Subsurface Geology Series 9
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Stratigraphic and Spatial Distribution of Oil and Gas Production in Kansas

K. David Newell, W. Lynn Watney,
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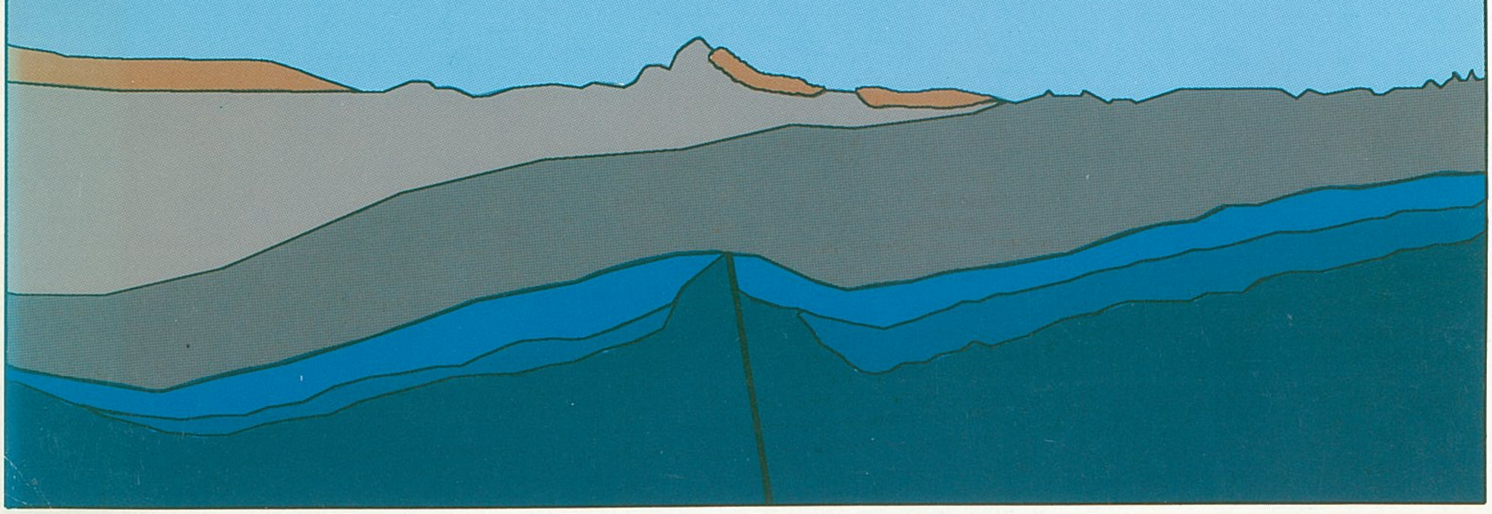

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Kansas Geological Survey
The University of Kansas
Lawrence, Kansas
1987

Cover design by Jennifer Sims, Kansas Geological Survey.
Figure 34 on page 57 shows an expanded version of the cross section idealized in the cover design.

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Introduction

The maps in this report have been compiled with the goal of acquainting the reader with the distribution of petroleum in Kansas. We feel that by knowing the geologic and spatial distribution of petroleum production in the state, one will be able to better predict where some future production may be found by either concentrating exploration efforts within existing production trends or by extending them. New trends and new pay zones of course can be discovered, but maps in this text will usually not be of direct help in such cases. In this report we have categorized Kansas petroleum production into several geologic pay horizons (fig. 1) and have included maps that show both the subsea and subsurface depths of this production. Pay horizons considered are sub-Arbuckle; Arbuckle; Simpson; Viola and Maquoketa; "Hunton" (Silurian and Devonian limestones); Chattanooga and Misener; Mississippian; Morrow and Atoka; Cherokee and Marmaton; Pleasanton, Kansas City and Lansing; Douglas, Shawnee, and Wabaunsee; Admire; Council Grove; Chase; Sumner; and Niobrara. Other maps include the number of pay zones and fields by discovery date and a series of maps that depict the volumetric distribution of petroleum production in the state. Each map is accompanied by a brief commentary with references that will direct the reader to more elaborate discussions in the geologic literature. A glossary also is included for nongeologists at the end of this report, which will help explain various geologic concepts and terms discussed in the text.

The maps in this report were generated in 1984 through 1987 using the facilities of the Automated Cartography Laboratory and Graphics Arts Department at the Kansas Geological Survey. GIMMAP (Geodata Interactive Management Map Analysis and Production), a computer-assisted cartography system developed jointly by the Kansas Geological Survey and the Bureau de Recherches Geologiques et Minieres, Orleans, France, is the software utilized to create the maps. The data base on Kansas oil- and gas-producing zones used to generate some maps in this report is a subset of a larger data base supplied by Petroleum Information Corporation (an A. C. Nielsen Company). This smaller data base has information on almost 53,000 pay zones distributed over approximately 49,500 production wells in Kansas. Such an extensive data base, constructed on reports from thousands of geologists and drillers over several years, is bound to contain some errors and misinformation. The authors have hopefully deleted most errors, but to catch all errors, such as incorrect well locations or pay-zone identifications, is virtually impossible. Correcting the data base is an ongoing project, and anyone who detects errors in the maps contained in this publication is invited to contact the authors in order that subsequent publications of this type can be more reliable. The authors also welcome any suggestions about other types of maps that also can be used to depict the distribution of petroleum production in Kansas.

Pay-zone and depth maps in this report were constructed by plotting productive or once-productive oil or gas wells as small squares. At map scale, each square is approximately 5/8 x 5/8 mi (1 x 1 km). Data available for western Kansas are relatively complete since 1964, the starting date of data compilation. Only selected development and exploration wells drilled prior to 1964 were added to this base, but the effect on producing areas at the scale of these maps is negligible except for very large fields drilled prior to 1964, such as the Hugoton gas area. Older producing areas such as the Cherokee basin in eastern Kansas also have data largely limited to recently drilled wells. The pattern of wells in eastern Kansas is therefore spotty and does not precisely follow known field outlines. Nevertheless, major producing trends are adequately defined.

The maps in this report are probably best used in conjunction with the 1:500,000 oil- and gas-field map (Paul and others, 1982) published by the Kansas Geological Survey. This map is periodically updated to show additional new fields and extensions of old fields. Additional information on production of individual fields is available from oil- and gas-production reports (e.g., Paul and Beene, 1985), periodically published by the Kansas Geological Survey. Previous publications on the distribution of pay zones in the state include Hilpman (1958) and maps by M. O. Oros in Ebanks (1975). Comparison of the earlier maps with the ones presented in this report is interesting because one can observe the development and extension of various producing trends. Seeing the growth of such trends is encouraging because with continued future exploration developments, the trends evident today may be extended even further. Good overviews of Kansas stratigraphy and geology can be obtained in Zeller (1968) and Merriam (1963). Several oil and gas fields are individually discussed in a five-volume set published by the Kansas Geological Society (1956, 1969, 1960, 1965, 1986) in Wichita, Kansas. The Kansas Geological Society volumes include maps and well-log correlations over individual fields, which can be particularly helpful to explorationists.

Acknowledgments—The authors gratefully acknowledge the help of Charlie Ross with the computer programming, Renate Hensiek and Pat Acker for preparation and drafting of some of the original figures, Jennifer Sims for preparation of graphics and the cover design, Lee Gerhard and Rex Buchanan (Kansas Geological Survey) and Jock Campbell (Oklahoma Geological Survey) for their helpful suggestions and encouragement, and Lea Ann (Millikan) Davidson who patiently typed the original manuscript of this report and its numerous subsequent revisions.

ERA	PERIOD	SERIES (where applicable)	STAGE (where applicable)	MAJOR PETROLEUM-PRODUCING ROCK GROUP	million yrs before present (m.y.B.P.)
Cenozoic	Quaternary				1.6
	Tertiary				66
Mesozoic	Cretaceous	Upper		Niobrara Formation	
		Lower			144
	Jurassic				208
	Triassic				245
Paleozoic	Permian		Custerian		
			Cimarronian	Sumner Group	
			Gearyan	Council Grove Group Chase Group Admire Group	296
	Pennsylvanian	Upper	Virgilian	Wabaunsee Group Shawnee Group Douglas Group	
			Missourian	Lansing Group Kansas City Group Pleasanton Group	
		Middle	Desmoinesian	Marmaton Group Cherokee Group	
			Atokan	"Atokan rocks"	
		Lower	Morrowan	"Morrowan rocks" basal Pennsyl. congl. (age is variable)	320
	Mississippian	Upper	Chesteran	"Chesteran" rocks	
			Meramecian	"chat," Miss. limestones	
		Lower	Osagian		
			Kinderhookian	Misener, "Kinderhookian" sandstone	360
	Devonian	Upper			
		Middle		"Hunton" limestone	408
		Lower			
	Silurian	Upper		"Hunton" limestone	
		Lower			438
	Ordovician	Upper		Maquoketa Formation	
		Middle		Viola Formation Simpson Group	
		Lower		Arbuckle Group	505
	Cambrian	Upper		Reagan, Lamotte Sandstone	
		Middle			
		Lower			570
Precambrian				fractured basement rocks	

FIGURE 1—Geologic timetable and Kansas rock chart showing the various producing zones considered in this report.

Structural features of Kansas

The Central Kansas uplift and Nemaha uplift are two major post-Mississippian structural highs that dominate the subsurface geology of Kansas (figure 2). These features and the basins adjacent to them have little or no expression at the surface, hence their discovery and subsequent delineation are largely based on the results of exploratory drilling. The Nemaha uplift was initially recognized as a major subsurface feature about 1915, and was formally named in a 1917 treatise on Kansas oil and gas by Moore and Haynes (1917). The Nemaha uplift is a complex north-northeast—south-southwest oriented feature which extends into Nebraska and Oklahoma. It is asymmetric with a gently dipping western flank and a faulted eastern flank. The Humboldt fault system (Condra, 1927) marks the boundary between the Nemaha uplift and the Cherokee and Forest City basins to the east (McQueen and Green, 1938).

Parts of the Central Kansas uplift were recognized as early as the 1920s, but Morgan (1932) formally named it and recognized its regional significance. The Central Kansas uplift is more symmetric than the Nemaha uplift. It trends northwest-southeast and is the locus of most of the major oil fields in the state. The basin lying between the Central Kansas uplift and Nemaha uplift was formally recognized and named the Salina basin by Barwick (1928).

The Pratt anticline extends southward from the Central Kansas uplift and separates the Hugoton basin (Maher and Collins, 1948) in southwest Kansas from the Sedgwick basin (Moore and Jewett, 1942) in south-central Kansas. The Hugoton and Sedgwick basins are structural embayments on the northern flank of the deeper Anadarko basin that extends across most of Oklahoma. Basement rocks in Kansas are buried deepest (-6,900 feet subea [-2,100 m]; Cole, 1976) in the Hugoton basin near the Kansas-Oklahoma state line in southern Meade County.

Most of the major, present-day structural features in Kansas, including the Nemaha and Central Kansas uplifts, were largely created by geologic deformation in Late Mississippian to Early Pennsylvanian time (Merriam, 1963). Before these late Paleozoic features were formed, a broad northwest-southeast-trending structural high dominated the geology of the state in Ordovician and Devonian time (figure 3). This feature is called the Central Kansas arch in south-central Kansas; its northwest and southeast extensions are respectively called the ancestral Central Kansas uplift and the Chautauqua arch (Merriam, 1963).

North of the Central Kansas-Chautauqua arch, a large basin developed, called the North Kansas basin by Rich (1933). With the development of the Nemaha uplift, the North Kansas basin was split into the Forest City and

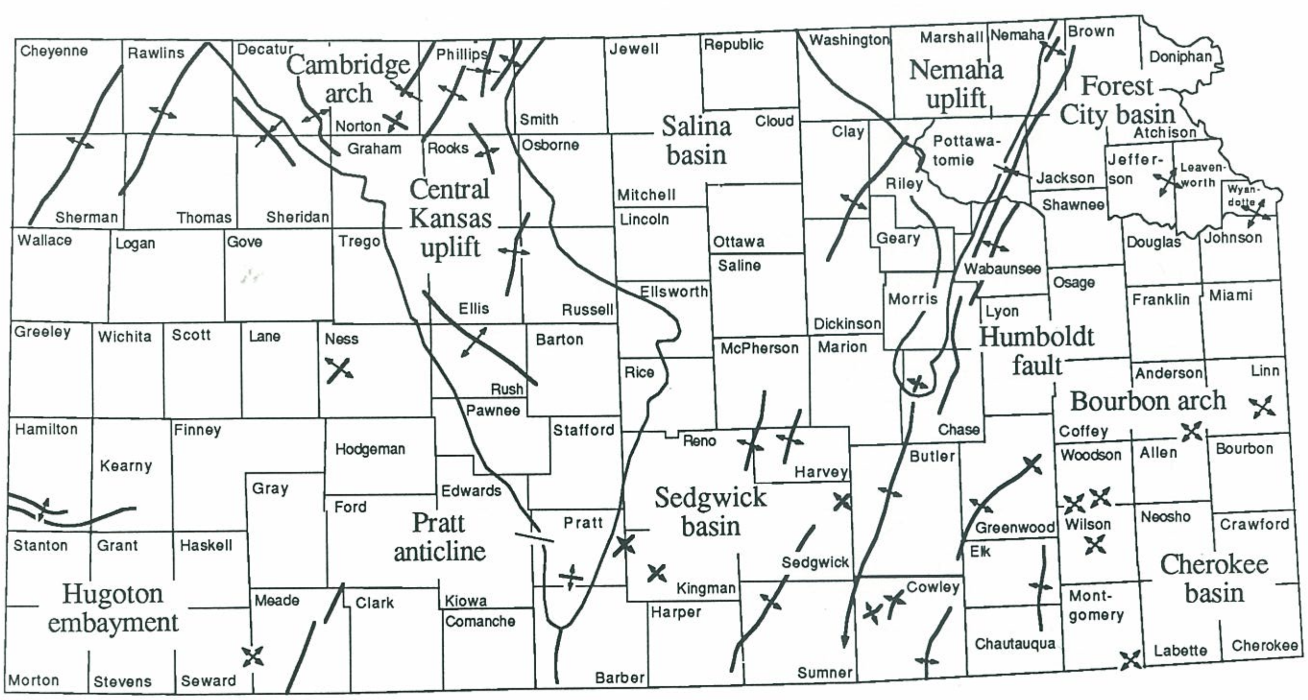


FIGURE 2—Post-Mississippian structural features of Kansas (from Merriam, 1963).

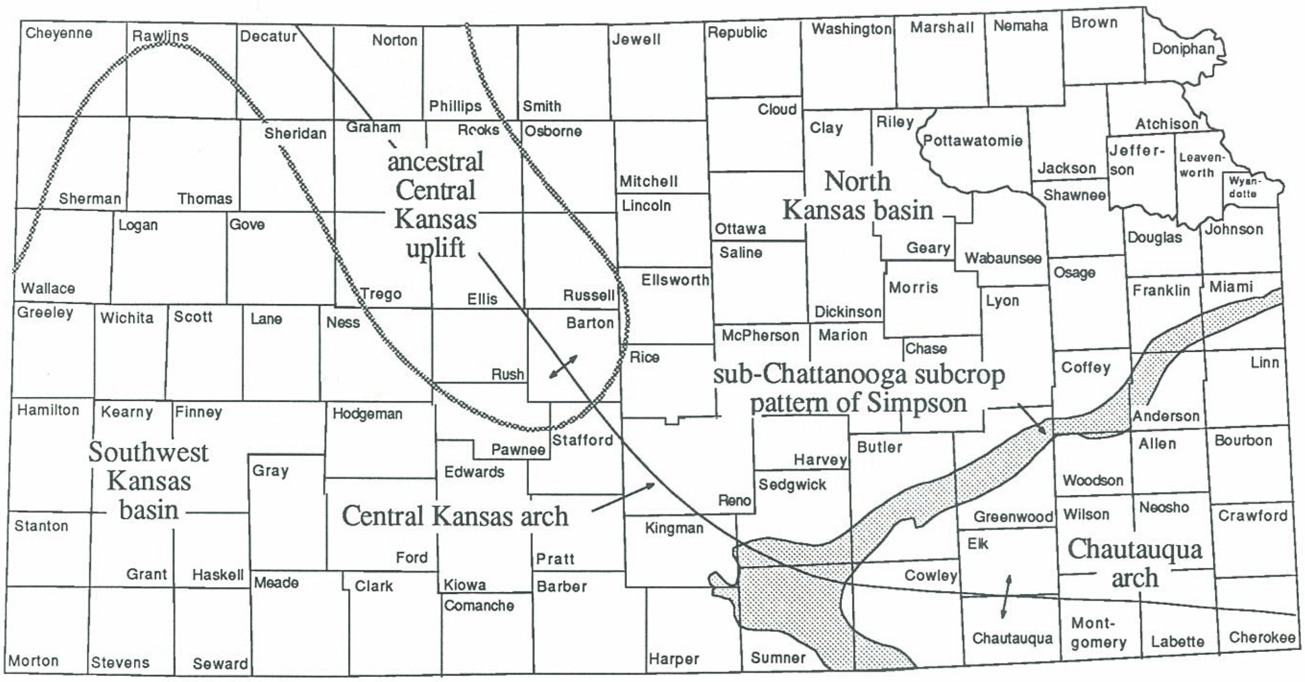


FIGURE 3—Pre-Mississippian-post-Ordovician structural features of Kansas (from Merriam, 1963).

Salina basins (Lee, 1956). Aside from major structural features such as the Central Kansas-Chautauqua arch, pre-Mississippian geologic structures in Kansas are difficult to recognize because their original geometry has been considerably altered by the more severe Late Mississippian-Early Pennsylvanian structural movements.

Distribution of known oil and gas fields

Figure 4 is a smaller version of the 1:500,000 map of oil and gas fields in Kansas (Paul and others, 1982). Petroleum production has been an important component of the Kansas economy for most of the twentieth century. Today the state ranks eighth among all states in annual oil production and fifth in annual gas production, with respectively 2.28 and 2.33% of the total U.S. marketed production (Paul and Beene, 1985). Over 71 million barrels of oil and 430 billion ft^3 of gas were produced in Kansas in 1983.

In the last 30 years, smaller oil pools have been the usual type of new discovery. In any exploration area, larger fields are characteristically found early but as the area becomes more completely explored, smaller and smaller fields are found (Meyer and Fleming, 1985). The numerous small fields currently being discovered in Kansas are therefore a natural reflection of its exploration maturity. Despite the smaller size of the new discoveries, several are made each year that extend old exploration trends and establish new ones.

At present, total proven oil reserves in Kansas are approximately 370 million barrels of oil. Original oil-in-place is estimated to have been 16.6 billion barrels, of which about 5 billion have probably been produced (Watney and Paul, 1983). In analyzing the distribution of oil fields by cumulative production for a period from 1890 to 1973, Harbaugh and Ducastaing (1981) concluded that the next 598 fields discovered (20% of the 1973 total) would contribute only 2 or 3% more to the total oil discovered in Kansas through 1973, approximately 55 million barrels. The succeeding 20% of the fields would contribute 48 million barrels. Enhanced oil-recovery techniques will no doubt provide for some of the recovery of 11.6 billion barrels still remaining in the ground. Total extra oil that may be produced by enhanced oil-recovery techniques may be approximately 2-3 billion barrels (Ebanks, 1975).

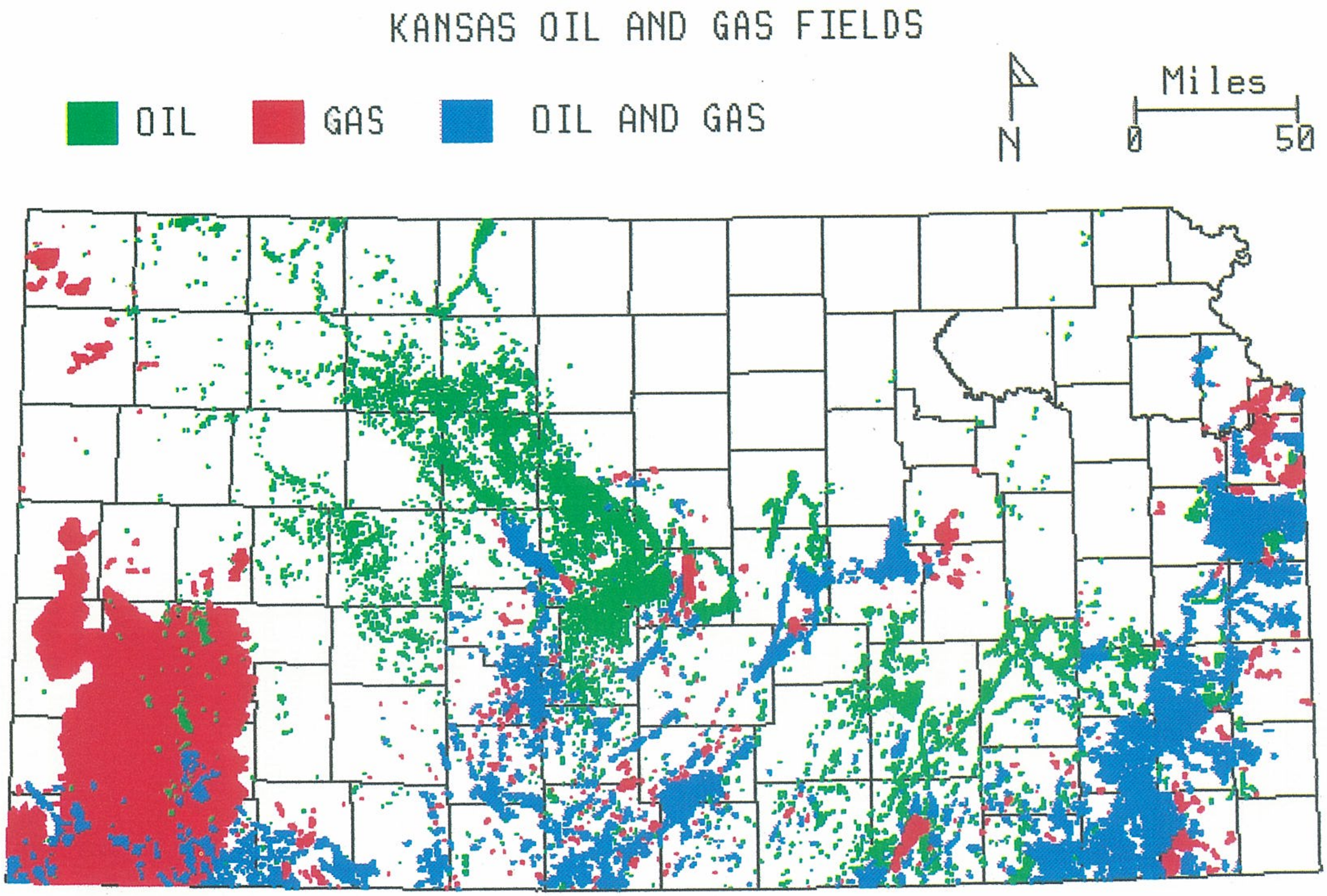


FIGURE 4—OIL AND GAS FIELDS OF KANSAS (BY FIELD OUTLINE).

