters were controlled by slight sea level fluctuations, freshwater and terrigenous influx, and minor topographic changes. Schizohaline conditions restricted faunal diversity. Sedimentation kept pace with subsidence, depositing up to 1300 feet of interbedded anhydrite, dolomite, and green to black shale.

Analysis of a core from the northern part of the basin revealed nine clastic and carbonate microfacies. These are: 1) dolomudstone, 2) bioturbated dolomitic claystone, 3) organic dolomitic wackestone, 4) argillaceous dolomudstone, 5) terrigenous claystone–shale, 6) algal packstone–grainstone, 7) intraclastic wackestone–packstone, 8) skeletal wackestone–packstone, and 9) coated grain–ooid grainstone. Repetitive interbeds of these units with anhydrite resulted in a patchwork mosaic of alternating supratidal, high and low intertidal, and shoal facies that reflect an oscillating environment.

Diagenesis occurred in several stages making environmental interpretation difficult. Early dolomitization preserved much of the original structures and textures. However, epi- and mesogenetic evaporite emplacement obliterated porosity and carbonate and skeletal microfeatures. Anhydrite occurs in several forms within all microfacies including: 1) displacive bedded nodular to massive, 2) fenestral, 3) crystallotopic and blocky replacive, and 4) poikilitic cement. [524]

## Isotope Geochemistry of Formation Waters in the Palo Duro Basin, Texas

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$\delta D$ and $\delta^{18}O$ values for formation waters in the Palo Duro Basin fall into two linear arrays on a $\delta D$–$\delta^{18}O$ diagram. One array, Group I, is characterized by constant $\delta D$ values of $-12 \pm 3$ ‰ and $\delta^{18}O$ values which range from $-1$ to 2.5 ‰. The second array, Group II, varies in $\delta D$ by 40 ‰ and ranges from the meteoric water line at $\delta D = -55$ ‰, $\delta^{18}O = -8$ to an end-member value of $\delta^{18}O = 0$, $\delta D = -12$, a point common to both arrays.

$\delta^{18}O$ of the carbonate aquifer rocks ranges from $+26.2$ to 29.9 ‰. Group I waters have $\delta^{18}O$ values indicative of isotopic equilibrium with these carbonates at the measured subsurface temperatures. The calculated water/rock ratio ranges from .3 to 3.9. A possible recharge water for these aquifers could have been an ancient meteoric water with $\delta^{18}O = -2.5$, $\delta D = -12$.

Group II waters are substantially depleted in $^{18}O$ relative to values expected for carbonate–water equilibrium. These waters have experienced minimal exchange with carbonates and can be readily interpreted as a mixture of meteoric waters with Group I waters. Group II waters are encountered as deep as 8200 feet.

We suggest that meteoric waters are able to penetrate deeply into the basin, primarily through permeable clastics near the margins of the basin. These waters migrate into the carbonate aquifers where they mix with older waters and also undergo isotopic exchange with the carbonate. This mixing process may also apply to other sedimentary basins where isotope data have been previously interpreted in terms of a single recharge water which undergoes isotopic evolution exclusively via rock/water interactions. [561]

## Petrologic Evidence of a Paleozoic Rift System in Oklahoma and Colorado

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A WNW-trending dike swarm consisting of at least 50 tholeiitic diabase dikes cuts Precambrian basement rocks in and around the Black Canyon of the Gunnison River, Colorado and in Unaweap Canyon near the Colorado–Utah border. A Rb–Sr isochron based on mineral separates from a dike in the Black Canyon area indicates an age of 495±15 m.y. which is statistically identical to a previously reported Rb–Sr date from another dike in the Black Canyon. Pooling the age data for these two dikes gives an age of 497±16 m.y. Whole-rock K–Ar dates on four of the dikes are scattered around the Rb–Sr date and indicate that, except locally, the dikes have

been relatively unaffected by reheating or hydrothermal activity since emplacement.

The dike swarm and the other Cambro–Ordovician igneous rocks in Colorado (Powderhorn alkalic complex, Wet Mountains alkalic complexes and dikes) are aligned along a linear WNW trend. Closely on line with this trend is a bimodal suite (basalt/gabbro–rhyolite/granite) of Cambrian igneous rocks in southern Oklahoma (Wichita and Arbuckle Mountains, Anadarko Basin). Petrologically all of the Cambrian and Cambro–Ordovician igneous rock types in Colorado and Oklahoma are typical of extensional tectonic regimes. From these data and consideration of documented Paleozoic tectonic activity along the trend of the plutons, it is concluded that throughout the Paleozoic, a WNW-trending tectonic zone extended from southeastern Oklahoma, through Colorado, and into southeastern Utah. Bimodal and alkalic igneous activity was restricted to the Cambrian and Cambro–Ordovician but tectonic activity occurred intermittently along the zone throughout the Paleozoic. [569]

## Appalachian–Ouachita Orogeny and Mississippi Valley–Type Lead–Zinc Deposits

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Many of the Mississippi Valley–type lead–zinc deposits in the central and eastern U.S. are interpreted to be related to rapid expulsion of fluids from pericratonic-foreland basins during Appalachian–Ouachita orogeny in late Paleozoic time. This model is consistent with fluid inclusion, geochemical, and geological studies that implicate the Ouachita–Arkoma basin as the source of the ore-forming fluids responsible for the abundant lead–zinc–barite deposits in the Ozark region. Thick Carboniferous flysch sediments accumulated in the Ouachita–Arkoma basin in response to the approaching land mass from the south. During the Ouachita orogeny, these sediments were folded and carried northward in complex thrust sheets that rode across coeval shelf sediments on the continental margin. The crustal collision, limited in time, resulted in the rapid migration of fluids onto the craton in response to sediment compaction and geopressure from tectonic and burial metamorphic processes. Ore deposition was localized in part by basement topography and zones of high permeability. Occurrences of lead and zinc in western Oklahoma and Texas flank the continuation of the Ouachita foldbelt into Mexico. Uplift of the Pascola arch during [the] Ouachita orogeny may have permitted Illinois basin water to flow northward and deposit ores in the Upper Mississippi Valley (C. Bethke et al., 1984, AAPG Bull., 68, p. 454).

The lead–zinc deposits of the folded Appalachians, located in shelf carbonates, share a similar relationship to deep foreland basins and orogeny related to crustal collision. Thus, crustal orogenic events, proceeding from north to south along the Appalachian foldbelt, and then from east to west along the Ouachita foldbelt, may have resulted in a major period of lead–zinc metallogeny in North America. [572]

### The Effects of Freshwater Diagenesis on Laminated Travertine Crusts, Arbuckle Mountains, Oklahoma

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Waterfall travertine deposits in the Arbuckle Mountains of Oklahoma reveal many interesting freshwater diagenetic phenomena. Among these diverse diagenetic features are coarsely crystalline, laminated crusts which retain virtually no evidence of their original character. The precursors of these low-magnesian calcite crusts are composed of two basic alternating layers: (1) layers of filamentous cyanophyte "bushes" in which each bush is encased by one or more spar crystals (spring–summer layers), and (2) layers of micritic, equidimensional crystals surrounding individual cyanophyte filaments (fall–winter layers). As diagenesis commences, the spar crystals enclosing algal bushes grow into the overlying micritic layers by aggradational neomorphism, forming coarse, columnar crystals several millimeters long oriented perpendicularly to the laminations. As the crystals increase in size, inclusion-rich laminations within the surrounding micrite are incorporated into the spar crystals, thereby maintaining the laminated appearance. The end result of this diagenetic process is a dense, laminated crust composed almost entirely of columnar crystals which commonly are 7–8mm long and 1mm wide. Such crusts display almost no evidence in thin section of their former constituents; only occasional vacuole-rich layers, sometimes containing vague filaments and/or filament molds, attest to the once-abundant algae.

These altered crusts resemble laminated deposits from many other non-marine accumulations. Since the crusts contain practically no evidence of the organisms and micrite initially present, it is possible that analogous deposits in other non-marine settings have been interpreted as solely inorganic in origin (no original organic framework), and the columnar crystals as having formed as a precipitate from solution rather than by aggradational neomorphism. [578–579]

### Slope/Rise Depositional Systems in Carboniferous Rocks, Frontal Ouachita Mountains

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The south-facing slope–rise systems for Carboniferous rocks across the frontal Ouachita Mountains [do] not resemble the axial-fan models of Walker/Mutti/Lucci and others. The greater slope angles across this belt

were accompanied by considerable instability. It is important to recognize the different morphologies of these steep-sloping depositional systems. The sandstone beds are restricted, with thickness of each package usually less than 500 feet. The sandstone slope fans have variable textures, mature compositions, and scattered fossiliferous limestones. Beds are generally structureless, though they may show internal deformation through [liquefaction]. Bedding planes are dominated by irregular scour features separating individual sandstone beds. Depositional processes appear to have been sandy debris flows, grain flows, or rare [liquefied] flows.