Approximately 34% of the volume of produced oil and known reserves of oil in Kansas have come from Pennsylvanian rocks (Adler, 1971). Mississippian, Devonian, and Silurian rocks account for about 14%; Middle and Upper Ordovician rocks account for about 12%; and Cambrian-Ordovician rocks account for about 40% of this total. With respect to the volume of produced and known reserves of gas, approximately 73% is from Permian rocks; about 13% is from Pennsylvanian rocks; about 11% is from Mississippian, Devonian, and Silurian rocks; and about 2% is from Cambrian-Ordovician rocks (Adler, 1971). Gas present in Cretaceous rocks in western Kansas was not considered at the time of this particular compilation.

Fields by decade of discovery

In 1860, as early as one year after Colonel Drake's historic well first produced oil near Titusville, Pennsylvania, drilling for petroleum reportedly commenced near Paola in Miami County in eastern Kansas (Haworth, 1908; Jewett, 1954). As early as 1884, Paola was supplied with gas piped in from a nearby field. Although further sporadic drilling found minor amounts of oil and gas in subsequent years, the first significant commercial oil field in Kansas was developed near Neodesha in 1893 (Owen, 1975). In addition to further oil development, by the latter part of the 1800s, several towns in eastern Kansas utilized gas produced from nearby gas fields for heating and illumination.

Most oil and gas produced in eastern Kansas was taken from Pennsylvanian Cherokee sandstones only a few hundred feet deep. The occurrence of sand bodies in the Cherokee formation was unpredictable; hence, exploration was more a matter of serendipity and extrapolating existing trends of production than an exercise in geologic science. Nevertheless, geology benefited from the hunches of wildcatters, and the knowledge gleaned from this drilling helped establish the principles on which modern petroleum geology is based. Erasmus Haworth, one of the early state geologists of Kansas, studied the drilling results in eastern Kansas and published his findings in a classic volume (i.e. Haworth, 1908) that related the occurrence of oil and gas to both structural traps (anticlinal closures) and stratigraphic traps (linear "shoestring" sand bodies). The origin and known distribution of the Cherokee shoestring sandstones were further elaborated upon by Bass (1934, 1936) and Bass and others (1937).

Figure 5 shows that most of the larger fields in eastern Kansas were discovered by 1920. Drilling continues in this region though, and small fields, new pay zones, and field extensions are still being discovered by individuals and small independent oil and gas companies.

The halcyon days of Kansas petroleum production were ushered in with the discovery of the El Dorado and Augusta fields in 1914 in Butler County. Since then the oil production of Kansas has generally increased until it peaked at 124.7 million barrels per year in 1956 (Oros, 1979). El Dorado, the most prolific oil field in Kansas, has produced over 290 million barrels of oil (see table 1). Both El Dorado and Augusta are structural traps associated with folding and faulting on the Nemaha uplift (Fath, 1921; Berry and Harper, 1948). Their discovery was largely based on surface mapping and as such, they represent some of the first fields found in the Midcontinent using science rather than "trendology" and luck (Owen, 1975). The conspicuous production of these fields also played a key role in assuring the success of the small oil companies, which eventually evolved into Cities Service Oil Company.

With the discoveries on the Nemaha uplift, exploration attention gradually focused westward in Kansas. Additional fields on the western flank of the Nemaha uplift were soon put into production. These fields included the Elbing field in Butler County and the Peabody, Covert-Sellers, and Florence fields in Marion County (Thomas, 1927). In 1919, the Walton field was discovered in Harvey County and was the first field to produce oil in the west ranges of Kansas and the Sedgwick basin (Jewett, 1954). In 1923, the first oil on the Central Kansas uplift was discovered with the opening of the Fairport field in Russell County (Oros, 1979). This field, like the El Dorado field, was prospected by surface geologic mapping (Allan and Valerius, 1929). Just before the discovery of the Fairport field, the Covert-Sellers field in Marion County was the farthest northwest in Kansas. The Fairport discovery was 120 mi farther northwest, and its discovery certainly surprised oil men of that era (Owen, 1975).

In the mid-1920s to the early 1930s, both surface-structure mapping and random drilling found new large fields on the Central Kansas uplift. Significant fields found early on the Central Kansas uplift include the Gorham and Hall-Gurney fields in Russell County, the Trapp field in Russell and Barton counties, the Bemis-Shutts field in Ellis County, and the Chase-Silica field in Rice and Barton counties (Owen, 1975).

Although exploration and development on the Central Kansas uplift continues at a brisk pace, and several small fields are still being found, most of the larger fields in this geologic province were found by the 1950s.

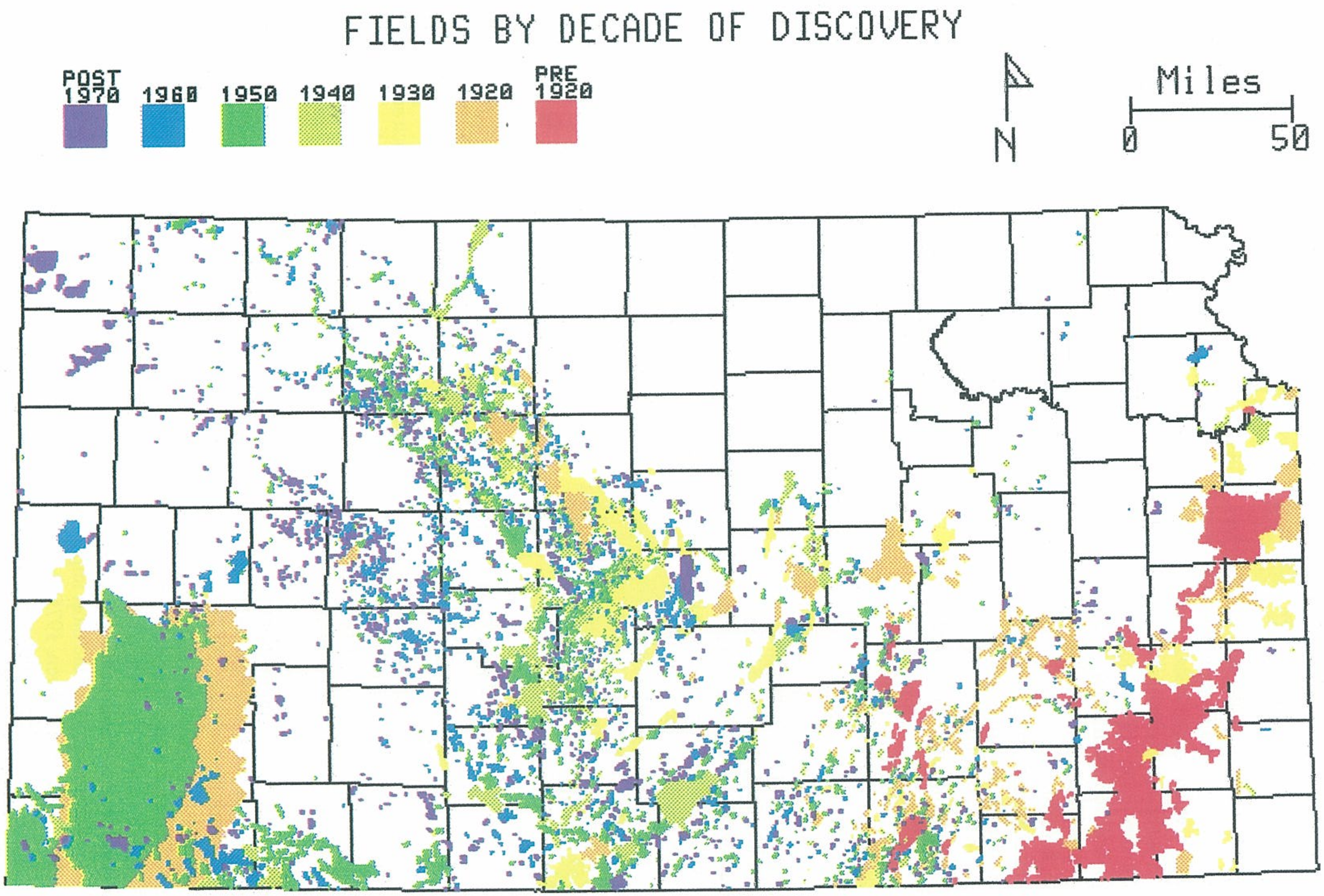


FIGURE 5—FIELDS BY DECADE OF DISCOVERY.

According to Petroleum Information (1982), the density of new-field wildcat wells on the Central Kansas uplift is the greatest of any province in the United States. The Central Kansas uplift also usually leads the state in the number of discoveries per year (Watney and Paul, 1983).

During the 1930s and 1940s, most of the larger fields in the Sedgwick basin and southern Salina basin were discovered by a variety of methods including shallow core-hole drilling, surface and subsurface mapping, and geophysical techniques (Merriam and Hambleton, 1959; Owen, 1975). Exploration south and west of the Central Kansas uplift has proceeded more slowly with most of the major discoveries occurring between 1940 and 1960. Most of the recent exploration successes in the state have been with several small fields discovered in a northwest-southeast-oriented trend straddling Ness, Gove, Lane, and Hodgeman counties southwest of the Central Kansas uplift.

The greatest single deposit of gas in Kansas is the Hugoton gas field, which covers several counties in southwestern Kansas. This field continues southward into the panhandles of Oklahoma and Texas and can also be identified in publications as the Panhandle-Hugoton field or Hugoton-Panhandle field, depending if the writer is a Texan or Kansan (Owen, 1975). Due to its vast extent, it was not recognized as a single entity until the late 1920s. The discovery of the Kansas sector of the field is generally considered to be in 1922, with the drilling of an exploratory well (Defenders and Traders Gas Co. No. 1 Boles) near Liberal in Seward County (Hemsell, 1939; Page, 1940; Hinton, 1952; Mason, 1968; Pippin, 1970; Owen, 1975). The ultimate recovery of the Hugoton-Panhandle field is estimated to be approximately 70 trillion ft^3 of gas (Pippin, 1970) and as such, it ranks as one of the greatest gas fields in the world. It may eventually produce 10% of the gas ultimately recovered in the United States (Mason, 1968).

Significant exploration plays have periodically developed in Kansas over the last three decades. In the late 1940s and early 1950s, the Forest City basin in the northeastern part of the state experienced a round of exploration activity after the discovery of the Davis Ranch field in Wabaunsee County (Jewett, 1954). Subsequent discoveries defined a trend of fields that extend along the axis of the basin all the way up into southeastern Nebraska. Activity in the Forest City basin has recently revived with the discovery of the McClain field in Nemaha County in 1982 (McCaslin, 1982).

In the 1970s, gas accumulations in the Cretaceous Niobrara Chalk in northwestern Kansas became attractive exploration targets. This trend continues into adjacent states (Hanley and Van Horn, 1982) and could be expanded over the next few years, provided gas prices remain firm. Oil fields in southwestern Kansas, underneath the Hugoton gas field and on the southwest flank of the Central Kansas uplift, are also recent significant exploration plays that have been substantially extended during the 1970s. These fields in general are associated with unconformities developed in and between Mississippian and lower Pennsylvanian strata. It is anticipated that many more fields will be discovered in this region (Watney and Paul, 1983).

Volumetric distribution of petroleum production

In addition to knowing the geographic distribution of petroleum production with regard to stratigraphic units and depth, it is also important to understand how petroleum is volumetrically distributed around the state. Records of petroleum production have been kept by the Kansas Corporation Commission and the Kansas Geological Survey for a number of years (cf., Paul and Beene, 1983; Kansas Corporation Commission, 1987) but translating this data into meaningful maps carries some unique challenges. Different areas of the state have been important at different times with regard to petroleum production. For instance, the Cherokee basin in eastern Kansas and Oklahoma was once one of the most important sources for oil in the United States (Owen, 1975), but now many of the most prolific producing fields have been abandoned or presently are dominated by stripper production. Although a field may have produced prolific amounts of petroleum, it may now be a nearly exhausted natural resource except through application of enhanced oil-recovery methods, whereas a much smaller field with less ultimate reserves may presently be producing considerably more petroleum. Expressing these differences on maps can be difficult, so the authors have constructed a series of maps in which petroleum fields are differentiated based on attributes concerning cumulative production and recent yearly production. By comparing the recent yearly production with the historic production, the reader may gain an appreciation for past, present, and even future importance of petroleum production in Kansas.

Figures 6 and 7 are color-coded maps expressing cumulative production of oil and gas fields in Kansas through 1982. Except for larger fields, detailed production records have not been kept for discoveries before 1944; therefore, many older fields (particularly those in the Cherokee basin in the eastern part of the state) cannot be considered in the maps in this report, which express various aspects of production volume.

All figures displaying field outlines utilize production data collected through 1982 (cf., Paul and

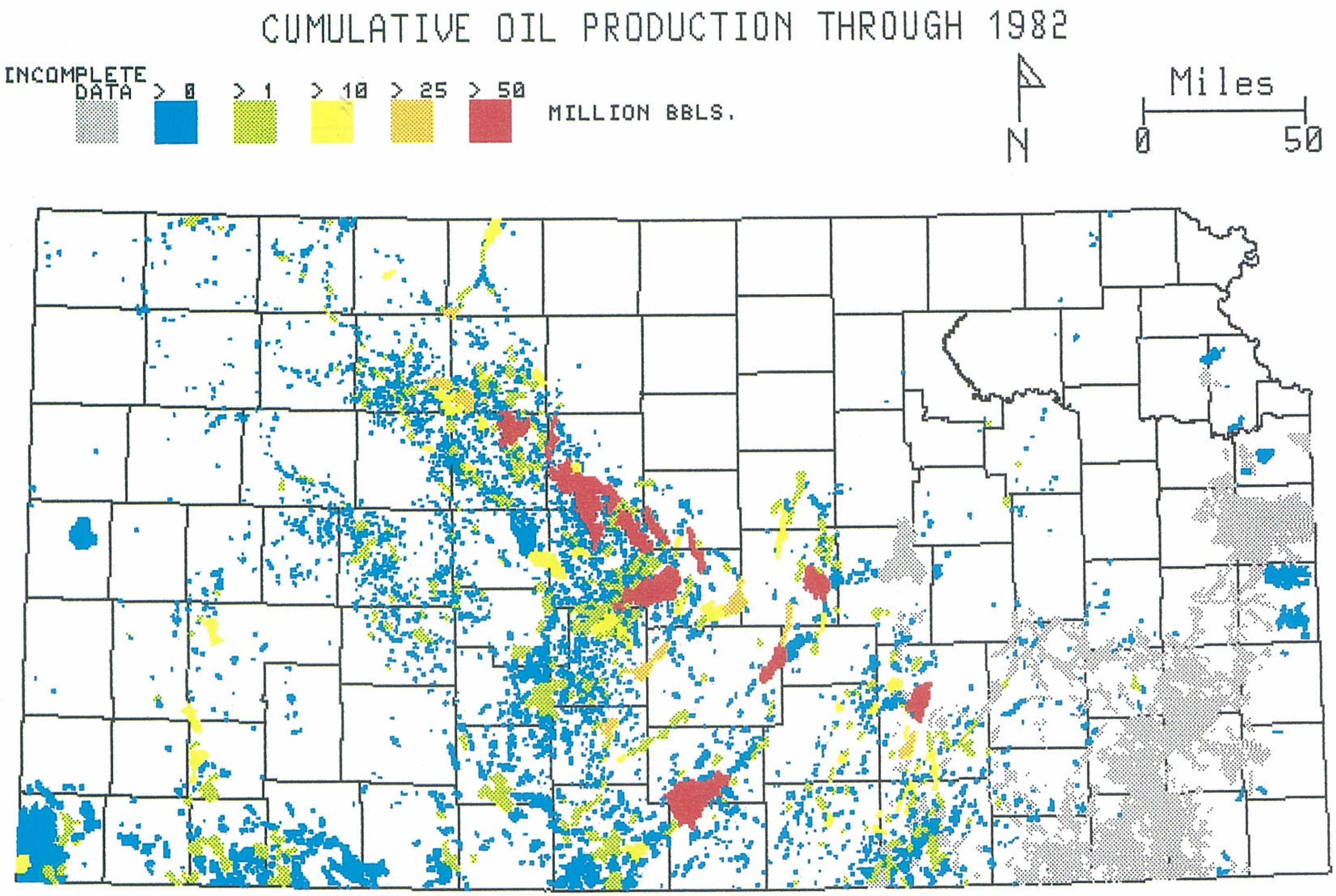


FIGURE 6—CUMULATIVE OIL PRODUCTION THROUGH 1982.

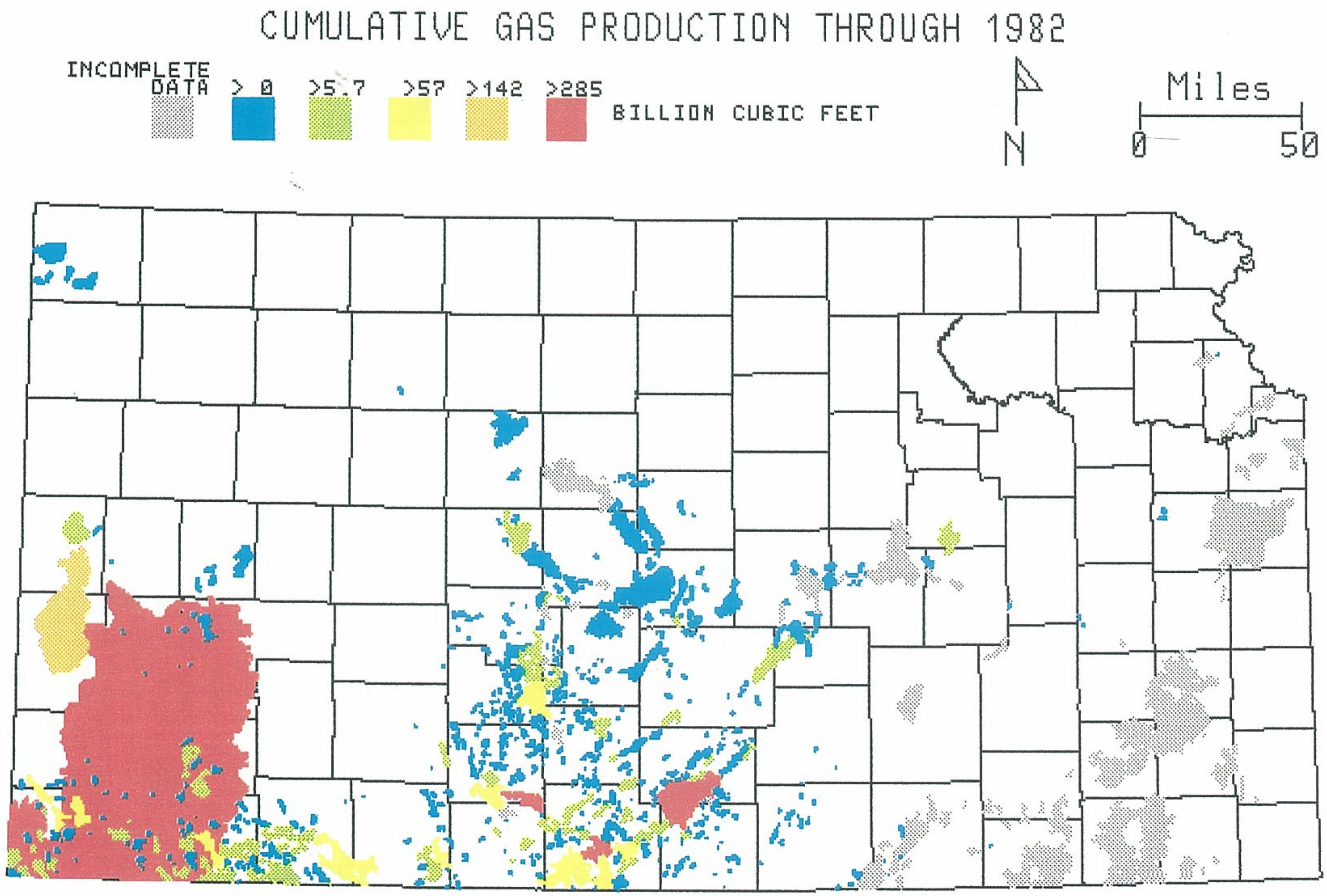


FIGURE 7—CUMULATIVE GAS PRODUCTION THROUGH 1982.

Beene, 1983). Field outlines are in digital form and are the same ones used in the latest computer-generated oil and gas map of the state published in 1982 (Paul and others, 1982). Acreages used in calculations of "productivities" (volume of production per acre) for oil and gas fields also were computed utilizing their digitized outlines.

Figure 6 illustrates that most large oil fields in the state reside in a northwest-southeast trend along a crest of the Central Kansas uplift called the Russell rib. However, the El Dorado field, the largest oil field in Kansas, is situated athwart a structural culmination of the Nemaha uplift. Although these fields were discovered several decades ago, they are still producing several hundred-thousand barrels of oil each year (table 1).

TABLE 1—Most significant established fields in Kansas. BO, barrels of oil; MMCF, million cubic feet (Shirley Paul, personal communication, 1987).

OIL

Geological province & field	Discovery date	County or area	1986 production	Cumulative recovery (through 1986)
NEMAHA UPLIFT				
El Dorado	1915	Butler	1,147,100 BO	290,993,500 BO
CENTRAL KANSAS UPLIFT				
Chase-Silica	1931	Stafford, Barton, Rice	1,185,300 BO	264,667,300 BO
Bemis-Shutts	1928	Rooks, Ellis	1,231,800 BO	237,589,600 BO
Trapp	1936	Russell, Barton	1,339,500 BO	223,966,500 BO
Hall-Gurney	1931	Russell, Barton	1,241,700 BO	143,961,100 BO
Kraft-Prusa	1937	Russell, Barton, Ellsworth	591,100 BO	129,061,300 BO
Gorham	1926	Russell	520,300 BO	91,482,400 BO
Geneseo-Edwards	1934	Rice, Ellsworth	272,800 BO	84,038,900 BO
SEDGWICK BASIN				
Burrton	1931	Reno, Harvey	513,300 BO	73,460,900 BO
Ritz-Canton	1929	McPherson	355,300 BO	70,960,600 BO

GAS

Geological province & field	Discovery date	County or area	1985 production	Cumulative recovery (through 1985)
ANADARKO BASIN				
Hugoton Gas Area	1922	southwest Kansas	316,550 MMCF	18,386,750 MMCF
Panoma Gas Area	1956	southwest Kansas	80,090 MMCF	1,188,460 MMCF
Greenwood Gas Area	1952	southwest Kansas	4,700 MMCF	954,800 MMCF
SEDGWICK BASIN				
Spivey-Grabs-Basil	1949	Harper, Kingman	12,590 MMCF	661,860 MMCF
ANADARKO BASIN				
Glick	1957	Kiowa, Comanche	5,050 MMCF	343,460 MMCF
SEDGWICK BASIN				
Medicine Lodge-Boggs	1927	Barber	1,120 MMCF	340,510 MMCF
ANADARKO BASIN				
Bradshaw	1937	Hamilton, Greeley	4,070 MMCF	163,570 MMCF
McKinney	1950	Meade, Clark	3,990 MMCF	154,520 MMCF
SEDGWICK BASIN				
Aetna	1935	Barber, Comanche	2,090 MMCF	148,100 MMCF
Hardtner	1954	Barber	900 MMCF	121,330 MMCF

The cumulative production of a field depends primarily on the length of time and rate it has been producing oil or gas. The rate of oil production varies throughout the life of a field according to its stage of development. After a field has been discovered, outpost wells are then drilled to find the boundaries of the field. During and shortly after this period of delineation, a field usually undergoes a primary phase of production that utilizes the initial elevated pressure of the fluids in the reservoir to help recover the oil. The rate of production is usually very high during this time. Once the primary energy of a reservoir dwindles and wells tapping the reservoir consequently experience a decrease in their rate of production, a phase of secondary recovery may be initiated by the operators of the field to reinvigorate the rate of production and increase the efficiency of oil recovery. Secondary recovery practices include pressure-maintenance procedures such as gas injection or water flooding.

Additional variables that influence cumulative production, illustrated in figures 6 and 7, include the reservoir volume of the field revealed in part by its areal distribution, the number of reservoirs or pay zones, and the number of wells that produce from the field. The production capacity of the wells and their spacing also are important. Reservoir permeability greatly influences the production capacity of wells, whereas the spacing of wells can be critical in efficiently producing possible isolated volumes of hydrocarbons in a heterogeneous reservoir. For gas fields, pressure can be a major factor in determining production capacity and volume because a given volume of a high-pressure reservoir will hold many more times the gas than the same volume at a lower pressure.

Figure 7 illustrates cumulative production from gas fields in Kansas. The largest gas fields are in the southwestern part of the state where the vast Hugoton, Panoma, and Greenwood fields produce from Pennsylvanian and Permian rocks in the Hugoton embayment of the Anadarko basin. The scale divisions of the cumulative-oil-production map (figure 6) and cumulative-gas-production map (figure 7) are roughly correlative in that for purposes of comparing volumetric information on oil and gas fields, approximately 5,700 ft^3 of gas is equivalent to a barrel of oil (Harbaugh and Ducastaing, 1981). The cumulative-production maps for oil and gas illustrate that there are numerous small fields in Kansas but few large fields. This type of distribution has been described as a "logarithmic decline" by Harbaugh and Ducastaing (1981). Despite their age, large fields still supply a considerable portion of the total production of the state.

Comparison of the cumulative-oil-production map (figure 6) with the cumulative-gas-production map (figure 7) indicates a general southward decrease of oil production which correlates with a concomitant southward increase in gas production in central and western Kansas. Fields on the northern part of the Central Kansas uplift and northeastern flank of the Hugoton embayment of the Anadarko basin produce little or no gas, whereas deeper fields in the Anadarko and Sedgwick basins produce large amounts of gas with comparatively little or no oil. Several fields produce both oil and gas. Natural gas produced in such fields may not necessarily come from the same pay zone as the oil. However, in many cases gas is produced from the same reservoir as the oil, either dissolved in the oil and co-produced during extraction, or produced from different wells if the gas is present as a separate phase in the reservoir (usually as a gas cap trapped above the oil).

One way of expressing the approximate gaseousness of a field producing both oil and gas is to calculate a gas-to-oil ratio for the field using records on its cumulative oil and gas production. The gas-to-oil ratio for fields in figure 8 is expressed in terms of standard cubic feet of gas per barrels of oil (SCF/BBL). One SCF is a cubic foot of gas at atmospheric pressure (14.7 psi) and 60° F. The scale is an exponential scale with 5.E2, 5.E3, 5.E4, 5.E5, and 5.E6 respectively representing 500; 5,000; 50,000; 500,000; and 5,000,000 SCF/BBL. Fields producing only gas or only oil are not shown on this map.

Figure 8 indicates gas-to-oil ratios for fields in Kansas generally increase southward toward the Anadarko basin. Relatively deep fields near the Oklahoma state line generally have the highest gas-to-oil ratios, whereas relatively shallow fields farther north along the Central Kansas uplift have very low gas-to-oil ratios.

Walters (1958) attributes the pattern of southward-increasing gaseousness to a process of "differential migration." This process assumes a prolific amount of oil and gas could have been generated in the deeper and hotter parts of the Anadarko basin in Oklahoma. This oil and gas would migrate updip by buoyancy through porous and permeable rocks northward into Kansas, filling many small and large structural and stratigraphic traps along the way. Oil and gas could then segregate by density in each trap, hence gas would be found at the top of a trap whereas oil would be found below the gas in lower parts of the trap. With additional migration of oil and gas into the trap or by decreasing the volume of the trap by structural tilting, reservoir fluids could leak out of the trap through a spillpoint that would be located in the structurally lower part of the trap. Oil, by virtue of its higher density and consequently lower position in the reservoir, would likely spill out of the trap before the overlying gas and continue moving farther updip. The net effect of several such fill-and-spill episodes would be to systematically decrease the gas-to-oil ratio for a series of fields in the updip (shallowing) direction along a migration path.

Another way to consider production data is to compare the cumulative production of a field with the area the field covers at the surface of the earth. According to this design, "productivity" of a field is expressed by the

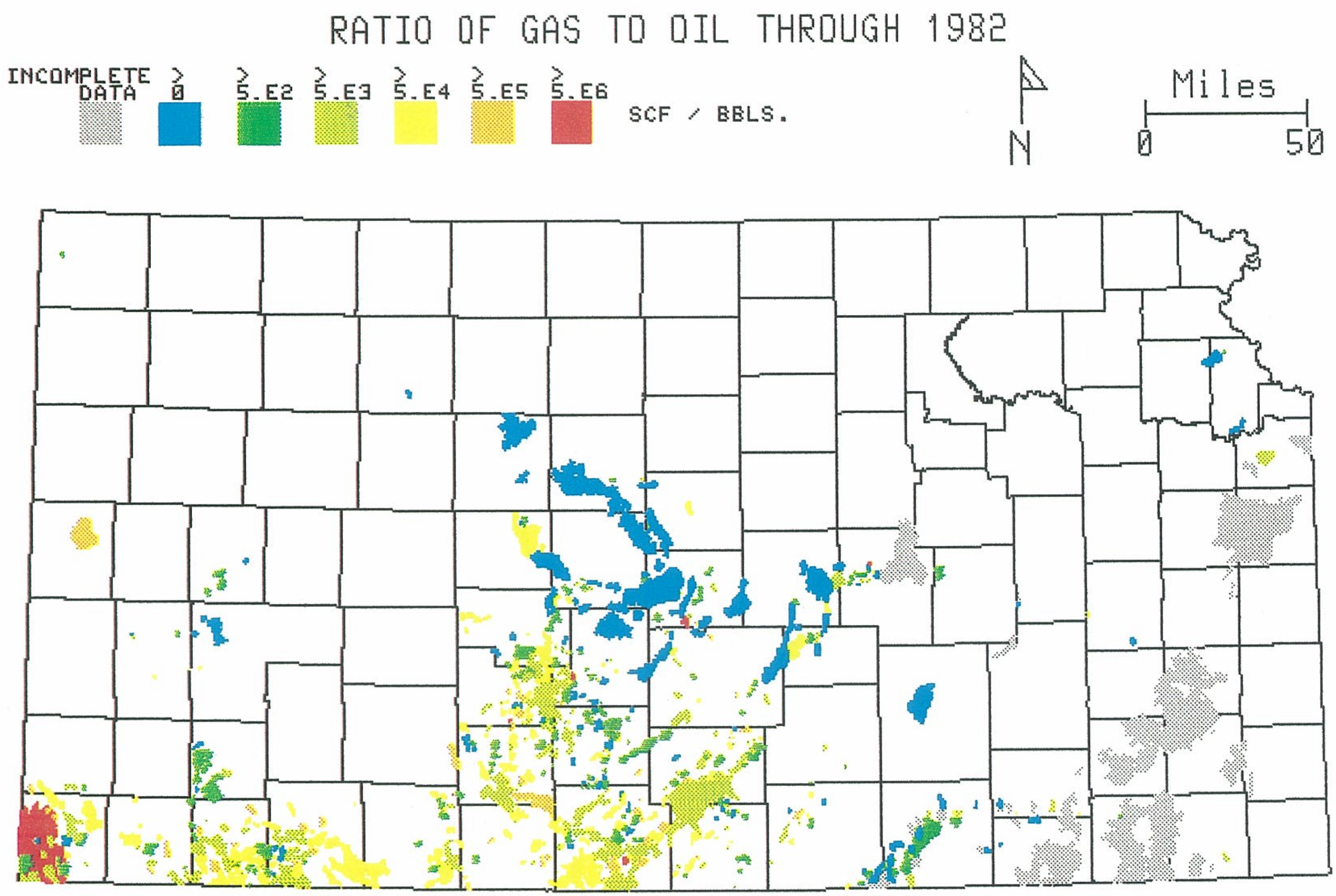


FIGURE 8—RATIO OF GAS TO OIL THROUGH 1982.

volume of production per acre at the surface—either barrels of oil per acre or million cubic feet of gas per acre. People who lease land for mineral rights and landowners may be particularly interested in this type of information.

Table 2 lists the most productive fields in Kansas on a production-per-acre basis. Comparison of this list to table 1 indicates that the largest fields, with respect to cumulative production, are not necessarily the richest fields if cumulative production per surface-acre ("productivity") is considered. Most oil fields having the greatest "productivity" in Kansas are curiously a group of venerable fields situated very close to each other on the Nemaha uplift and the eastern flank of the Sedgwick basin in Sumner, Cowley, Butler, and Sedgwick counties. Most of these fields are structural traps with several pay zones in Pennsylvanian and lower strata. El Dorado, the largest field in Kansas, is not sufficiently "productive" to be in table 2, but nevertheless, as of 1982, it had a very respectable cumulative "productivity" of 9,889 barrels of oil per acre and ranked 12th out of 3,690 oil fields evaluated.

The cumulative oil "productivity" map for 1982 (figure 9) also indicates that several very "productive" fields are situated on the northern part of the Central Kansas uplift, particularly in parts of Russell, Ellis, and Rooks counties. Major fields in this region that have been very "productive" include the Fairport field in Russell County, the Russell field in Russell County, the Bemis-Shutts field in Ellis County, and the Ray field located at the corners of Rooks, Graham, Norton, and Phillips counties. Most fields in this part of the Central Kansas uplift produce from porous limestones and dolomites of the Arbuckle and Lansing-Kansas City groups. Figure 9 also indicates fields in southwestern Kansas are not very "productive" with respect to oil, but, as discussed above, this is due to the propensity of fields in this area to produce more gas than oil.

Table 2 and figure 10 indicate most gas fields with the greatest cumulative "productivities" are in the Hugoton embayment of the Anadarko basin and the adjacent western flank of the Sedgwick basin. The minimum size considered for table 2 was 640 acres (1 mi^2). Gas fields usually have a broader spacing of wells than oil fields, so mapping field outlines for some gas fields can be more arbitrary than for oil fields. If field limits are underestimated, anomalously high productivities may be calculated, particularly for smaller gas fields.

Most of the top-ten gas fields in table 2 are stratigraphic traps with most of their production coming from Marmaton, Morrow, and Mississippian pay zones. As of 1982, the Hugoton field had a cumulative "productivity" of 6.31 million ft^3 per acre and ranked 80th out of 680 gas fields considered. The prolific Panoma and Greenwood gas fields have even less cumulative production per acre than the Hugoton field; the Hugoton, Panoma, and Greenwood fields respectively rank as first, second, and third in cumulative gas production as a result of their vast size.

Figures 11 and 12 are maps respectively recording the 1982 oil and gas production per acre for fields in Kansas. Fields reporting no production for 1982 are not shown on these maps. These maps, when compared to the map showing fields by decade of discovery (figure 5), illustrate that many of the larger, older fields in the state (particularly on the Central Kansas uplift) still produce oil and gas at respectable rates comparable to many younger fields. However, figure 11 also indicates many of the more productive oil fields on a barrel-per-acre basis in 1982 are relatively small fields. Most of these fields were discovered in the 1970s and 1980s on the northern part of the Central Kansas uplift (primarily in Graham, Rooks, Trego, and Ellis counties) and on the northeastern flank of the Hugoton embayment (primarily in Gove, Lane, and Ness counties). Fields in the northern part of the Central Kansas uplift mainly produced from limestone reservoirs in the Arbuckle and Lansing-Kansas City groups, whereas fields on the northeastern flank of the Hugoton embayment generally produce from Mississippian limestone reservoirs.

Most of the relatively young fields that display very good annual "productivities" are in an early stage of their production declines and will probably record considerably lower annual "productivities" in years to come. Many of the fields on the northern part of the Central Kansas uplift that have very good oil "productivities" for 1982 (figure 11) are located in proximity to the fields displaying high cumulative oil "productivities" (see figure 9), hence some of the younger fields in this region may also eventually register high cumulative "productivities." Although many of the oil fields in the northeastern flank of the Hugoton embayment (principally Gove, Lane, Ness, and Hodgeman counties) also display very good "productivities" for 1982, it is difficult to say whether their cumulative "productivities" will be as high as the fields on the northern part of the Central Kansas uplift. These Mississippian fields are a relatively new production trend that has not had as much time as some older trends to produce great quantities of oil, hence cumulative "productivities" for many of these fields are still relatively low. Nevertheless, detailed analyses of production declines for individual fields in the northeastern part of the Hugoton embayment probably could indicate their ultimate production and cumulative "productivity."

Figure 11 also indicates fields in southwestern and eastern Kansas display relatively low year-long oil "productivities." As stated above, the low oil "productivities" in southwestern Kansas can be attributed to the high gas-to-oil ratio of the fluids produced in this region. Conversely, fields in eastern Kansas are among the oldest in the state, hence they are well along on their production declines and this accordingly is expressed as relatively low

TABLE 2—Most productive fields in Kansas on basis of production per surface acre. BO, barrels of oil; MMCF, million cubic feet of gas; BO/Acre, barrels of oil per acre; MMCF/Acre, million cubic feet of gas per acre.

OIL

Geological province & field	Discovery date	County or area	Cumulative recovery (through 1982)	Acreage	Productivity
NEMAHA UPLIFT					
Churchill	1926	Sumner, Cowley	20,470,228 BO	974	21,020 BO/Acre
Oxford	1927	Sumner	17,695,414 BO	1,158	15,280 BO/Acre
Slick-Carson	1924	Sumner, Cowley	15,877,768 BO	1,139	13,940 BO/Acre
FOREST CITY BASIN					
Davis Ranch	1949	Wabaunsee	7,648,923 BO	625	12,240 BO/Acre
NEMAHA UPLIFT					
Augusta North	1914	Butler	16,406,448 BO	1,379	11,900 BO/Acre
SEDGWICK BASIN					
Valley Center	1928	Sedgwick	23,453,102 BO	2,108	11,130 BO/Acre
Caldwell	1929	Sumner	1,823,329 BO	165	11,050 BO/Acre
Guelph	1951	Sumner	3,704,610 BO	341	10,860 BO/Acre
Voshell	1929	McPherson	32,442,900 BO	3,101	10,460 BO/Acre
NEMAHA UPLIFT					
Hittle	1925	Cowley	10,395,550 BO	1,024	10,150 BO/Acre

GAS
(640 acres minimum size)

Geological province & field	Discovery date	County or area	Cumulative recovery (through 1982)	Acreage	Productivity
ANADARKO BASIN					
Borchers	1959	Meade	54,641 MMCF	1,147	47.64 MMCF/Acre
SEDGWICK BASIN					
Medicine Lodge-Boggs	1927	Barber	336,897 MMCF	16,548	20.37 MMCF/Acre
Rhodes Northeast	1956	Barber	29,665 MMCF	1,464	20.26 MMCF/Acre
Sharon Northwest	1956	Barber	42,060 MMCF	2,149	19.57 MMCF/Acre
ANADARKO BASIN					
Richfield West	1962	Morton	18,343 MMCF	965	19.01 MMCF/Acre
Glick	1957	Comanche, Kiowa	322,062 MMCF	18,525	17.39 MMCF/Acre
CENTRAL KANSAS UPLIFT					
Unruh	1945	Barton	14,745 MMCF	1,080	13.65 MMCF/Acre
SEDGWICK BASIN					
Boggs Southwest	1955	Barber	63,694 MMCF	4,754	13.40 MMCF/Acre
ANADARKO BASIN					
Wilburton	1959	Morton	44,054 MMCF	3,303	13.34 MMCF/Acre
SEDGWICK BASIN					
Donald	1946	Barber	21,080 MMCF	1,733	12.16 MMCF/Acre

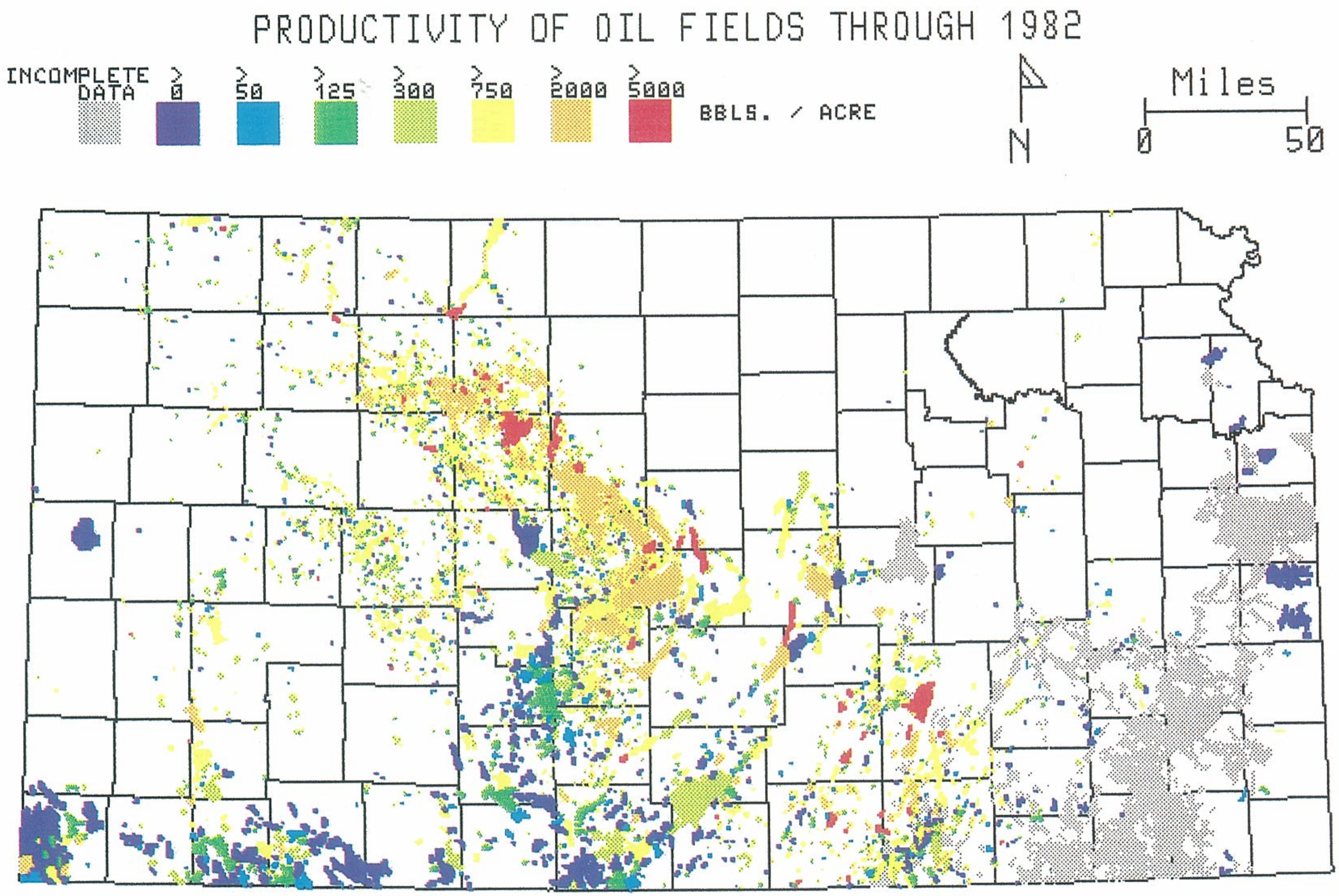


FIGURE 9—PRODUCTIVITY OF OIL FIELDS THROUGH 1982.