Rubble fans developed as short-lived submarine slumps that are interbedded with the slope fans, consisting of disrupted mudrocks with disseminated sand grains or variable-sized blocks or sandstone or limestone. The position and occurrence of rubble fans outline belts of higher slopes across the northern margin of the Ouachita Trough. They should not be mistaken for being the product of internal, bedding-plane deformation due to orogenesis or subduction. [601]

## Deep-Marine Fan Deposits of the Pennsylvanian Jackfork Group, Rich Mountain, Arkansas and Oklahoma

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A 40-km long outcrop at Rich Mtn in the Frontal Ouachitas exposes 1.4 km of S-dipping, sandy-silty-clayey Jackfork strata. It parallels the East-to-West paleocurrent direction shown by contained sedimentary structures and well displays downcurrent facies relationships. Beds of facies, or lithofacies, A (medium, poorly to well sorted, thick-bedded sandstone), C (medium to fine, normally graded sandstone to shale), E (fine, thin-bedded sandstone, siltstone and shale) and G (shale) of Mutti and Ricci Lucchi are common, but facies B, D and F beds are absent to rare. The section contains at least 15 deep-marine fan-lobe sequences comprising proximal lobe, distal lobe, lobe fringe and starved basin deposits.

Proximal lobe deposits display 2 associations. Vertically symmetrical E–A–E sequences thicken and coarsen then thin and fine upward; they are 10 to 35 m thick and commonly enclosed by G. Positive A–E–G sequences thin and fine upward and are 6 to 20 m thick. They superficially resemble channel-fill deposits but display only small-scale, never large-scale, basal scour surfaces and associated erosional features.

Distal lobe deposits also show 2 associations. Symmetrical E–C–E sequences thicken and coarsen then thin and fine upward; they are 10 to 40 m thick and enclosed by G. Negative E–C sequences thicken and coarsen upward and are 3 to 6 m thick; several are capped and truncated by channel-fill sandstones of facies A up to 2.5 m thick.

Lobe fringe deposits are mostly facies E sequences up to 15 m thick with rare interleaved facies C beds. In places E grades into starved basin mudrocks and shales which themselves form sequences from a few up to 60 m thick. They vertically separate the different fan-lobe sequences.

Facies transitions include proximal lobe to distal lobe to lobe fringe to starved basin. The large, elongate Bengal Fan is a reasonable, modern analogue in terms of both tectonic setting and fan geometry. [608]

## Southern Source of the Jackfork Sandstone Determined by Petrography, Cathodoluminescence of Quartz, and Hafnium Content of Zircons

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The upper Jackfork Sandstone of the southern Ouachita Mountains in S.W. Arkansas is a moderately to poorly sorted quartz arenite. It was deposited as a thick flysch sequence in a complex array of submarine fans adjacent to the southern margin of the N. American craton. Its source area is unknown, although northerly (cratonic) and southerly sources have been proposed.

This study utilized standard petrography, cathodoluminescence (CL) of quartz, and microprobe analysis of hafnium in zircons to detect genetic affinities between the Jackfork Ss. and coeval sandstone units of adjacent basins. Most of the units studied are quartz arenite, so meaningful conclusions based solely upon petrologic variables are not possible. However, statistical comparisons of frequency distributions of CL colors of detrital quartz and hafnium content of zircons reveal genetically-related similarities which indicate the Jackfork's source.

The Jackfork Ss. was derived from the south, from the same proximate source as the Parkwood Fm. of the Black Warrior Basin in Alabama. The Jackfork has very little affinity with Carboniferous sandstones of the Illinois Basin, and therefore was not supplied from that direction.

Predominance of brown-CL quartz, relative abundance of micaceous rock fragments, and absence of appreciable feldspar in the Jackfork imply that a low grade metamorphic and sedimentary orogenic highland was present adjacent to the southern margin of N. America during the late Paleozoic. Analogy with the Antler Foreland Basin (Mississippian) and the Banda Arc (Neogene) suggests that the Ouachita highland was composed of N. American continental crust mantled by slope and rise sedimentary rocks which were slightly metamorphosed, uplifted, and eroded during collision with a southern plate or microplate. [616]

## Geologic Simulation of Processes in the Palo Duro Basin of Northwest Texas

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To help evaluate the potential for geologic processses to affect a possible repository located in the Palo Duro Basin of West Texas, a Geological Simulation Model (GSM)) is being developed at Pacific Northwest Laboratory under direction from the Office of Nuclear Waste Isolation. The GSM uses Monte Carlo simulation to predict the evolution of the site over times ranging from 10,000 to 1,000,000 years. Phenomena that the model takes into account include geomorphic, tectonic, salt movement, and climate processess. In general the model is site specific to the Palo Duro Basin. However, the reasons for using a computer model as *one* part of the safety assessment are common to all sites. These reasons include the need to 1) use probability distributions rather than discrete numbers for geologic rates and magnitudes, 2) account for the significant interactions that exist among disruptive phenomena, 3) determine the sensitivity of output to variations in the input parameters in order to optimize time and money expenditures on additional data collection and analysis, 4) place bounds on possible events, and 5) explicitly reveal the conceptual model and provide a degree of auditability.