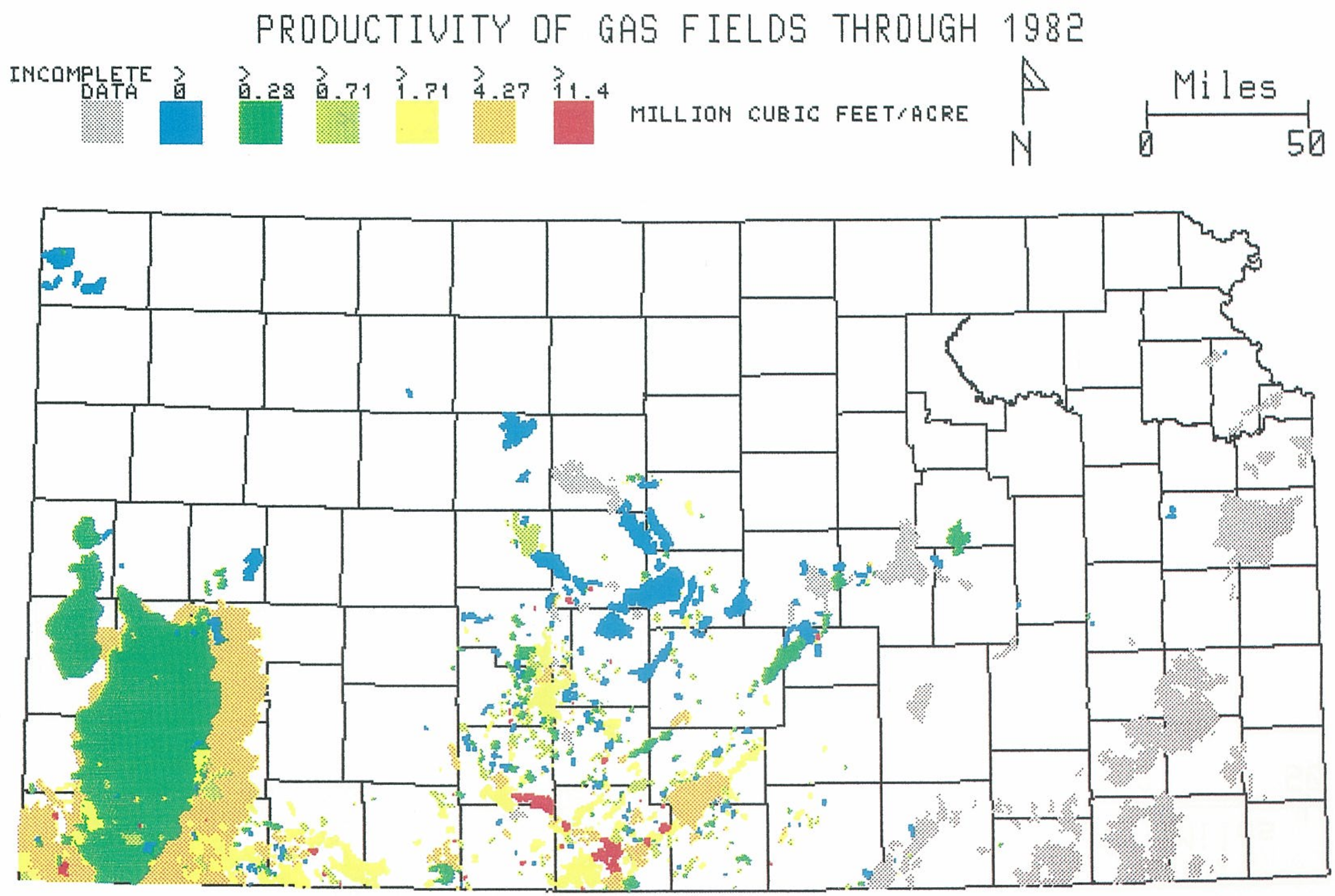


FIGURE 10—PRODUCTIVITY OF GAS FIELDS THROUGH 1982.

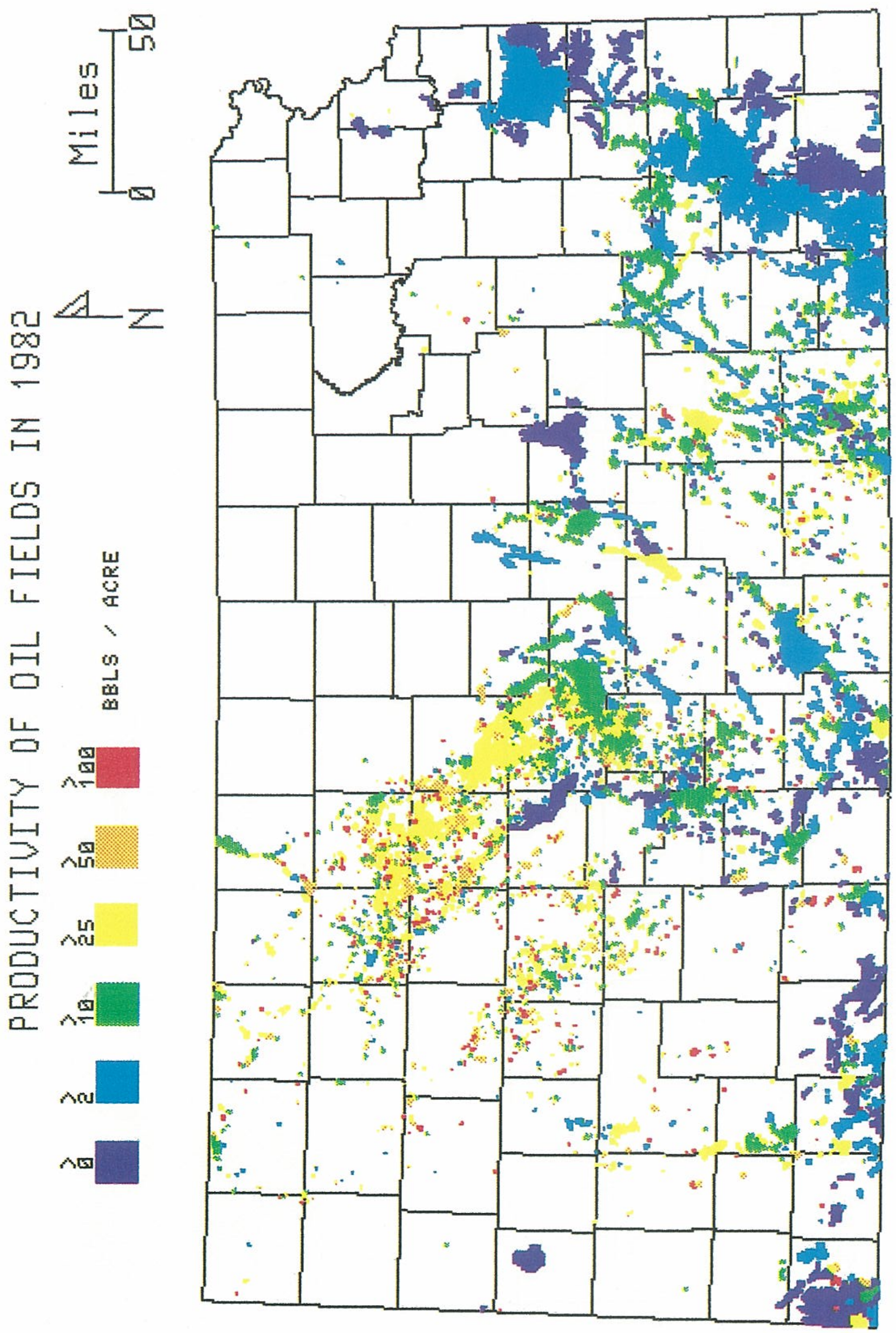


FIGURE 11—PRODUCTIVITY OF OIL FIELDS IN 1982.

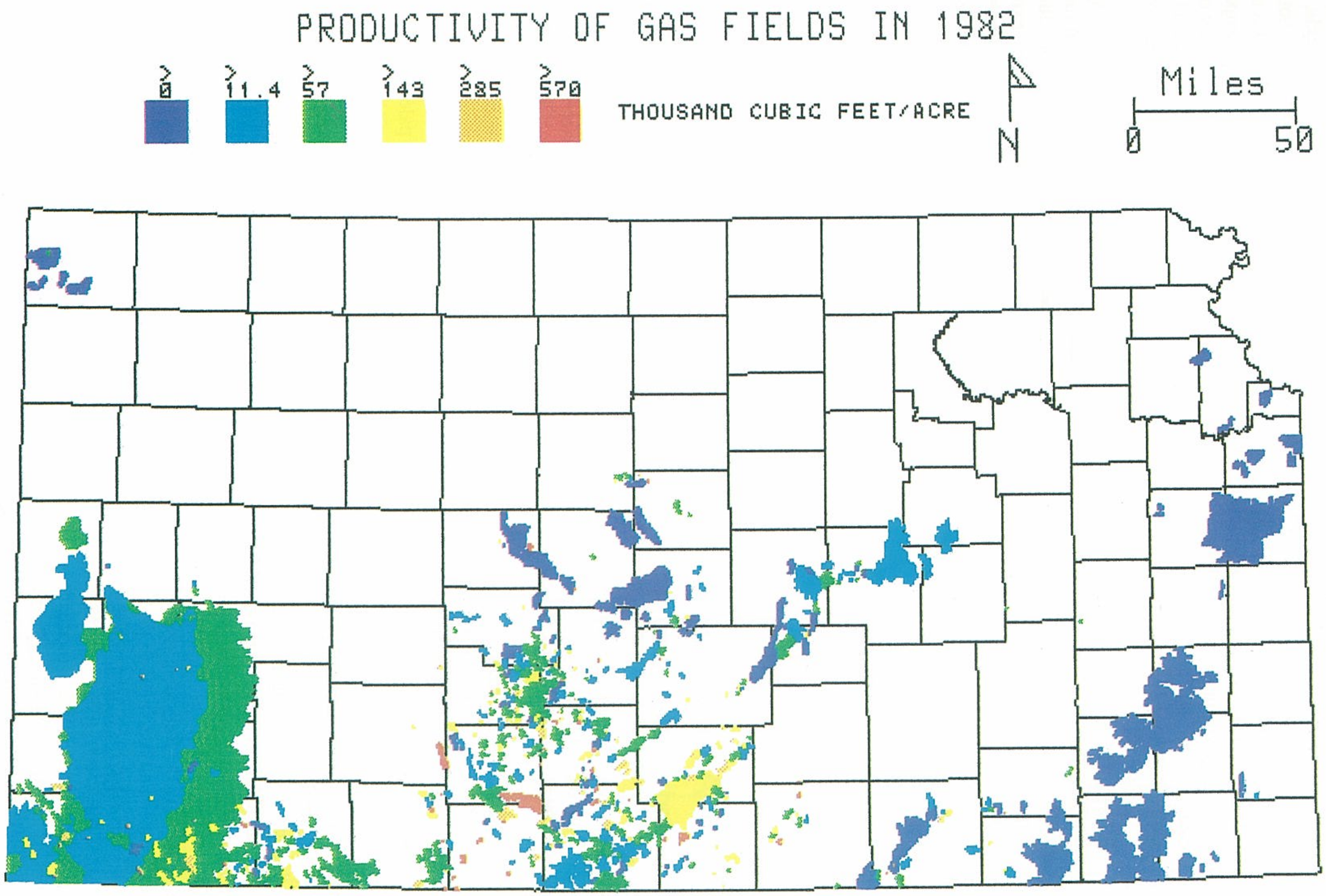


FIGURE 12—PRODUCTIVITY OF GAS FIELDS IN 1982.

volumes of oil per acre on the oil "productivity" map for 1982.

The 1982 gas "productivity" map (figure 12) has less well-defined trends than the 1982 oil "productivity" map (figure 11), but it is apparent that many of the more "productive" gas fields are situated in south-central Kansas in the eastern part of the Hugoton embayment and the western part of the Sedgwick basin. Some of these fields include the Glick field in Kiowa and Comanche counties, the Pleasant Valley field in Ford and Kiowa counties, and the Sullivan field in Harper County. It also is interesting to note that in contrast to the 1982 oil "productivity" map (figure 11), there are not as many gas fields on the 1982 gas "productivity" map that are both extremely small and very "productive." The difference probably is due more to economic rather than geologic factors, in that to produce a gas field a pipeline and gathering system must be built. In some circumstances, compressor facilities also must be constructed. This can require a substantial capital investment before any gas can be sold. Small gas fields, unless they are very close to an existing pipeline, may not justify this capital investment. However, small oil fields may be more economic to produce than gas fields of comparable area because operators of small oil fields can rely on tanker trucks utilizing existing roads to haul the oil to the nearest pipeline or refinery, which is less expensive in most cases than pipeline construction.

Cumulative and annual "productivity" maps are useful as measures of the present and possibly future vitality of a producing field. In turn, this information may be helpful in evaluating exploration areas if the explorationist is reasonably confident that the known fields in the exploration area can serve as analogs to the undiscovered fields.

Stratigraphic distribution of petroleum

Sub-Arbuckle
(Cambrian and Precambrian rocks)

Sub-Arbuckle rocks are only locally important host rocks for petroleum reservoirs in Kansas. These rocks include the Reagan Sandstone and locally fractured basement rocks.

The Reagan Sandstone is Late Cambrian in age and averages 40 feet (12 m) in thickness (Goebel, 1968a). It is the basal Paleozoic transgressive sandstone that lies directly on Precambrian basement rocks and as such, its composition and texture can be markedly influenced by the underlying basement. The Reagan can either be quartzose, arkosic, or feldspathic; texturally, it can range from fine to coarse grained.

Oil production from the Reagan is locally important on the Central Kansas uplift where overlying Arbuckle Group rocks are absent due to erosion or nondeposition (figure 13). In such areas, fractured basement rocks underlying the Reagan may also be productive. Both Reagan and basement production occur in close association on buried Precambrian hills formed along structural highs that crop out beneath the sub-Pennsylvanian angular unconformity. Fields producing from Reagan sandstones include the Otis-Albert field in Rush and Barton counties (Miller, 1968) and the Norton field in Norton County (Merriam and Goebel, 1954).

According to Walters (1946, 1953), fields that produce oil and gas, in part, from fractured Precambrian basement rocks include the Kraft-Prusa, Eveleigh, Trapp, Beaver, and Bloomer fields in Barton County; the Ringwald, Heinz, Orth, and Chase-Silica fields in Rice County; and the Gorham and Hall-Gurney fields in Russell County. These fields align along two northwest-southeast-trending uplifts respectively called the Rush rib, which extends from Rush County into Barton County, and the Russell rib, which extends from Russell County into northwest Rice County. The oil from fractured basement rocks in these areas probably migrated into these rocks from overlying Pennsylvanian rocks or nearby Arbuckle dolomites located on the flanks of these structures and paleotopographic highs (Walters, 1953).

The potential for additional sub-Arbuckle production would be localized in areas where uplifts and paleotopographic highs bring these rocks into contact, or near contact, with possible hydrocarbon carrier beds associated with the sub-Pennsylvanian angular unconformity in parts of the Central Kansas and Nemaha uplifts. As it is likely that most major structural anomalies such as these have already been detected in the heavily drilled Central Kansas uplift, the future potential of the sub-Arbuckle rocks in Kansas is probably small. However, the petroleum potential of the 1.1 billion-year-old Central North American rift system (CNARS) is not yet determined (Lee and Kerr, 1983; Dickas, 1984). This geologic province extends from northern Wisconsin southward into Kansas and is located underneath the eastern part of the Salina basin (figure 14; Yarger, 1983). Interlayered arkoses and basalts fill this rift (Scott, 1966), but organic-rich shales may also be present (Lee and Kerr, 1983).

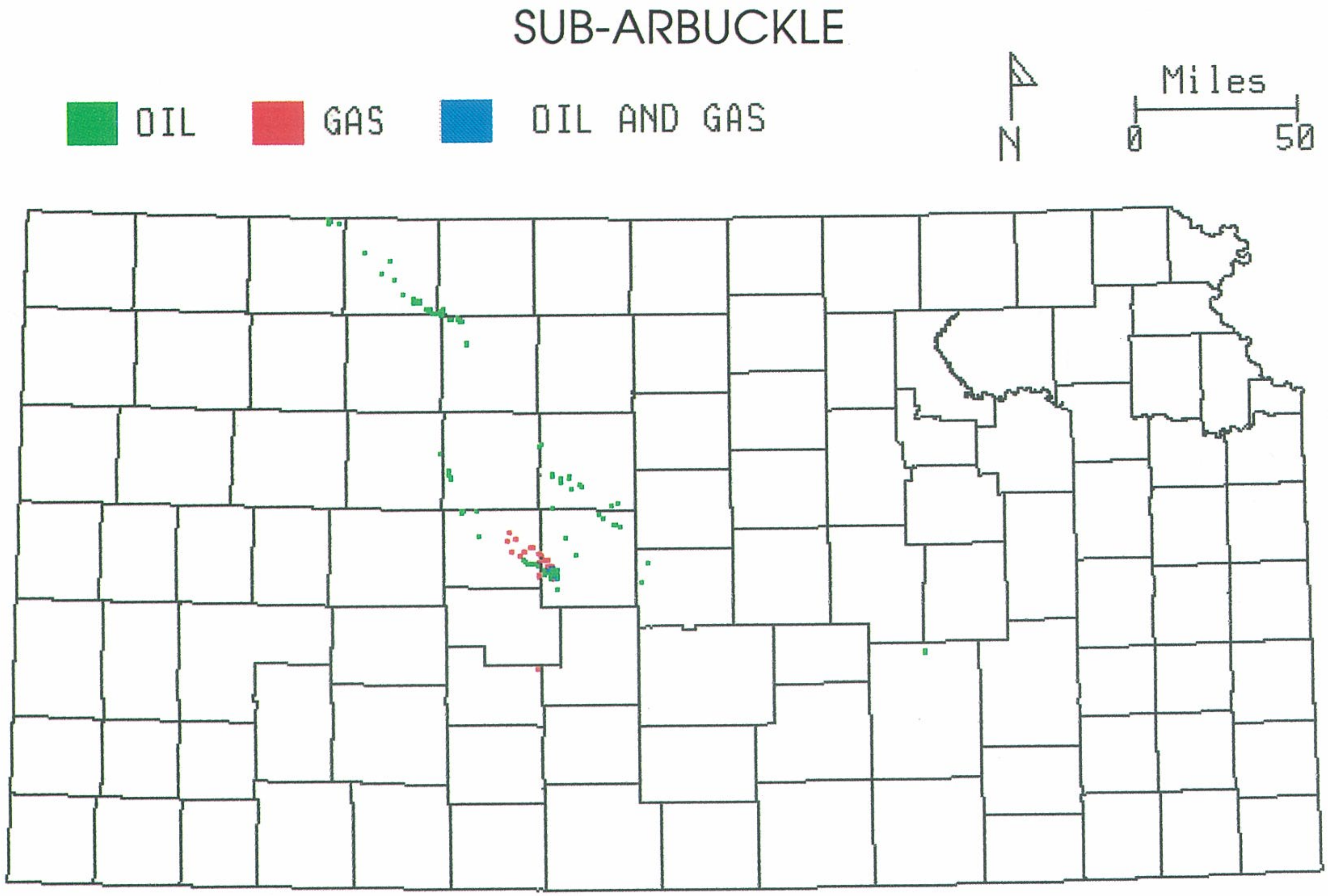


FIGURE 13—SUB-ARBUCKLE PRODUCTION.

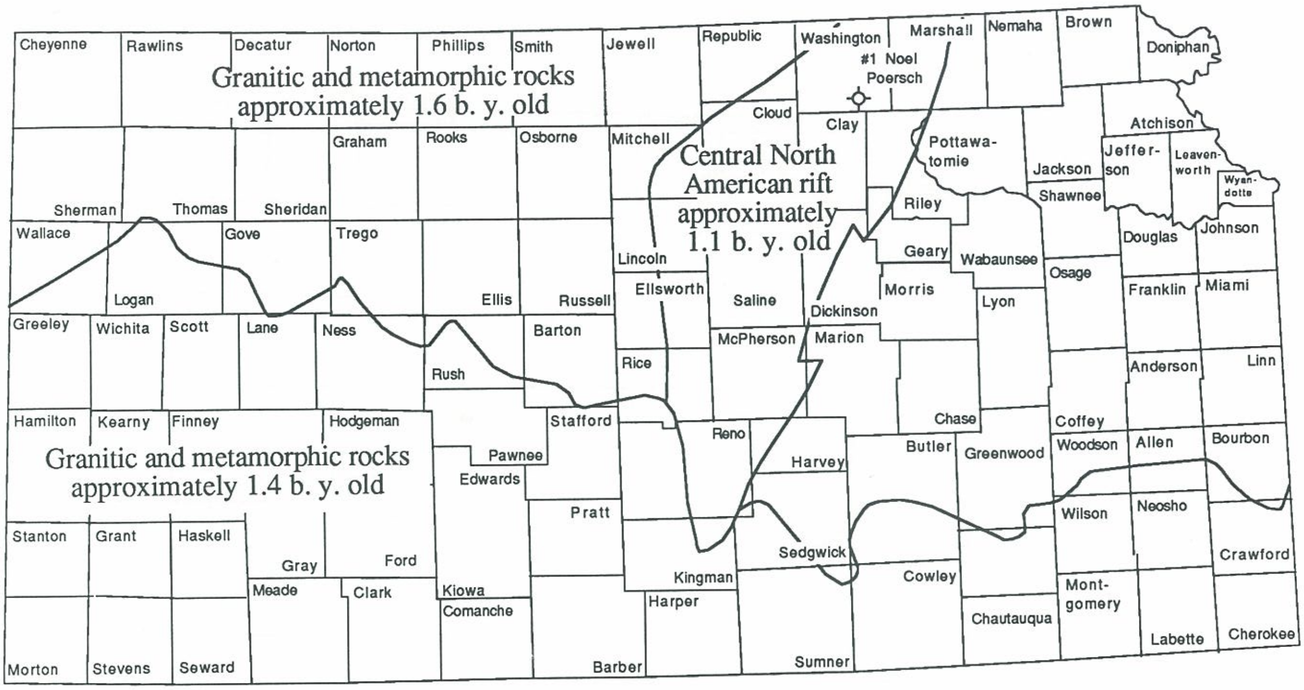


FIGURE 14—Precambrian basement terranes in Kansas, based on information in Bickford and others (1981) and Yarger (1983).

Thickness of the sedimentary and volcanic sequence in this buried block-faulted geologic province may reach 26,000 ft (8 km; Serpa and others, 1984). The deepest well to date in Kansas, the #1 Noel Poersch, was the first significant test of CNARS rocks (figure 14). This well was drilled to 11,300 ft (3,447 m) in southeastern Washington County in 1984. Although no commercial accumulations of hydrocarbon were found, other wells need to be drilled in the rift to evaluate its hydrocarbon potential.

Arbuckle

(Cambrian-Ordovician)

Arbuckle oil production (figure 15) is mostly concentrated over the Central Kansas uplift and its southward extension, the Pratt anticline. Production is also locally important in southeastern Kansas, such as at the prolific Augusta and El Dorado fields in Butler County. Gas production is locally important in southwestern Barton County and eastern Pawnee and Rush counties.

Rocks of the Arbuckle Group are composed mostly of light gray to white vuggy, cherty dolomite. The unit has been subdivided and correlated with equivalent exposed strata in adjacent states by study of insoluble residues (McCracken, 1955). It is thin to absent in parts of northeastern Kansas, including Marshall, Pottawatomie, Riley, western Nemaha, and eastern Washington counties, due to pre-Simpson uplift and erosion (Lee, 1956). Farther south along the Nemaha uplift, it is locally absent due to pre-Pennsylvanian erosion over several structures in Chase and Butler counties (Jewett 1951, 1954) and on the Cambridge arch in parts of Norton and Decatur counties and locally along basement highs in the Central Kansas uplift (Walters, 1946; Merriam, 1963). In other areas of Kansas, the Arbuckle dolomite can be quite thick. It generally thickens southward and is in excess of 1,000 ft (305 m) thick along the Kansas-Oklahoma state line (Cole, 1975).

The Arbuckle Group is the most significant pay zone on the Central Kansas uplift, having produced approximately 1.4 billion barrels of oil from 1929 to 1968 (Adler, 1971). Several hundred fields are productive from Arbuckle rocks on the Central Kansas uplift. Most of these fields are structural and structural-stratigraphic traps that produce oil or gas from the top of the Arbuckle section, which is in direct contact with unconformably overlying Pennsylvanian beds (Walters, 1958). Porosity is significantly enhanced by solution and weathering at the top of the Arbuckle, where it crops out beneath the sub-Pennsylvanian unconformity (Walters, 1958; Adler, 1971). Dolomitization also enhances its porosity (Walters, 1958).

Off the Central Kansas uplift and parts of the Nemaha uplift, the Arbuckle is generally nonproductive, a major exception being the Voshell field in McPherson County (Hiestand, 1933). Arbuckle rocks constitute a

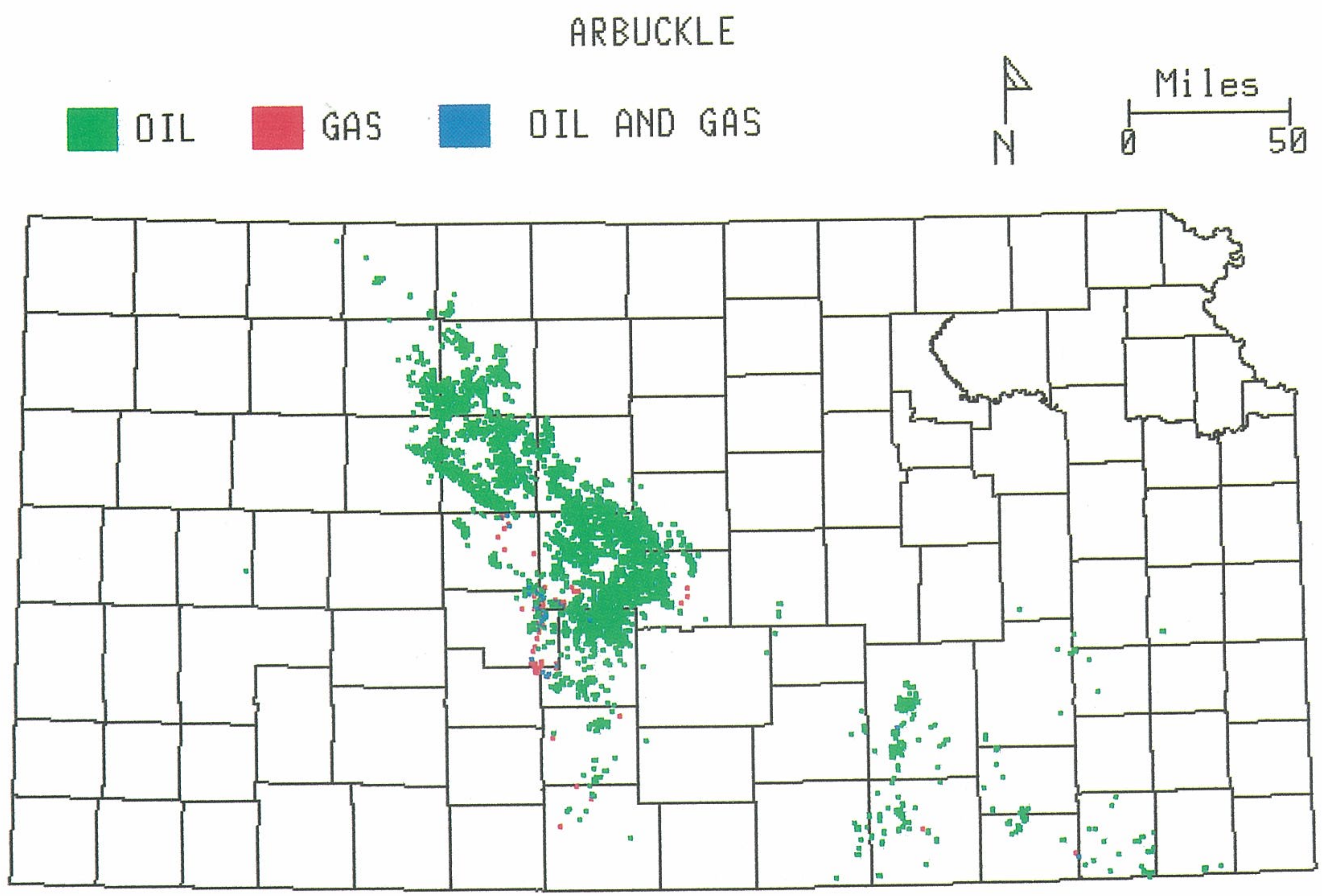


FIGURE 15—ARBUCKLE PRODUCTION.

major component of the "Stapleton zone," a porous, weathered zone developed on Cambrian-Ordovician strata that crop out beneath the sub-Pennsylvanian unconformity in the El Dorado field in Butler County (Fath, 1921; Reeves, 1929). The weathered Arbuckle rocks at the El Dorado field were extremely productive with up to 17,000 barrels of oil per day production (Fath, 1921). Nearby at the South Augusta field, daily production of oil per well of up to 7,000 barrels was recorded from weathered Arbuckle rocks (Berry and Harper, 1948). Both the El Dorado and Augusta fields were found by surface geologic mapping.

Scattered Arbuckle production occurs in southeastern Kansas and extends into Oklahoma (Akin, 1964). In this region pre-Chattanooga erosion has stripped off Devonian, Silurian, and Middle and Upper Ordovician strata so the Chattanooga Shale lies directly on the Arbuckle. The Chattanooga Shale is probably the source rock for the Arbuckle oil fields in southeastern Kansas, such as the Coffeyville field in Montgomery County (Foster, 1929; Jewett, 1954). Like the Central Kansas uplift, the Arbuckle pay zones are almost always close to the top of the unit, but in some fields in Oklahoma, productive zones are reported to be substantially within the Arbuckle (Bloesch, 1954).

In addition to the El Dorado and Augusta fields, major fields that produce oil from the Arbuckle include the Chase-Silica field straddling the Rice-Barton county line, the Bemis-Shutts field in Ellis County, the Hall-Gurney field in Russell County (Riggs and others, 1963), the Trapp field in Barton and Russell counties, the Kraft-Prusa field in Barton County (Walters and Price, 1947), and the Otis-Albert field in Rush and Barton counties (Walters, 1946, 1953, 1958). According to Walters (1958), the distribution of oil and gas in the Arbuckle pay zones over the Central Kansas uplift conforms to the principles of differential entrapment as described by Gussow (1954). Oil-water contacts increase in elevation, and gas content decreases systematically northward in several Arbuckle fields on the Central Kansas uplift, thereby indicating northward migration of Arbuckle oil possibly ultimately derived from Oklahoma. In this model, a given Arbuckle trap on the uplift should have been filled by oil to its spillpoint. Additional oil subsequently channeled into this trap from downdip areas would then migrate through the spillpoint of the trap into other higher traps which would, in turn, fill with oil to their spillpoints.

Future potential of the Arbuckle rocks include areas where the unit is in contact with possible carrier beds along the sub-Pennsylvanian unconformity. Such areas include structural highs on the Pratt anticline, Central Kansas uplift, and Nemaha uplift. Additional minor production is possible in southeastern Kansas, where northwest-southeast structural trends paralleling the Chautauqua arch may intersect with north-northeast-south-southwest structural trends paralleling the Nemaha uplift. Stratigraphic traps in the Arbuckle are also a possibility where porous beds within it may truncate along the flanks of an anticline. In cases such as this, the oil in the Arbuckle may not necessarily be found at the culmination, or highest point, of the anticline. Correlation and mapping of porosity zones within the Arbuckle and their subcrop pattern as they are truncated by an overlying unconformity may be useful in finding these types of stratigraphic traps.

Simpson
(Middle Ordovician)

Simpson production (figure 16) is primarily limited to south-central Kansas. Production trends are evident along the periphery of the Central Kansas uplift and down the Pratt anticline in localities where the Simpson Group crops out beneath the sub-Pennsylvanian unconformity. Scattered production is also present in Sumner, Butler, and Coffey counties in southeastern Kansas where Simpson sandstones are beveled on the flanks of the Chautauqua arch due to pre-Chattanooga erosion. Production also occurs scattered throughout the Sedgwick basin and isolated localities in the Forest City basin. The Simpson is also a component of the "Stapleton zone," the porous zone that is locally developed beneath the sub-Pennsylvanian unconformity at the El Dorado field in Butler County (Jewett, 1954).

The Simpson Group is the basal unit of a long-term oceanic inundation on the North American continent called the Tippecanoe transgression (Adler, 1971). Although the Simpson was probably deposited over most of the state, subsequent erosional events have removed it from various parts of the state. Late Mississippian-Early Pennsylvanian tectonic movement accounts for the removal of the Simpson over much of the Central Kansas uplift, the Nemaha uplift, and northwestern Kansas. The Simpson also is absent in southeastern Kansas southeast of a line running from Cowley County to Miami County (Merriam, 1963). The absence of Simpson in this area is due to the broad northwest-southeast-trending Chautauqua arch that developed in pre-Devonian (pre-Chattanooga) time.

The Simpson is thickest off the flanks of the old Chautauqua arch. In northeastern Kansas in the western flank of the Forest City basin and eastern flank of the Salina basin, it reaches a maximum thickness of 150 ft (45 m). In southern Kansas it thickens southward to a maximum of 250 ft (75 m) in Harper County near the Kansas-Oklahoma state line (Cole, 1975). It continues to thicken southward into Oklahoma where it is divided into several different stratigraphic units (Ireland, 1965). Locally anomalous thicknesses of Simpson rocks in eastern Kansas in which the unit is in excess of 400 ft thick (125 m) are attributed to sinkholes developed in the underlying Arbuckle Group carbonate rocks (Leatherock, 1945).

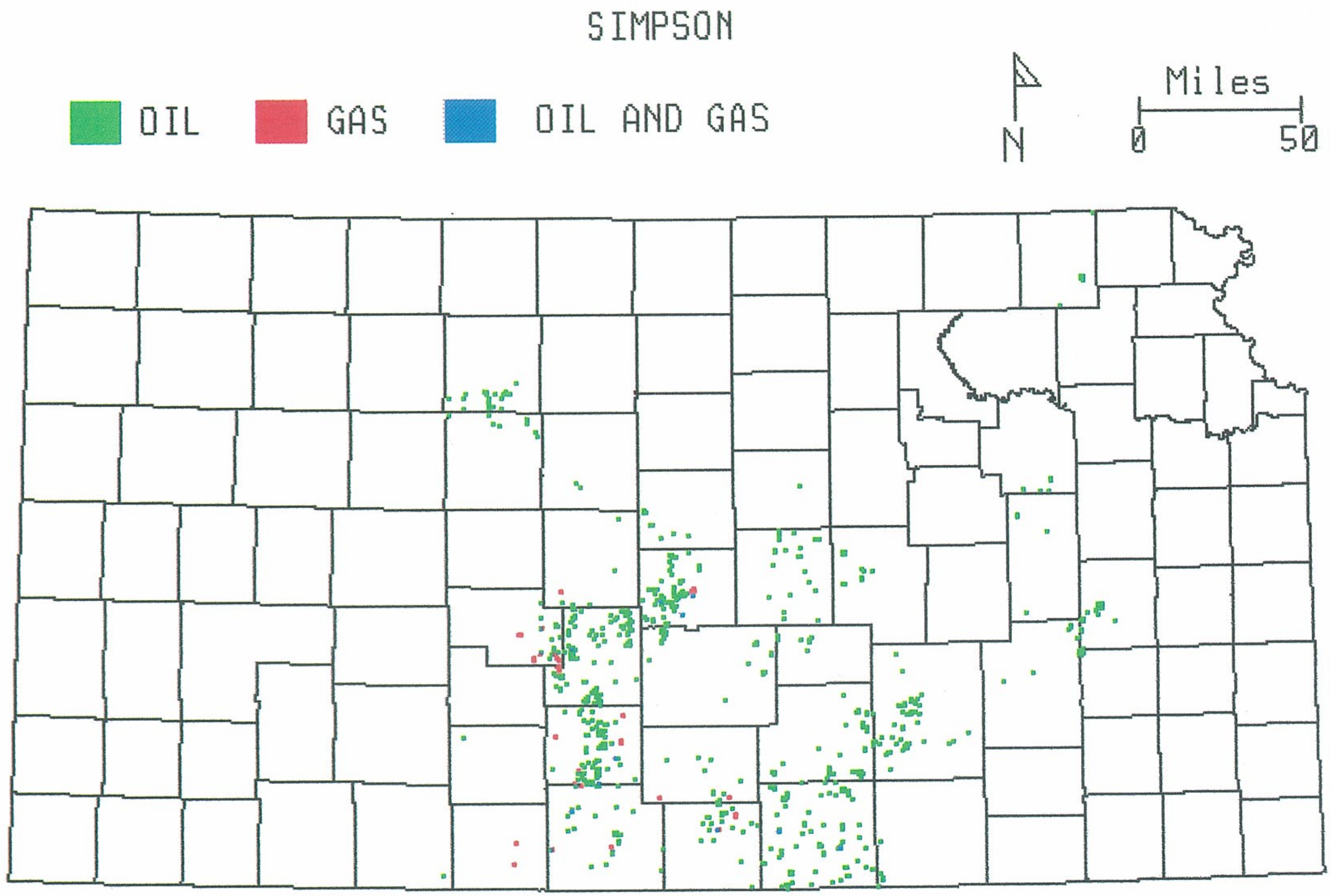


FIGURE 16—SIMPSON PRODUCTION.

The Simpson Group in Kansas is dominantly a sand-shale sequence with minor amounts of carbonate rock. The main reservoir rocks within the Simpson Group are light-gray, quartz-rich sheet sandstones sometimes called the St. Peter or Wilcox sandstone (Goebel, 1968b). More than one producing zone can be present. Shales in the Simpson are credited as being source rocks for the oil in the Forest City basin (Newell and others, 1985).

Simpson oil accumulations can be categorized into three geologic settings: 1) structural-stratigraphic and stratigraphic traps in which the Simpson is truncated by the sub-Pennsylvanian unconformity, 2) structural-stratigraphic and stratigraphic traps in which the Simpson is truncated by the pre-Chattanooga unconformity, and 3) structural traps in which the Simpson lies in its normal stratigraphic succession above the Arbuckle Group and below the Viola formation. The first type of trap usually occurs along the periphery of the Central Kansas uplift and along the crest of the Nemaha uplift and Pratt anticline. The second type of trap is characteristic of the Simpson in southeastern Kansas along its subcrop trend on the northern flank of the Chautauqua arch. The third type is found in the Forest City basin, the Sedgwick basin, and southern part of the Salina basin between the subcrop limits of the Simpson.

Fields on the Pratt anticline and the flanks of the Central Kansas uplift where Simpson sandstones truncated by the sub-Pennsylvanian unconformity produce oil or gas include the Coats field in Pratt County (Curtis, 1956; Brewer, 1959), the Brehm field in Pratt County (Willis, 1965) and the Tobias field in Rice County (Waller and Brewer, 1964; Brewer, 1965). Fields producing oil from the Simpson where the Simpson rests directly beneath the sub-Chattanooga unconformity include the O.S.A. and Gillian fields in Sedgwick County (Howell, 1965; Shawver, 1965a, b). Oil fields contained in Simpson rocks in which the Simpson is not beveled by either the sub-Pennsylvanian or sub-Chattanooga unconformities include the McClain field in Nemaha County, the Boggs field in Barber County (Jacques, 1956), the Haven field (Richardson and Matthews, 1956a) and Wisby and Wisby North fields in Reno County (Donnelly, 1965), the Grant field in Harper County (Devlin, 1965), the Greenwich (Cole, 1960) and Wichita fields in Sedgwick County (Scott, 1960), the Wilmington field in Wabaunsee County (Young, 1960), the Fall Creek field in Sumner County (Bass and Lukert, 1959), and the Lindsborg field in McPherson County (Brewer, 1959).

More exploration possibilities exist for finding Simpson oil reservoirs in the three geologic settings mentioned above. Sub-Pennsylvanian structural-stratigraphic traps flanking the Central Kansas uplift and along the Pratt and Nemaha uplift are worthwhile targets. Conspicuous gaps exist in which undiscovered Simpson fields may be present along the Simpson sub-Chattanooga subcrop trend in southeast Kansas. Simpson sandstones may also be long-shot exploration targets in structures in the Sedgwick and deeper parts of the Salina basins inasmuch as shales within the Simpson may be viable oil-source rocks (Newell and others, 1985). Simpson rocks may also be prospective in the Hugoton embayment, but Rascoe (1971) reports this unit is thin in this region and contains poorly developed sandstone beds.

Viola and Maquoketa
(Middle and Upper Ordovician)

Viola and Maquoketa production (figure 17) is scattered over south-central and northeast Kansas in approximately the same distribution as the underlying Simpson Group (figure 16). Oil production dominates, but both gas and oil are produced on the Pratt anticline. Viola reservoirs and the "Hunton" limestone farther upsection constitute the main producing horizons in the Forest City basin. Both the Viola and Maquoketa produce oil in the southern part of the Salina basin. Elsewhere, Viola production dominates, and the Maquoketa is not a viable reservoir.

The Viola Limestone occurs throughout the state except in northwest Kansas, the northern part of the Nemaha uplift, and the Central Kansas uplift due to pre-Pennsylvanian erosion. It is also absent in southeast Kansas due to pre-Chattanooga erosion on the Chautauqua arch (Merriam, 1963). The Viola is thickest in Jewell and Republic counties where it exceeds 300 ft (92 m; Cole, 1975). The Viola is composed of fine- to coarse-grained limestones and dolomites containing variable quantities of chert (Bornemann and others, 1982). Dolomitic limestones characterize the unit in south-central Kansas, but farther north in the Forest City and eastern Salina basin it is almost all dolomite (Goebel, 1968b; Cole, 1975). Types of porosity vary, but intergranular, vuggy, moldic, and fracture porosity all occur (Caldwell and Boeken, 1985; St. Clair, 1985). Informal subdivisions of the Viola in Kansas have been defined by Taylor (1947), Ver Wiebe (1948), and St. Clair (1985).

The Maquoketa formation immediately overlies the Viola but is limited to only the Salina, Forest City, and northern Sedgwick basins. It is dominantly greenish-gray shale (Cole, 1975), but in central Kansas the lower part of this unit is a gray, porous, crystalline dolomite that may be partly equivalent to the upper part of the Viola. This dolomite is well-developed in Saline and northern McPherson counties and constitutes the main reservoir in the Salina-Lindsborg oil-field trend.