The model is currently undergoing review and comments from the general geologic community would be very useful. This work was supported by the U.S. Department of Energy under contract DE-AC06-76RLO 1830.

[622]

## Evidence Supporting an Evaporitic, Shallow Marine Paleoenvironment for the Cool Creek Formation of Oklahoma

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The Ordovician Cool Creek Formation of Oklahoma consists of over 400 meters of shallow marine sediments that were deposited in an arid to semiarid environment. Evidence supporting this is found in both the Slick Hills (Southwestern Oklahoma) and the Arbuckle Mountains.

Field observations of stratigraphic sections resembling sabkha sequences and samples containing pseudomorph molds shaped suspiciously similar to vanished evaporites led to further investigations in the laboratory. Thin section analysis of partially silicified carbonate sediments revealed large, tabular pseudomorphs filled with dense microcrystalline calcite. "Cauliflower" chert nodules (Chowns and Elkins, 1974) found in dolomitic matrices were lined with lath-shaped silica crystals and filled in with megaquartz. Closer examination of megaquartz crystals revealed tiny laths of relict anhydrite and gypsum. SEM and EDAX analysis showed the presence not only of calcium sulphate, but also strontium sulphate, celestite.

In some cases, marine transgressions led not only to a change in the type of sediment deposited over the sabkha evaporites, but also contributed to the formation of collapse breccias. As algal mounds were formed, the evaporite minerals were dissolved in the raised water table zone. The voids were not always quickly filled by secondary precipitates. Consequently, the weight of the overlying sediments caused the partially lithified matrix sediments of the former sabkha to founder and form collapse breccias. [629]

## Evidence for a Late Pennsylvanian–Early Permian Regional Thermal Event in Missouri, Kansas, Arkansas, and Oklahoma

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Homogenization temperatures from fluid inclusions in the abundant hydrothermal, vug-lining dolomite collected from mines, quarries, and drill core in Missouri, Kansas, Arkansas, and Oklahoma indicate the passage of highly saline fluids significantly hotter than consistent with reasonable geothermal gradients. Data from these samples combined with those of earlier studies provide evidence for broad-scale heating of the Paleozoic section to temperatures of 90°–160°C. Inclusion temperatures increase from about 90° in sphalerite from northwest and central Missouri, and northeast Kansas, to about 115° in dolomite from the Viburnum Trend, to 140° and 160° for dolomites from northern Arkansas and southwest Missouri, respectively. The observed temperatures may reflect the thermal gradient of slowly cooling fluid moving northward out of a deep sedimentary basin such as the Arkoma.

The heated fluids may have been driven by some combination of compaction, gravity draining, and geopressuring in response to tectonic and metamorphic processes. Temperatures of 200°–300°C have been documented for fluids expelled from the 12 to 18 km thick Ouachita section. Basin fluids migrating northward could have precipitated traces of sulfides and large quantities of hydrothermal dolomite throughout their flow path. Economic concentrations of PbS and ZnS were deposited in regions where fluid-flow was focused by basement topography and/or zones of high permeability. On a smaller scale, no localized or steep thermal gradients from major ore districts (e.g. Viburnum and Tri-state) out into barren host rock have been found. Thus, thermal equilibrium between fluid and host rock is implied, suggesting a major, regional thermal event rather than localized thermal anomalies. [640]

## Subnormal Pressures in the Palo Duro Basin Caused by Regional Hydrodynamic Conditions[1,2]

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Fluid pressures in the Deep-Basin Brine Aquifer of the Palo Duro Basin are subnormal by up to 1,000 psi, giving hydraulic head values 700 m below the water table of the High Plains aquifer. Various effects of lithostratigraphy and topography on subnormal pressures were investigated using a two-dimensional finite element model representing the complex geometry of geologic facies along a 550 km long east–west cross section through the basin. Permeability values of the geologic facies were estimated from drill-stem tests, pumping tests, laboratory tests of cores, and typical values of equivalent geologic materials. Boundary conditions include prescribed recharge rates along the High Plains surface and prescribed head along known recharge or discharge boundaries.