The Viola and Maquoketa are not major producers of oil in the Midcontinent, but the most significant production from these units in the Midcontinent occurs in

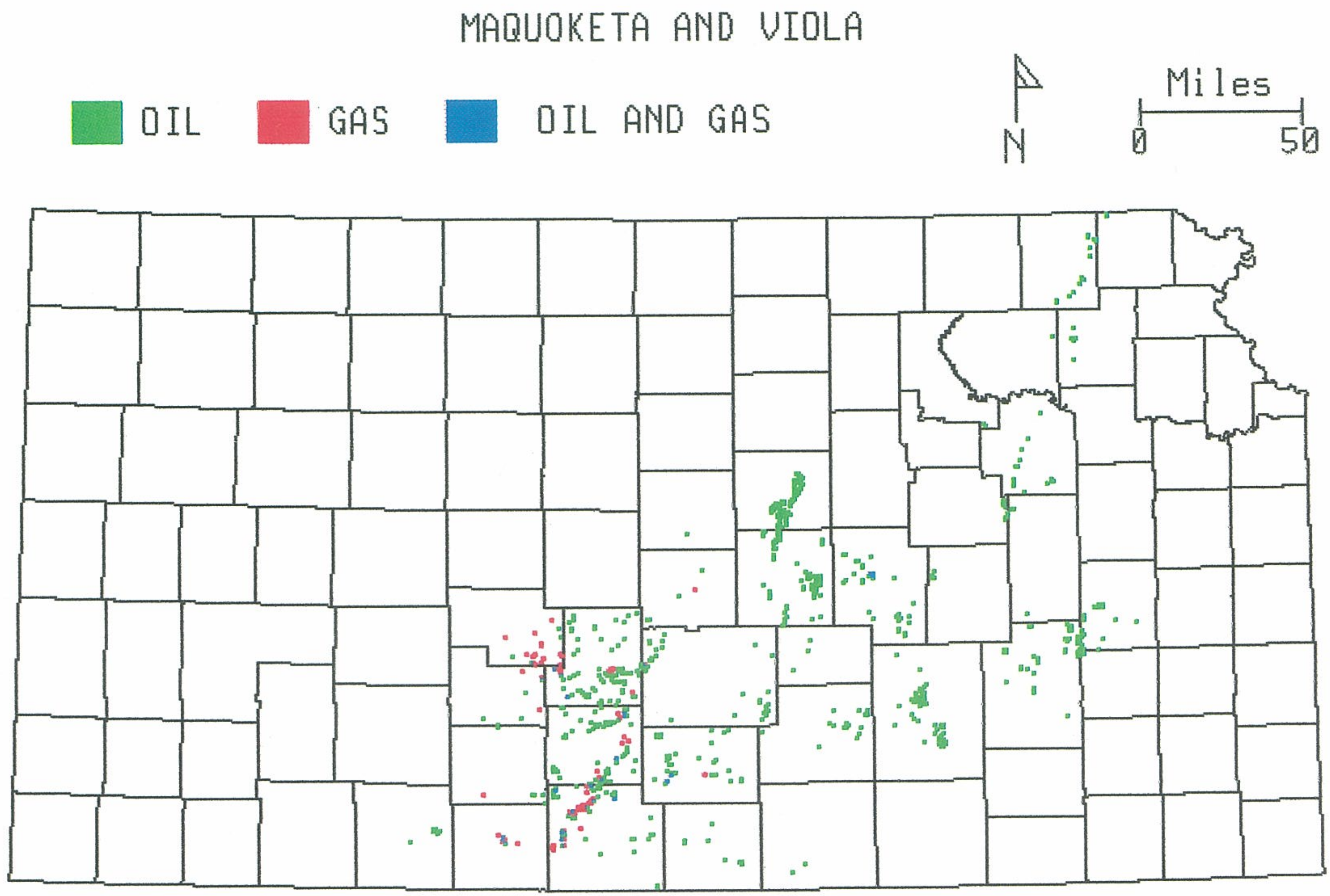


FIGURE 17—VIOLA AND MAQUOKETA PRODUCTION.

Kansas (Adler, 1971). Major fields in the Forest City basin are almost all structural traps that produce from the Viola. These fields include the McClain, McClain Southwest (McCaslin, 1982; Caldwell and Boeken, 1985), Strahm, Sabetha, and Strahm East fields in Nemaha County (Elster, 1960a, b, c); the Mill Creek (Lewis, 1960a), Newbury (Lewis, 1960b), Ashburn (Brinegar, 1960), Wilmington (Young, 1960), and Davis Ranch fields (Smith and Anders, 1951; Anonymous, 1960a) in Wabaunsee County; and the Comiskey, Comiskey Northeast (Hilpman, 1960), and John Creek fields (Anonymous, 1960b) in Morris County. Structural traps with minor possible stratigraphic components produce from Maquoketa and Viola reservoirs in the Salina-Lindsborg trend in Saline and McPherson counties. These fields, which include the Lindsborg field (Brewer, 1959; Thatcher, 1961), the Smolan field (Talbott, 1954), and the Gillberg, Salina, Swenson, and Olsson fields, are important because they are the major producers in the largely unproductive Salina basin.

The Viola Limestone also produces oil in certain localities where it crops out beneath the sub-Pennsylvanian unconformity such as the "Stapleton zone" of the El Dorado field in Butler County (Biederman, 1966) and in the large Zenith-Peace Creek stratigraphic trap in Stafford County (Imbt, 1941; Paddleford, 1941; Kornfeld, 1943). Other fields include the Deerhead field (Tucker, 1956) and Rhodes field (Clark, 1956; stratigraphic traps in Barber County); the Lerado and Lerado Southwest fields (structural traps in Reno County; McGinness, 1956); the Willowdale (Cruce, 1956) and Alameda fields (King, 1965a, b; structural traps in Kingman County); and the Nescatunga field (Capps, 1965; a structural trap in Comanche County). Gas is structurally trapped in the Viola in the Cunningham field in Kingman and Pratt counties (Rutledge and Bryant, 1937; Page, 1940).

Future potential of the Viola and Maquoketa formations include structural and stratigraphic traps where the units crops out beneath the sub-Pennsylvanian unconformity along the flanks of the Central Kansas uplift and on regional structural highs such as the Nemaha uplift and Pratt anticline. Possibilities also exist for similar traps along the sub-Chattanooga subcrop trend on the northern flank of the Chautauqua arch. The Maquoketa and Viola formations may also be the best potential producing zones in the deeper part of the Salina basin, just as they presently are in the Forest City basin. Although the Viola is present in southwestern Kansas in the deeper part of the Hugoton embayment, it has not yet been productive. Rascoe (1971) attributes this to the absence of adequate seals above the Viola west of Pawnee, Edwards, Kiowa, and Comanche counties. Perhaps future test wells may reveal Ordovician pay zones in this region, if favorable trapping conditions are eventually found.

Silurian and Devonian limestones

Silurian and Devonian production trends in Kansas include a broad east-west trend covering six counties in east-central Kansas (Marion, McPherson, Harvey, Reno, Butler, and Sedgwick counties) and a north-northeasterly trend starting in Morris County and extending to the Kansas-Nebraska state line (figure 18). The former trend is in the northern part of the Sedgwick basin; the latter trend is in the axis of the Forest City basin and on the adjacent Nemaha uplift. Silurian and Devonian rocks in Kansas are largely limited to north-central and northeast Kansas, so the small areal distribution of production of this unit is partly a reflection of its limited extent. These rocks are thickest in the northeast part of the state around eastern Nemaha County where they reach a maximum thickness of about 650 ft (200 m; Jewett and Merriam, 1959).

Silurian and Devonian rocks in Kansas are commonly identified by drillers as the "Hunton" formation. This name, which is applied to the package of limestones and dolomites sandwiched between the overlying Chattanooga Shale and underlying Maquoketa Shale, is a misnomer in that the true Hunton Formation in the Midcontinent is a unit of *Lower* Devonian limestones deposited in the Ardmore and Anadarko basins in southern Oklahoma. Equivalent strata in Kansas are missing due to erosion or nondeposition (Adler, 1971).

The missing Lower Devonian strata in the Kansas "Hunton" rocks represent a significant period of erosion or nondeposition in the rock record that is expressed by only a subtle unconformity. Although the unconformity between the Silurian and Middle Devonian limestones and dolomites can be recognized in a few localities by a zone that carries varying but low percentages of sand grains (Lee, 1943, 1956; Merriam, 1963), the unconformity is difficult to recognize if this sandy zone is absent (Hilpman, 1967). "Hunton" rocks have been zoned, however, on a regional basis by study of insoluble residues and microfossils (Lee, 1956; Ireland, 1967). In cases where these rocks can be differentiated by lithology alone, the Devonian component of the unit is generally composed of gray to brown, fine-grained, crystalline dolomite or limestone with minor chert, whereas the Silurian part is also cherty but generally consists of slightly coarser grained and slightly sandy dolomite with vuggy porosity (Merriam, 1963).

Silurian and Devonian rocks in Kansas are not significant petroleum reservoirs in the Midcontinent (Adler, 1971), but they are locally significant pay zones in the Forest City and northern Sedgwick basins. Fields producing from these rocks in the Forest City basin include the Livengood field in Brown County (Rascoe,

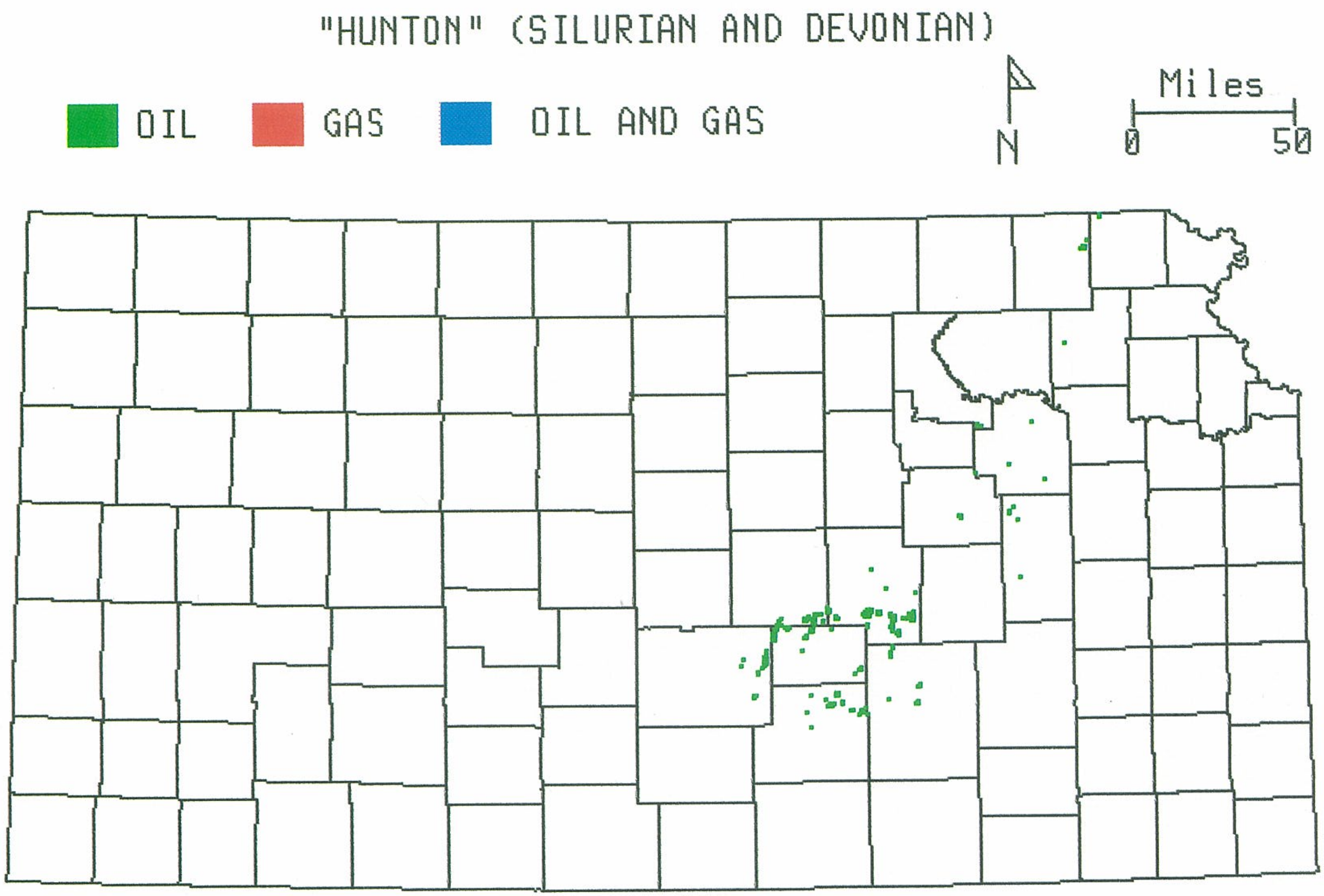


FIGURE 18—SILURIAN AND DEVONIAN PRODUCTION.

1960); the Sabetha (Elster, 1960a), Strahm (Elster, 1960b), and Strahm East fields (Elster, 1960c) in Nemaha County; and the Davis Ranch field in Wabaunsee County (Smith and Anders, 1951; Anonymous, 1960a). On the Nemaha uplift immediately west of the Forest City basin, Silurian-Devonian rocks that crop out beneath the sub-Pennsylvanian angular unconformity constitute the main pay horizon in the Yaege field in Riley County (Goebel, 1960). Other "Hunton" fields on or flanking the Nemaha uplift include the Fairplay field in Marion County (Stubbs and Wright, 1960) and the Gingrass field in Harvey County (Johnson, 1960).

Some of the fields in Marion and McPherson counties are due to southwestward-dipping "Hunton" rocks being truncated to the north by a broad buried valley filled with the younger Chattanooga Shale. This buried valley, called the McPherson Valley by Lee (1956), is the updip seal for an east-west trend of stratigraphic traps extending across southern Marion and McPherson counties. The fields in this trend include the "Hunton" oil in the multi-pay Hollow-Nikkel field (Bunte and Fortier, 1941), the Graber field in Harvey County, and the Unger field in Marion County (Brown, 1960). Other fields in Kansas producing from Silurian-Devonian rocks include the Goessel field in McPherson and Marion counties, the Burrton field in Reno and Harvey counties, and the Wenger field in Marion County (Jewett, 1954).

Future potential of Silurian-Devonian rocks in Kansas includes additional structural traps that may be found in the Forest City basin. Additional stratigraphic traps may also be found on the south side of the McPherson Valley in the northern Sedgwick basin, but the larger of these traps have probably been found. The continuation of this valley in the Forest City basin in the vicinity of eastern Chase County may be prospective though. Stratigraphic traps on the north side of the valley in northern Marion and McPherson counties are a possibility, but none has been found so far. Perhaps the general west-southwest tilt of the strata north of the valley prohibits formation of such traps. Additional fields on the Nemaha uplift, analogous to the Yaege field in Riley County, are also viable exploration plays.

Chattanooga and Misener
(Upper Devonian and Lower Mississippian)

Misener sandstone, at the base of the Chattanooga Shale, produces oil from fields scattered throughout central Kansas (figure 19). Major production from the Misener and other sandstones near the base of the Chattanooga Shale is presently concentrated in the Wil field in eastern Edwards County and the Lyons West field in central Rice County.

The Chattanooga Shale is generally identified by drillers in Kansas as the Kinderhook shale. Similarly, sandstones at or near its base can be called Kinderhook sands. The Chattanooga is known as the Woodford Shale in Oklahoma while the basal sandstone is still called the Misener. In Arkansas, the Misener sandstone is identified as Sylamore Sandstone Member (Adler, 1971). The Chattanooga Shale is present over the eastern half of Kansas except for structural highs along the Nemaha uplift where it was eroded in Late Mississippian to Early Pennsylvanian time. In Brown and eastern Nemaha counties, it is greater than 250 ft (75 m) thick, but it generally thins westward to a featheredge in central Kansas (Goebel, 1968c). In northern McPherson and Marion counties, the Chattanooga Shale fills a broad ancient valley eroded into older rocks. This valley, called the McPherson Valley, contains Chattanooga Shale in excess of 250 ft (75 m) in thickness (Lee, 1956). In north-central Kansas, the Chattanooga Shale is a gray, greenish-gray, and red shale with minor limestones (Lee, 1956; Goebel, 1968c), but in southeast Kansas it is a black pyritiferous shale. These latter characteristics suggest it may be capable of generating petroleum.

The Misener sandstone at the base of the Chattanooga Shale is extremely erratic in its development. It can be several meters thick near the Central Kansas uplift but elsewhere, generally away from the uplift, it may only be represented by a slightly sandy zone at the base of the Chattanooga Shale (Goebel, 1968c). Lee (1956) states the Misener sandstone is commonly composed of well-rounded quartz sand grains that probably represent reworked Simpson sandstones. A similar conclusion was made by Amsden and Klapper (1972) for the Misener in Oklahoma. The locus of Misener sand deposition is probably strongly controlled by the northwest-southeast-trending ancestral Central Kansas uplift, the pre-Mississippian predecessor to the Late Mississippian-Early Pennsylvanian Central Kansas uplift.

Sandstones at or near the base of the Chattanooga Shale are not a major source of hydrocarbons in the Midcontinent (Adler, 1971), but they can produce locally significant amounts of hydrocarbons. Two such areas in Kansas, the Wil field in eastern Edwards County (Stevens, 1960; McCaleb and Wheeler, 1965) and the Lyons West field (Ehm, 1965; Wright, 1965), are stratigraphic traps where Misener sandstones are truncated updip by the sub-Pennsylvanian unconformity. Other fields in Kansas which produce petroleum from sandstones at or near the base of the Chattanooga Shale include the Valley Center field in Sedgwick County (Wright, 1960), the Voshell field in McPherson County (Hiestand, 1933), and the Haviland field in Kiowa County (James, 1956).

The presence of the Wil field and Lyons West field is encouraging, because other such stratigraphic traps may be found around the Central Kansas uplift. Else-

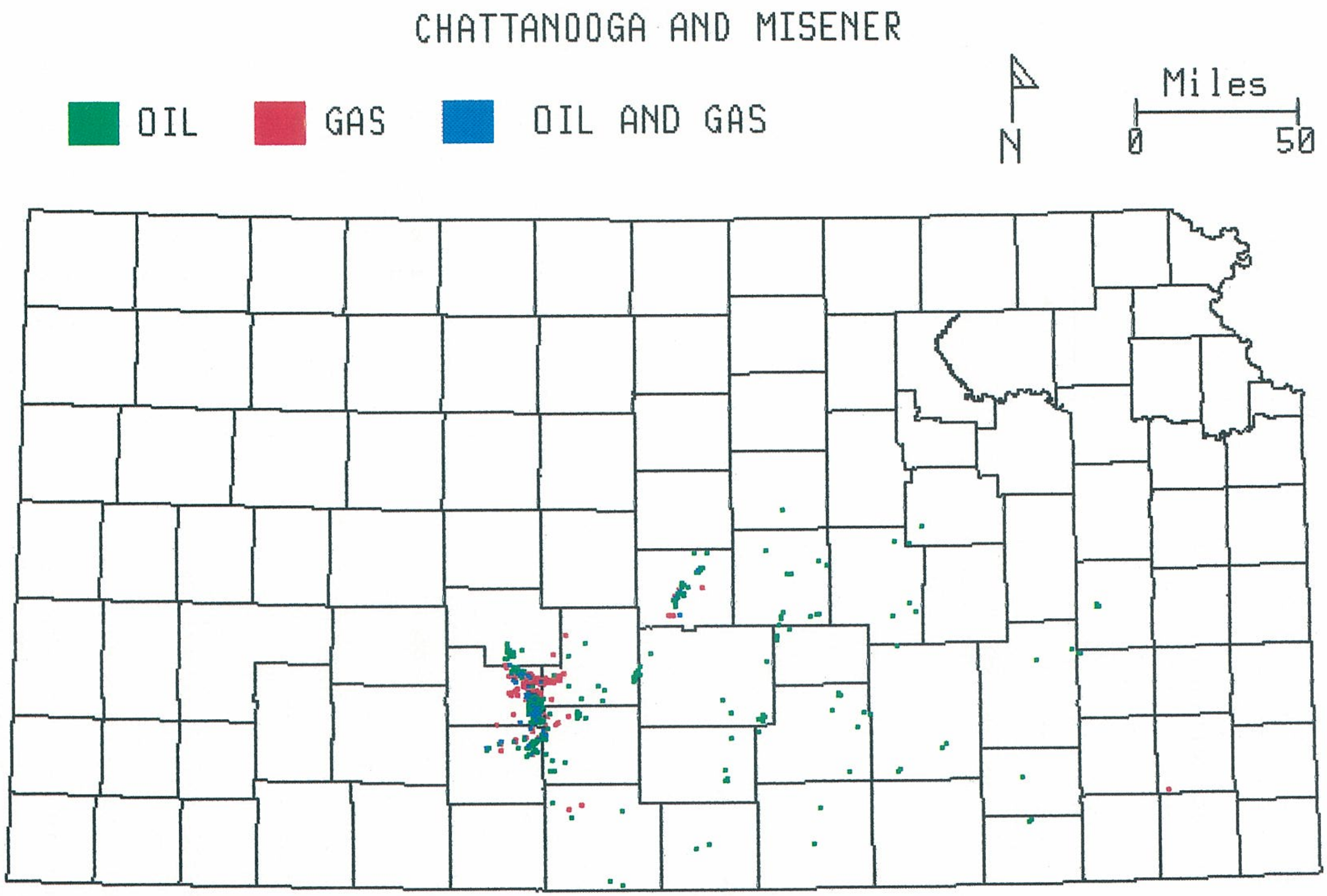


FIGURE 19—CHATTANOOGA AND MISENER PRODUCTION.

where, predicting the location of Misener reservoirs before drilling is difficult because the unit developed so erratically. Perhaps with cores and other geologic studies, once a Misener pay zone is found, its trend could be predicted and subsequently exploited by follow-up drilling.

Mississippian

Mississippian production extends across all of southern Kansas (figure 20). Oil production dominates on the flanks of the Nemaha uplift and western side of the Cherokee basin, but scattered gas production occurs farther east. Gas and associated oil and gas production occur on the Pratt anticline, Sedgwick basin, and in the Hugoton basin near the Kansas-Oklahoma state line. Oil production without significant gas occurs farther north on the flank of the Hugoton basin southwest of the Central Kansas uplift.

Mississippian rocks in Kansas can be divided into two general sequences. The younger group of rocks is Chesteran in age and consists of marine and nonmarine shales and sandstones with minor limestones. Unconformably below the Chester rocks is a group of shallow-marine limestones, cherts, and cherty limestones that are Kinderhookian, Osagian, and Meramecian in age. Although the Chattanooga Shale is in part Mississippian in age, discussion of its production is separate from this section.

Chesteran rocks are quite thick in the Anadarko basin in Oklahoma but are present in Kansas only in the southwestern part of the state underlying parts of Stanton, Grant, Haskell, Morton, Seward, and Meade counties. These rocks are situated in the axis of the Hugoton basin and thicken southward into Oklahoma. The thickness of the Chesteran rocks at the Kansas-Oklahoma state line is approximately 500 ft (150 m) (Goebel, 1968d, e).

The Kinderhookian, Osagian, and Meramecian limestones that underlie the Chesteran rocks in southwestern Kansas are present all over the state except where they have been removed by late Mississippian-early Pennsylvanian erosion over the Central Kansas uplift and parts of the Nemaha uplift. The thickness of the Mississippian rocks is largely dependent on structural movement that occurred during late Mississippian-early Pennsylvanian time. Mississippian rocks are thin to absent by erosion on uplifts and local anticlines but are relatively thick in synclines and basins. The pre-Chesteran-age Mississippian rocks in Kansas are thickest in the Hugoton basin where approximately 1,400 ft (425 m) of these rocks are preserved (Goebel, 1968d, e).

Most of the Mississippian production in the Midcontinent occurs at or near the top of the Mississippian section just below the sub-Pennsylvanian unconformity (Adler, 1971). Solution weathering of the Mississippian limestones commonly produces a residual cherty, porous weathered zone just beneath the unconformity that is called the Mississippian "chat" by drillers. According to Ver Wiebe (1950), "chat" is a modification of the word "chert" and was originally identified as such in wells drilled in the Welch (i.e. Welch-Bornholdt) field in Rice County. The chat is thickest in the vicinity of the Central Kansas uplift and Pratt anticline and can be quite variable in its reservoir characteristics. Porosity and permeability of the chat are difficult to predict, particularly in wildcat locations. In many places it is several meters thick and is difficult to differentiate from overlying Pennsylvanian basal conglomerates that may also serve as reservoir rocks.

Porous oolite zones within pre-Chesteran limestones are also productive in some fields in the Hugoton embayment such as the Pleasant Prairie field in Haskell and Finney counties (Roby, 1959, 1961; Bennett, 1960) and the Nunn (Aukerman, 1959) and Damme (Schmidlapp, 1959) fields in Finney County. Development of the porosity zones within the Mississippian limestones is erratic and therefore hard to predict; nevertheless, they may represent intriguing targets as off-structure stratigraphic traps.

Mississippian rocks produce in several hundred fields in Kansas. Most of the larger fields are combination structural-stratigraphic traps in which porous chat and overlying conglomerates change to nonporous chat or limestone in an updip direction (Adler, 1971). Some traps of this type include the Lost Springs field in Marion County (Shenkel, 1955), the Wherry and Welch-Bornholdt fields in Rice County (McNeil, 1941; Clark and others, 1947), the Spivey-Grabs-Basil field in Kingman and Harper counties (Frensley and Darmstetter, 1965), and the Wil field in Edwards County (Stevens, 1960). Other significant fields in Kansas producing from Mississippian rocks include the Voshell field in McPherson County (Hiestand, 1933), the Winterschied field in Woodson County (Jewett, 1954), the Burrton field in Harvey and Reno counties, and the McClouth field in Jefferson County (Lee and Payne, 1944). Significant Chesteran production occurs in the McKinney field in Meade and Clark counties (Jamieson, 1959) and several other fields in the Hugoton embayment.

The widespread distribution of Mississippian production in both large and small fields indicates this unit will be a potential target horizon in virtually all wildcat wells drilled where Mississippian rocks are present in Kansas. Subtle stratigraphic traps, attributable to varying reservoir quality of the chat and overlying basal Pennsylvanian conglomerates, will probably be exploration targets in densely drilled areas of the state. Although small discoveries may be the norm in the more heavily drilled areas, larger fields may be a possibility in deeper, sparsely drilled areas such as the Hugoton embayment and western Kansas. Mississippian reservoirs are major pay horizons

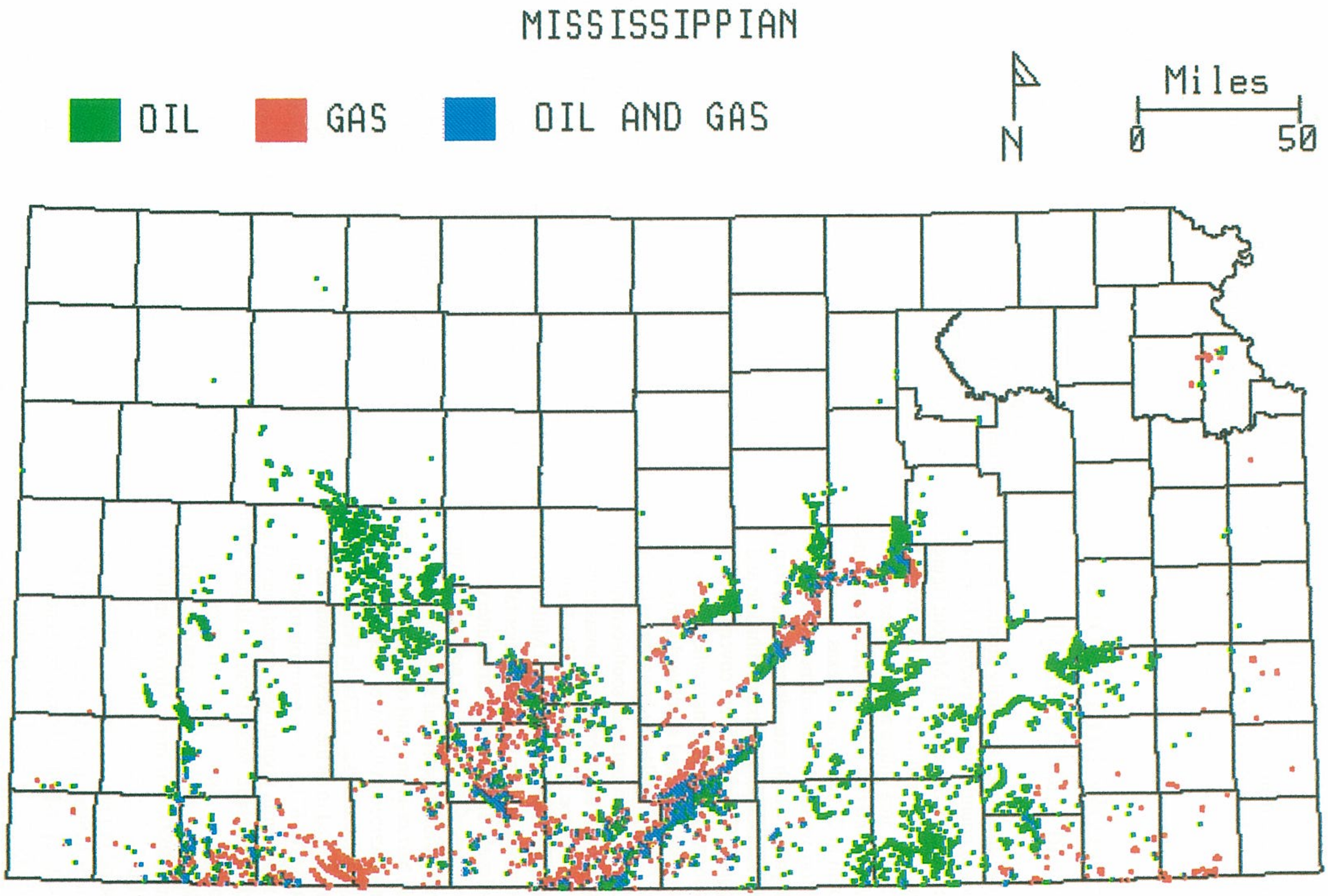


FIGURE 20—MISSISSIPPIAN PRODUCTION.

in a recent exploration play in Gove, Ness, and Lane counties southwest of the Central Kansas uplift. This production trend gained significance in the 1970s and continues today as an area of active drilling. Watney and Paul (1983) anticipate many more fields similar to these fields will be found along the subcrop trends of the Mississippian limestones in southwestern Kansas.

Morrow and Atoka

(Lower and Middle Pennsylvanian)

Morrow sandstones primarily produce gas from the southern tier of counties in southwestern Kansas (Clark, Meade, Seward, Stevens, and Morton; figure 21). Oil production extends northward from this area to form a triangular producing area with a northern apex in Wallace County. The Atoka interval is not productive in Kansas but is to the south in Oklahoma and Texas.

The Morrow and Atoka sediments were deposited in a large embayment which extends northward from the Anadarko basin situated in the Texas Panhandle and western Oklahoma. The embayment covers much of eastern Colorado and western Kansas where these sediments wedge out eastward and northward along a zone extending from Cheyenne County in northwestern Kansas to Clark and Comanche counties in south-central Kansas. Maximum thickness of the interval in Kansas is in excess of 500 ft (150 m; Rascoe and Adler, 1983). Prior to deposition of the Morrow sediments, the Midcontinent was emergent undergoing erosion during a major fall in worldwide sea level. The Morrow-Atoka interval represents a transgression of the sea, albeit a staggered one, onto a pre-Pennsylvanian erosional surface.

Beach, barrier-island, and offshore-marine sand bars have been described in the lower Morrow (McManus, 1959; Adams, 1964; Khaiwka, 1973a, b; Franz, 1984) and are commonly referred to as the "Keys sandstones" (Rascoe and Adler, 1983). These reservoir rocks are lenticular and range from poor to well-sorted, very fine to coarse-grained, glauconitic, fossiliferous, feldspar-rich to clean quartz sandstones, commonly with pores partly filled by calcite, dolomite, quartz, and kaolinite or chlorite clay minerals (Franz, 1984). The upper Morrow strata was dominated by fluvial-deltaic depositional conditions that reflect a still-stand or minor regression of the sea. Specific depositional environments include stream-mouth bar, distributary-channel, and fluvial point-bar sandstones (Swanson, 1979; Franz, 1984). These sandstones are commonly coarse-grained, locally conglomeratic, cross-bedded, and bear plant fossils. Carbonate cements and clay minerals are again present. The primary source for these sediments appears to have been the Transcontinental arch that crosses northern Colorado and western Nebraska. The Central Kansas uplift and Sierra Grande uplift in southeastern Colorado were locally very important sources of sediment.

The Atoka sediments in southwestern Kansas are a repetitive sequence of thin limestones and shales and reflect a more extensive inundation of the sea onto the continent. Local Atoka-age, lenticular sandstones were probably deposited along the eastern limit as ancient shoreline sediments in western Kansas analogous to the Morrow, although these deposits have yet to be recognized.

Significant oil and gas fields in Kansas produce from primarily lenticular, upper Morrow sandstones ranging in thickness from 2 to 60 ft (0.6-18.2 m). Structural-stratigraphic traps dominate fields producing from Morrow sandstones in western Kansas. Structural objectives have resulted in multi-pay fields with Morrow sandstones, which locally produce across the structures. The Eubank field in Haskell County is a large multi-pay field located on a significant anticline which was revealed by mapping shallower Permian strata. The Morrow is a minor pay here because it contains a lenticular sandstone of limited extent (Fugitt and Wilkinson, 1959). Another Morrow sandstone is an oil reservoir along its pinch out at the north end of the Pleasant Prairie anticline in Finney, Kearney, and Haskell counties (Roby, 1959). Sand accumulated in a structural saddle at the Sequoyah field, a small field in Finney County (Tucker, 1959), and in a lenticular deposit on the crest of another anticline at the Patterson field in Kearney County, a small but highly productive field (Davis, 1959). The Taloga field in Morton County produces oil from several Morrow sandstones on an asymmetric anticline (Anonymous, 1959c).

Significant gas fields producing from the Morrow in southwestern Kansas include the Harper Ranch pool in Clark County, interpreted as an offshore sand accumulation in an embayment along a shoreline (Waite, 1956). The trap in the McKinney field in Meade and Clark counties occurs as an updip pinch out of sandstone discovered using subsurface-geology techniques (Jamieson, 1959); Liberal Southeast field in Seward County, a petroleum accumulation in a lenticular Morrow sandstone reservoir discovered by core drilling of a structural anomaly associated with the Permian Stone Corral marker; Liberal-Light field also in Seward County, a large stratigraphic trap found by random drilling (Strohmeyer, 1959). The Interstate field discovered in Morton County using subsurface and seismic methods produces gas and oil from a lenticular lower Morrow sandstone which crosses an anticline (Anonymous, 1959a). The Sparks field has thick, basal and lower Morrow sandstones on a structural closure discovered by seismic prospecting (Rupp, 1959). The Lexington field in Clark County is a large field associated

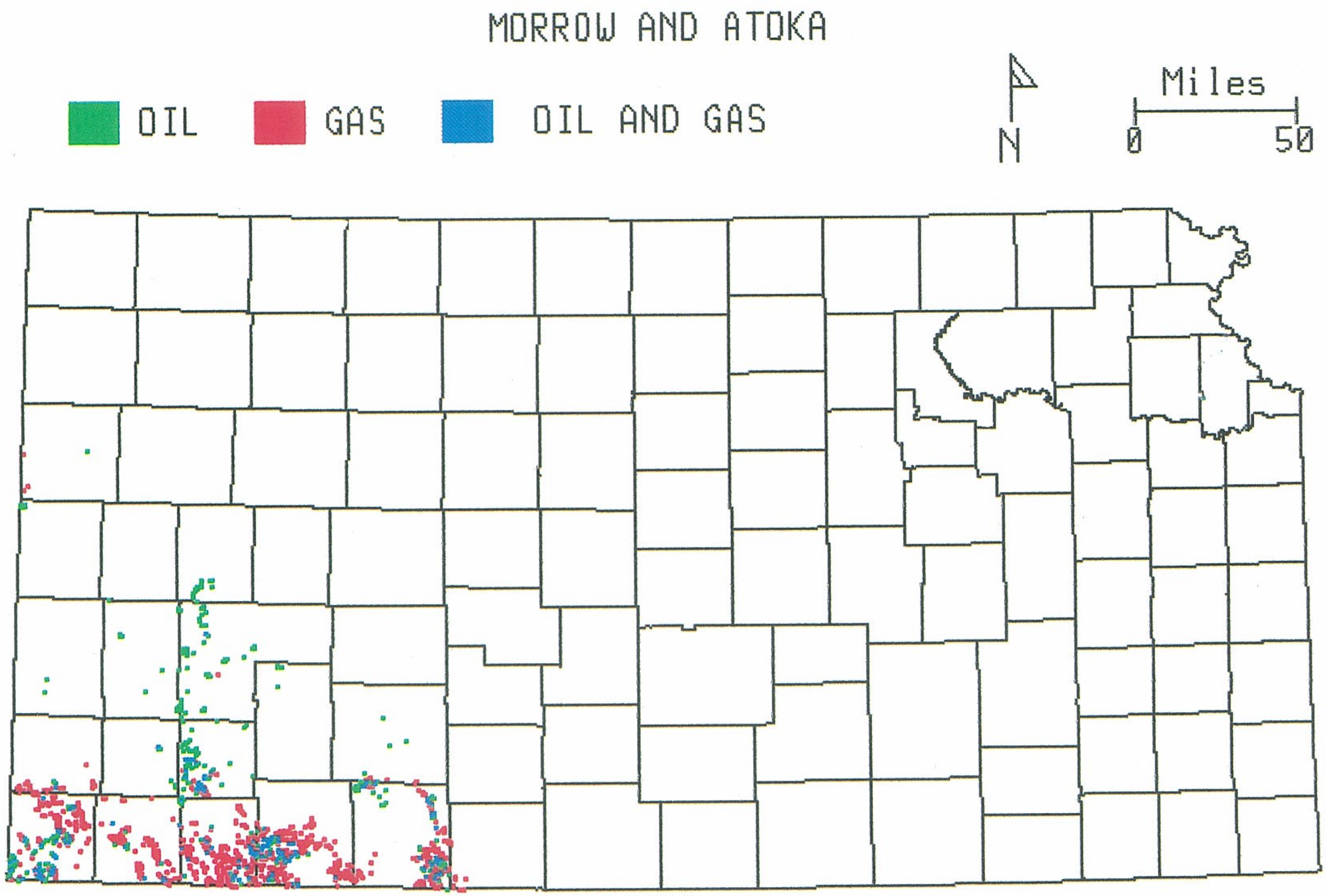


FIGURE 21—MORROW AND ATOKA PRODUCTION.

with a thick, valley-fill Morrow sandstone which rests on an unconformity developed on the Mississippian rocks (Watney and Paul, 1983).

Drilling for Morrow production is concentrated along established production within the southern tier of counties and in Finney and Haskell counties. Recent Morrow discoveries and extensions in extreme western Kansas and eastern Colorado indicate favorable conditions for oil accumulation in these areas (Paul and Beene, 1985).

Morrow sandstone reservoirs are highly lenticular and are the result of a range of depositional conditions. A low drilling density and a lack of cores and detailed knowledge of these rocks have required that exploratory prospects involve primarily structural trapping. Drilling based on mapping of shallow structural anomalies has been very successful in finding moderate- to large-sized fields such as the Eubank field in Haskell County, Liberal Southeast in Seward County, and Pleasant Prairie field in Finney, Kearney, and Haskell counties. Similarly, the drilling of seismically detected structures has also resulted in significant oil and gas discoveries (such as the McKinney field in Meade and Clark counties, Richfield field in Morton County, and Sparks field in Stanton and Morton counties).

Basal Morrow valley-fill sandstones following a southeast-to-northwest trend analogous to Lexington field in Clark County will offer continued exploration targets. Subsurface methods have been credited with the discovery of some of the Morrow oil and gas fields, including Lexington and Harper Ranch, although reflections of the sandstone reservoir in Lexington field are visible on high resolution, CDP seismic profiles that cross the field. What have been found to date are primarily combination structural-stratigraphic traps involving pinch out of sandstones along an unconformity or lensing out of sandstone into shale. As the information base grows, the knowledge of depositional trends should permit improved assessment of characteristics of stratigraphic traps, which should help to lower the risk in their exploration and development.

Cherokee and Marmaton
(Desmoinesian, Middle Pennsylvanian)

A large area of oil and gas production from the Cherokee Group and the Marmaton Group is found in eastern Kansas in the Cherokee basin east of the Nemaha uplift. The map of this production (figure 22) only displays a portion of the producing wells from this interval in eastern Kansas because many of the fields producing from Cherokee and Marmaton reservoirs were discovered and exploited before accurate records were kept on exploratory and production drilling. Another concentration of oil production is on and immediately west of the Central Kansas uplift. Oil and gas production are also scattered across southwest Kansas and the Pratt anticline in south-central Kansas.

The Cherokee Group, the lower of the two groups, is a succession of shale with lenticular sandstones, thin coals, and minor limestones (Zeller, 1968). The deposits are predominantly fluvial-deltaic, with minor terrestrial and open-marine rocks. The major producing sandstones in eastern Kansas, such as along the "Golden Lanes," have been described as marine bar deposits and meandering alluvial-stream deposits (Rich, 1923; Rich, 1926; Bass, 1934; Hulse, 1979). Many lesser Cherokee sandstones so abundant in this area of the state have also been described as distributary-channel and crevasse-splay deposits which were part of successive deltaic depositional systems (Harris, 1985). The oil and gas commonly accumulates in updip areas of these sandstone bodies, and consequently they have been classified as combination structural-stratigraphic traps (Busch, 1959).

In western Kansas the Cherokee Group becomes much more marine, with limestones eventually replacing the sandstones of the east, particularly in the upper Cherokee. The Cherokee Group was deposited on an extensive pre-Pennsylvanian erosion surface on the flanks and over the crests of the Central Kansas uplift where it locally pinches out. Lenticular sandstones occupy the lower Cherokee including those that fill valleys incised into the underlying strata, apparently cut by rivers directed off the Central Kansas uplift (Walters and others, 1979). The basal Pennsylvanian sandstones and conglomerates locally deposited during the Cherokee and Marmaton intervals are best developed in the vicinity of uplifts, which were a major source area for these deposits. The basal Pennsylvanian conglomerate can range in age up to Missourian in local areas on the crest of the Central Kansas and Nemaha uplifts, where the Kansas City Group rests directly on the Precambrian and Arbuckle (Merriam, 1963). In general, the age of the basal Pennsylvanian deposit would be oldest on the lower flanks of these uplifts and become progressively younger up into their crests. Lower Pennsylvanian strata are limited to the lower reaches of the basins as previously described. The basal Pennsylvanian sandstones are classified here as Middle Pennsylvanian and are included in the Cherokee and Marmaton map (figure 22).

Marmaton and Cherokee limestones are productive across western Kansas. The strata are components of cyclothems and the main producing units are regressive (upward-shallowing) limestones. High-energy deposits such as oölitic limestones or mud-dominated carbonate buildups are altered and leached by exposure of these carbonates to weathering late during the development of each cycle (Caldwell, 1985). Daniels (1985) describes a later period of dissolution after burial of carbonate and a resultant porosity formation which may have a significant impact on local reservoir development.