The model indicates a shallow flow system governed primarily by topography segregated by a low permeable evaporite aquitard from a deeper flow regime recharging in the New Mexico area and passing deep beneath the Pecos River into the central basin. The model simulates the observed underpressuring in the Deep-Basin Brine Aquifer with good accuracy. Abnormally low fluid pressures commonly have been related to the effect of erosional unloading which results in dilation of the rocks and decrease in rock temperature. Test runs using different values of permeability for the evaporite aquitard and the deeper units indicate that the underpressuring is caused primarily by the presence of relatively permeable granite-wash deposits in the Deep-Basin Brine Aquifer and by the overlying Permian evaporites. The granite wash effectively drains the deeper aquifer more easily than it can be recharged, and the evaporite aquitard effectively isolates the deeper section from the higher hydraulic heads of the High Plains aquifer. The Pecos River apparently enhances underpressuring beneath the western part of the High Plains by serving as a discharge area for water that would otherwise move downdip into the deeper aquifer.

[1] Publication authorized by the director, Bur. Econ. Geol., UT–Austin.
[2] Study funded by U.S. Dept. Energy, Contract No. DE-AC97-83WM46651. [650]

## Sedimentology, Structure, and Thermal Maturity of the Lower Atoka Formation, Frontal Ouachitas, Arkansas

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The lower member of the Atoka Formation in Arkansas is comprised mostly of interbedded sandstone turbidites and mudrocks of Pennsylvanian age. Paleotectonic reconstructions of the Ouachita Mountains suggest that a south-dipping subduction zone was active at the time of Atokan deposition. Our data demonstrate that, instead of a restricted wedge of trench turbidites, a large radial submarine fan extended parallel to the continental margin.

Lithofacies associations and depositional cycles are indicative of several distinct submarine-fan sub-environments, including distributary channels and levees, depositional lobes, interchannel/interlobe, and basin plain. Large inner-fan feeder channels have not been observed, however. Paleocurrent data show that sediment gravity flows traveled from east to

west, and facies changes define a transition from middle fan to basin plain in the same direction. It is likely that a single submarine fan lengthened at least 300 km.

The structural style displayed by Atokan strata is typical of a foreland fold-and-thrust belt rather than an oceanic subduction complex. Sediments were undoubtedly well-consolidated prior to thrust imbrication, but the overall burial history of the sedimentary section appears closely linked to thrusting events. Thermal maturity data, for example, can be correlated with geologic structures. Within the western half of the study area, mean vitrinite-reflectance ($R_o$) values range from 2.15% to less than 1.00%. These data indicate that strata presently exposed at the surface were once buried by as much as 8–10 km of additional section. Moreover, the $R_o$ values increase progressively toward major thrust faults, and there is local evidence of frictional heating along fault zones. [680]

## Composition of Fluids Extracted from Sphalerite, Galena, and Dolomite in Mississippi Valley–Type Deposits of the Mid-Continent: Implications for the Origin of the Fluid

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Sodium, potassium, calcium, magnesium, fluoride, chloride, bromide, and sulfate concentrations were determined for fluid inclusions in minerals from Mississippi Valley–type deposits in the Viburnum trend and the Tristate and northern Arkansas districts and in unmineralized rock distant from these deposits. Fluids extracted from sphalerite, galena, and hydrothermal dolomites from these occurrences have remarkably similar compositions considering that they are hosted by Cambrian-through-Pennsylvanian rocks and separated by hundreds of kilometers. The fluids typically contain 16 to 24 percent dissolved solids, and have the following weight ratios: Na/Cl, 0.40 to 0.48; Na/K, 18 to 22; Ca/Mg, 8 to 12; and Cl/Br, 75 to 250. Chloride-to-bromide weight ratios are variable but are consistently less than the seawater ratio (292). The variability of bromide may be due to bromide derived from organic matter during fluid migration.

Fluid compositions in the three areas studied are different from fluid compositions in other midcontinent Mississippi Valley–type districts. Average Na/K weight ratios of fluids from southern Illinois, central Tennessee, and the upper Mississippi Valley are 14.7, 8.2, and 16.5, respectively, and average Ca/Mg ratios are 6.5, 17.3, and 7.3, respectively.

Although no known evaporites exist regionally, the fluids from southern Missouri and northern Arkansas have a composition very similar to formation waters of south-central Texas, interpreted by Land and Presbindowski (1981, J. Hydrol., 54, p. 51–74) to have been evolved from the dissolution of deeply buried evaporites of the Gulf of Mexico basin. [682]