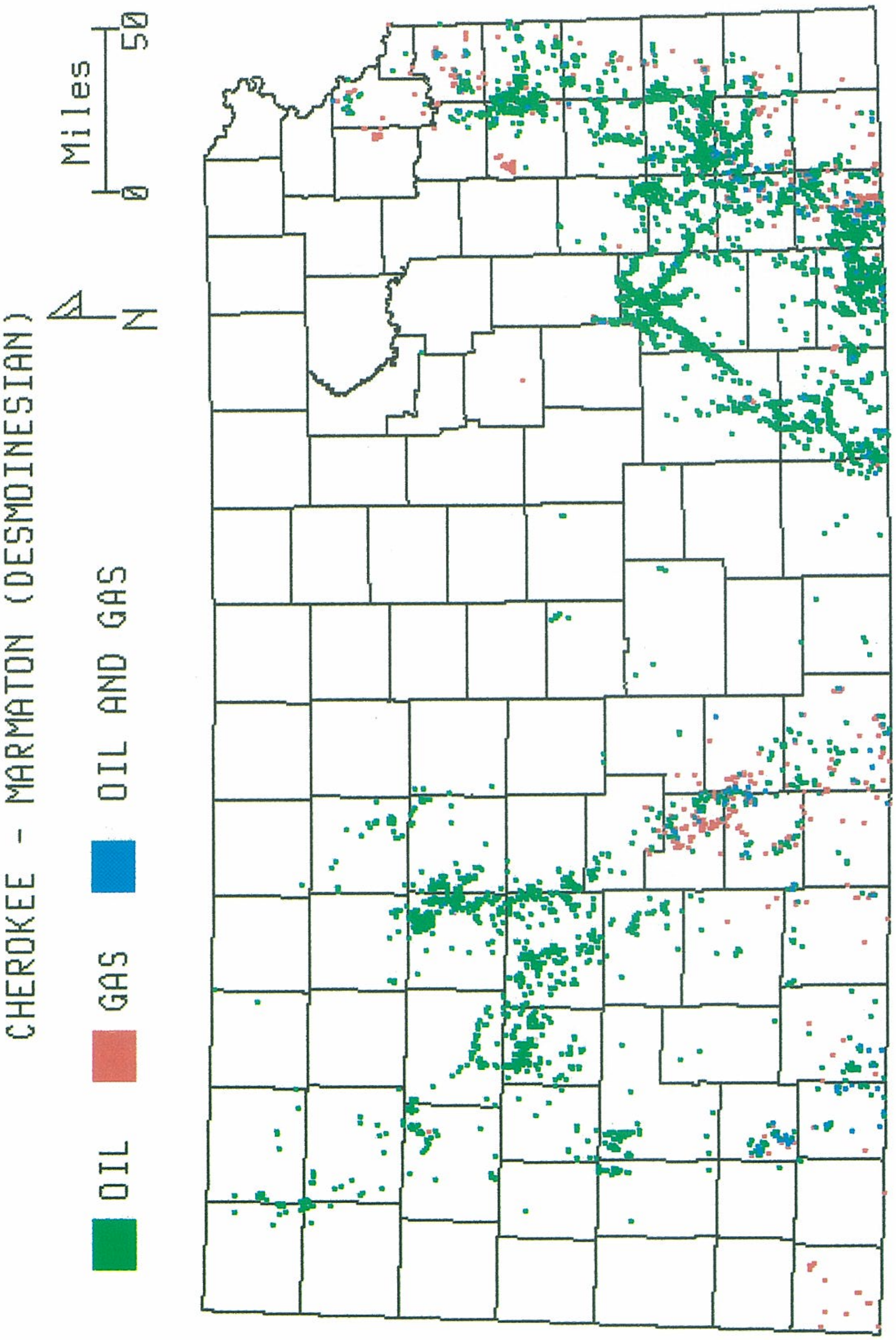


FIGURE 22—CHEROKEE AND MARMATON PRODUCTION.

The Cherokee sandstones of southeastern Kansas constitute some of the oldest exploration plays in the Midcontinent including the initial oil discovery for the state in Miami County in 1860. Rapid development did not occur until the early 1900s. By 1904, principally from Cherokee reservoirs in eastern Kansas, annual oil production was over four million barrels. Extensive development of Cherokee oil and gas fields took place from Miami to Montgomery counties from 1900 to 1910. The large oil pools in "Bartlesville" shoestring sandstones, which are part of the "Golden Lanes," such as the Smock-Sluss, Weaver, and Fox-Bush fields in Butler County and the Sallyards pool in Greenwood County were found and developed in the 1920s (Jewett, 1954). The Busch City oil field in Anderson County is an example of a shoestring-sandstone stratigraphic trap having dimensions of up to 55 ft (17 m) in thickness, 1,000 to 2,000 ft (300-600 m) in width, and 14 mi (23 km) in length (Charles, 1941; Reinholtz, 1982). The Coffeyville field, one of the first to be developed in Kansas, is a large structural-stratigraphic trap located on a dome along the Chautauqua arch and includes gas production from the lenticular Cherokee sandstones (Jewett, 1954).

Seismic, core drilling, and subsurface methods have been employed to find anticlinal closures with Marmaton and Cherokee pay zones in western Kansas. Some reservoirs are commonly lenticular sandstones, others are limestones with local porosity development. Recognition and prediction of rock properties is therefore important in order to understand the extent of these reservoirs. An example of a significant field in western Kansas includes Damme field in Finney County, a structural trap with multiple pays including an oölitic Marmaton limestone (Schmidlapp, 1959). The Nunn field in Finney County and the Llanos field in Sherman County are multi-pay pools discovered using seismic. Both have pay zones in both the Cherokee and Marmaton groups (Aukerman, 1959; Byers, 1959). Subsurface and core drilling were also used to substantiate the Llanos prospect before it was drilled.

The Eubank field in Haskell County is a large multi-pay field on an anticlinal closure discovered using subsurface geology. It produces from oölitic Cherokee limestone and dolomitic and oölitic Marmaton limestones (Fugitt and Wilkinson, 1959). The Pleasant Prairie field in Finney, Kearney, and Haskell counties is analogous to the Eubank field (Roby, 1959).

Examples of basal Pennsylvanian sandstone and conglomerate pay zones include structural-stratigraphic traps in multi-pay fields including the Wil field in Edwards and Stafford counties, an updip pinch out of conglomerate (McCaleb and Wheeler, 1965); and the Sunny Slope and Groff fields in Trego County and the Southeast Oro pool in Pawnee County where the Cherokee is almost entirely composed of sandstone or conglomerate that pinches out northeastward onto the Central Kansas uplift (Ash, 1965; Costa, 1965). Stratigraphic traps have been few, but one in particular, the small Sun City pool in Barber County tested an amazing 3,000 barrels of oil per day in the discovery well from a locally thick, very vuggy, coarsely-crystalline Marmaton limestone, locally referred to as the Massey zone (Spaulding, 1959). Similar opportunities for stratigraphic traps include sand-filled paleochannels described by Walters and others (1979).

Several small fields produce from a lower Cherokee sandstone called the Burgess in the Salina basin in central Kansas including Ash Grove, Bonaccord, and Bonaccord Northeast in Dickinson County (Steder, 1960). The Yaege field in Riley County includes oil production from the basal Pennsylvanian conglomerate (Goebel, 1960).

Desmoinesian sandstones of southeast Kansas and northeast Oklahoma have been the most productive Pennsylvanian reservoirs of the Midcontinent. Substantial carbonate buildups equivalent to the Marmaton of Kansas are major producers along the rim of the Anadarko basin in central Oklahoma (Rascoe and Adler, 1983; Michlick, 1984).

Development of reservoirs in the Desmoinesian stage in southeastern Kansas is mature with thinner once-uneconomic zones now being sought. In northeast Kansas in the Forest City basin, drilling density is still relatively low. Recent discoveries of oil and gas in the southeastern part of the Forest City basin are an optimistic sign that additional reserves will be found (Paul and Beene, 1985). Surface and subsurface mapping used to search for structural traps will continue to be the mainstay of exploration in this area as dictated by the economics of the anticipated small reservoirs. Seismic surveys may provide more opportunities, but will be done in a restricted way. Enhanced oil recovery will provide many opportunities in the future for eastern Kansas because of low drilling costs and certain favorable characteristics of the reservoirs that make them suited for existing enhanced oil-recovery processes (Ebanks, 1975).

Recent successes in the Marmaton and Cherokee limestones and sandstones in western Kansas are occurring as companies explore low-relief structures in less heavily drilled areas west of the Central Kansas uplift (Paul and Beene, 1985). Integrated studies of stratigraphic and sedimentologic information from wireline logs, cuttings, and cores should help to optimize the selection of structures that provide better opportunities for favorable reservoir development.

Lansing, Kansas City, and Pleasanton

(Missourian, Upper Pennsylvanian)

Oil production from Missourian-stage strata is widespread over western and central Kansas (figure 23). It is concentrated over the Central Kansas uplift but is more widely scattered in adjacent basins. Gas production is limited in these same areas and, in addition, includes extreme eastern Kansas and southwestern Kansas on the flanks of the Cimarron arch.

Missourian strata in Kansas are divided from bottom to top into the Pleasanton, Kansas City, and Lansing groups. The Pleasanton Group is primarily composed of shale and lenticular sandstones. These sandstones, locally referred to as the Hepler and Knobtown, serve as gas and oil reservoirs in eastern Kansas where the Pleasanton Group is thicker and the sandstones best developed. The Kansas City and the Lansing groups are a sequence of alternating limestones and shales, commonly combined in the subsurface and referred to as the Lansing-Kansas City. These later two groups are by far the dominant Missourian-producing intervals in Kansas. Seven or more major limestones comprise the Lansing-Kansas City throughout the subsurface. One or more can serve as a reservoir unit which varies according to local attributes of the limestone. The reservoir limestone is commonly the regressive limestone of a cyclothem, analogous in kind to those in the overlying Virgilian Pennsylvanian strata. The Hushpuckney and Stark shale members of the Swope and Dennis formations locally serve as gas reservoirs in southeastern Kansas where they are black and fractured. These strata are part of a considerable succession of cyclic sediments called cyclothems. The four-component cycle in the Lansing and Kansas City groups commonly has a thin, lower transgressive limestone overlain by a marine shale which is commonly black and high in natural gamma radiation. The marine shale commonly serves as a subsurface marker for correlation. The main reservoir rock is the succeeding member of the cyclothem, the regressive limestone which by definition represents a shallowing-upward unit. The regressive limestone commonly has a porous, commonly grain-rich reservoir interval near its top. The grain-supported fabric is the result of high-energy marine depositional conditions. The shallow-water and exposed conditions occurring shortly after deposition of the rock have commonly significantly enhanced the original porosity and permeability of the regressive limestone. Furthermore, local, low-relief structural anomalies appear to be favored sites for reservoir development (Watney, 1980, 1984, 1985).

The largest Missourian fields in the state are structural traps on the Central Kansas uplift, including the only giant field (116 million barrels ultimate recovery) in the Lansing-Kansas City—the Hall-Gurney field in Barton and Russell counties (Rascoe and Adler, 1983). Other large fields on the Central Kansas uplift include the Bemis-Shutts field in Ellis County, and the Trapp field in Russell and Barton counties. The majority of other fields in Kansas are combination structural-stratigraphic traps. Examples include the Alameda field in Kingman County, which produces from multiple zones including two limestones in the lower Kansas City Group. This field is located along the crest of one of a series of northeast-southwest-trending faulted anticlines located in the northeastern portion of the Sedgwick basin (King, 1965a, b). The Rosedale field, also in Kingman County, is another field with multiple pays, including a limestone reservoir in the Kansas City Group with local vuggy porosity development (Richardson and Matthews, 1956b). This field was found using seismic profiling as an exploration tool.

The Valley Center and Goodrich fields in Sedgwick County are multi-pay fields with up to four producing limestone intervals in the Lansing-Kansas City characterized by erratic porosity development. These fields were discovered through core drilling and also are located on one of the prevailing northeast-southwest-trending anticlines in the Sedgwick basin (Wright, 1960; Kirk, 1960). The Fitzsimmons field in Pratt County is analogous to the above fields but produces from only one limestone in the Kansas City, where it is thick with moldic and vuggy porosity development (Brown, 1956). The Tobias field in Reno County is another multi-pay field on an anticline on the southeast edge of the Central Kansas uplift. A single limestone in the Lansing Group is producing in association with the local thickening of the unit (Brewer, 1965).

The Cambridge arch in northwest Kansas is another locus of Missourian petroleum reservoirs. The Adell anticline in Sheridan County is the site of a number of Lansing-Kansas City oil fields (Merriam, 1963). The Adell field is a large multi-zone Lansing-Kansas City pool discovered by core drilling and seismic confirmation (Lane, 1959a). Other fields such as the Hardesty and Jennings fields (Lane, 1959b,c) and the Pollnow field (Anonymous, 1959b) and Warner field (Curtis, 1959), all in Decatur County, are seismic or core-drilled discoveries found on anticlinal closures which produce from up to three limestones in the Lansing-Kansas City. Porosity is localized or discontinuous in these fields (Curtis, 1959).

The area west of the Central Kansas uplift has been the focus of recent activity of wildcat exploration and development (Paul and Beene, 1985). The Pendennis South field in Lane County is an example of an established field discovered using seismic interpretation. A northeast-trending anticline produces from five zones in the Lansing-Kansas City in which the porosity is variable, primarily associated with oölitic limestones (McCoy, 1965). The large Wil field in Edwards County contains a Missourian pay zone in the Kansas City Group, a porous, fossiliferous, oölitic limestone situated on a local structural closure (McCaleb and Wheeler, 1965). The Pleasant Prairie field is a large anticlinal trap covering parts of Finney, Kearney, and Haskell counties. Oölitic limestone lenses associated with carbonate buildups which cross these and other structures in the area are locally productive (Roby, 1959; Brown, 1984). Eubank field in Haskell County (Fugitt and Wilkinson, 1959) has multiple pays of this type located on a strong north-south anticlinal trend. A half-dozen Lansing-Kansas City oölitic and grainstone reservoirs produce from intervals that locally thicken over the structure. The general patterns in thickness do not correlate with structure (Brown, 1963).

Cahoj field in Rawlins County in northwestern Kansas produces from all carbonate zones in the Lansing and Kansas City groups at varied locations in the field. Cahoj is situated on a well-defined structure with an excess of 25 ft of closure on the top of the Lansing Group. Oil production is not confined to structural closure but follows divergent porosity development in carbonate rock in flank positions. Early structural deformation apparently produced topographic relief which substantially influenced both depositional environments and early diagenesis (Watney, 1980).

The Wilsey-Wilde gas area in Morris County in eastern Kansas produces from multiple zones including an oölitic limestone in the Lansing-Kansas City on a structural closure over the Nemaha uplift (Smith, 1960). The Davis Ranch pool in Wabaunsee County is an anticlinal closure in the Forest City basin discovered by surface mapping. It is a multi-pay field including one limestone zone from within the Lansing-Kansas City Group (Smith and Anders, 1951).

Missourian oil and gas fields are distributed widely across southwest Nebraska (DuBois, 1985; Prather, 1985), Kansas, Oklahoma, and Texas. These accumulations are in structural, stratigraphic, and combination structural-stratigraphic traps developed in a variety of rocks, including sandstone, carbonate, and granite wash (Rascoe and Adler, 1983).

Pure stratigraphic traps have been found in the Missourian section, but these are small and thus far insignificant to overall production. Abbyville field in Reno County is a one-well field with a single pay zone in oölitic limestone in the lower Kansas City that is neither structurally high or low. It was discovered by random drilling (Anonymous, 1956). A concerted effort to understand the regional deposition and diagenesis of the carbonate-reservoir rocks may reduce the risk in the search for stratigraphic plays in this region.

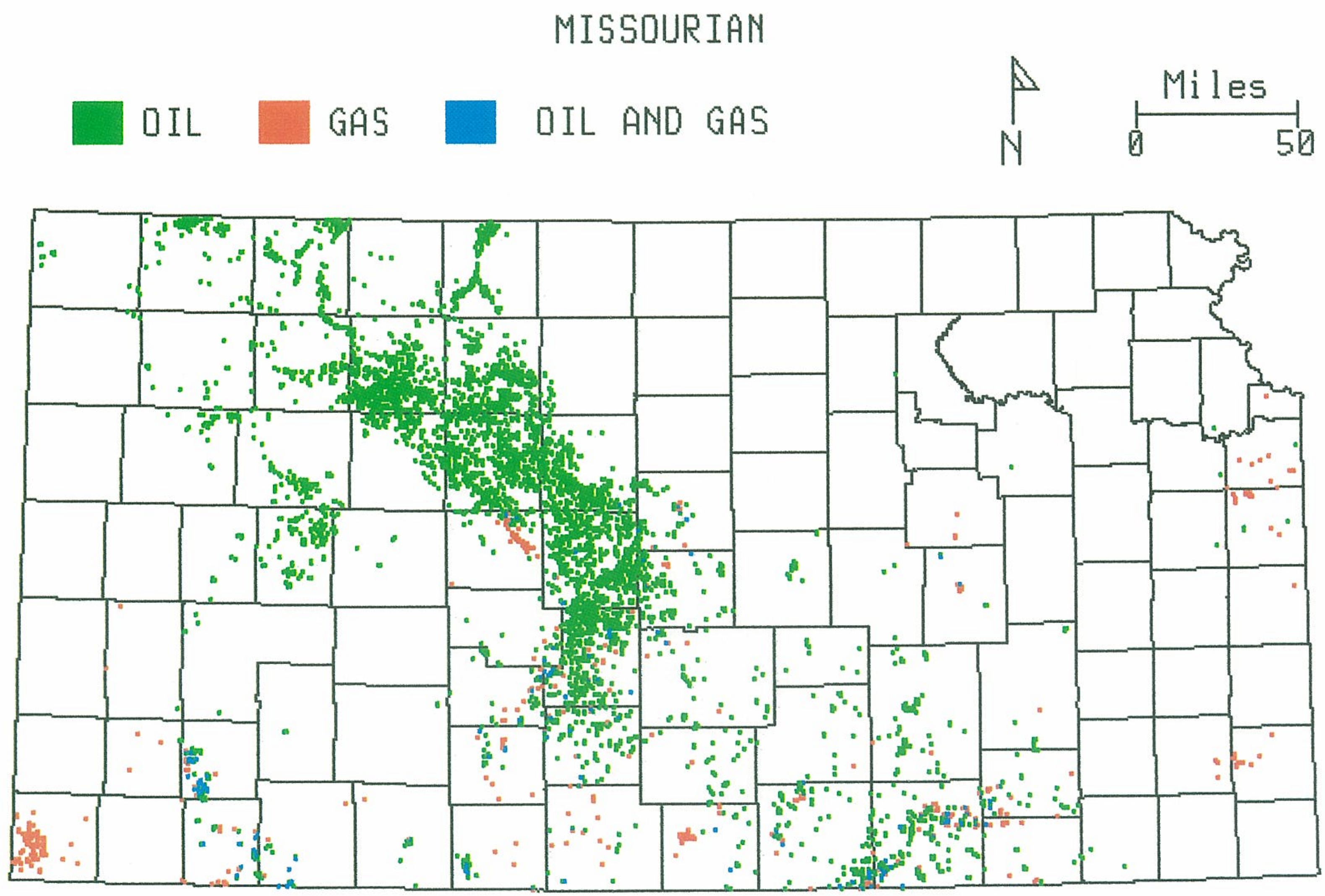


FIGURE 23—Lansing, Kansas City, and Pleasanton production.

Douglas, Shawnee, and Wabaunsee
(Virgilian, Upper Pennsylvanian)

The distribution of oil and gas fields in the Virgilian-stage strata is similar to Missourian strata below and is associated with major structural features such as the Central Kansas uplift, the Pratt anticline, and restricted portions of the Nemaha uplift (figure 24). Scattered fields are present in the Sedgwick basin and western Kansas, and a large gas area occurs in Morton County. Oil production is concentrated over the northern Central Kansas uplift.

The Virgilian Stage, comprising the Douglas, Shawnee, and Wabaunsee groups, is composed of cyclic limestones, shales, and minor sandstones and coal. The carbonate reservoirs of the Shawnee and Wabaunsee groups are predominately shallowing-upward, regressive limestones producing primarily from the Toronto, Topeka, and Howard limestones. The sandstones are generally lenticular and are thickest in southern and southeastern Kansas. The Douglas Group is primarily shale with intervals of sandstones and thin limestones, thickening from less than 50 ft (15 m) in northwest Kansas to greater than 400 ft (120 m) in southeast Kansas (Jewett and others, 1968). The depositional environments change from predominately marine in western and central Kansas to marginal marine in southern and southeastern Kansas and eventually to fluvial in central Oklahoma (Ball, 1964). Thick sandstones in central Kansas pinch out northward onto a marine shelf in the western Sedgwick basin and provide for notable stratigraphic traps.

The Greenwood gas area in Morton County is a structural-stratigraphic trap that produces on the northeast flank of the Cimarron arch where porous carbonate grainstones and oölites pinch out into nonporous carbonate and clastic rock (Wingerter, 1959, 1968). Seventeen different limestones in the Wabaunsee and Shawnee groups produce in over 250 wells from this third-largest gas field in the state. Several other notable stratigraphic traps involve the updip pinch out of sandstones in the Douglas Group, including the Rhodes field in Barber County discovered by core drilling (Clark, 1956) and the Whelan pool, also in Barber County, which produces from the Elgin Sandstone Member of the Shawnee Group. Unlike the Rhodes field, the Whelan pool was discovered by random drilling (Brewer, 1956). The Nurse field in Barber County and the Lerado pool in Reno County are combination structural-stratigraphic traps caused by a pinch out of Douglas sandstone over the crest of an anticlinal closure (Douglass, 1956; Steincamp, 1965). An extensive "Stalnaker" sandstone which grades northward into shale along a zone from Harper, Kiowa, Sedgwick, Cowley, and Chautauqua counties has provided many opportunities for gas accumulation such as that described for Sullivan field in Harper County (Walton and Griffith, 1985).

The Lerado pool in Reno County produces from Langdon and Indian Cave sandstones of the Wabaunsee Group in addition to Douglas sandstone. The Howard and Topeka limestones locally produce oil from structures on the Cambridge arch in northwest Kansas such as at the Jennings field in Decatur County. The Toronto Limestone Member has continued to be an important oil-producing interval on anticlinal closures in southwestern Kansas, such as the Holt field in Seward County (Jacques, 1959).

Eighteen percent of the ultimate gas production from all Pennsylvanian fields in the Midcontinent will likely come from just two large Virgilian stratigraphic traps: the Greenwood and the Mocane-Laverne gas areas in the Oklahoma Panhandle (Rascoe and Adler, 1983). Stratigraphic traps will also be important finds in the future for the carbonate reservoirs of the Shawnee and Wabaunsee groups, but will likely remain secondary in importance to the more oil-prone, older Pennsylvanian targets. Sandstones in the Douglas Group will continue to be important producing intervals in south-central Kansas. Regional studies using core and log interpretation will help to identify favorable trends for exploration not apparent today.

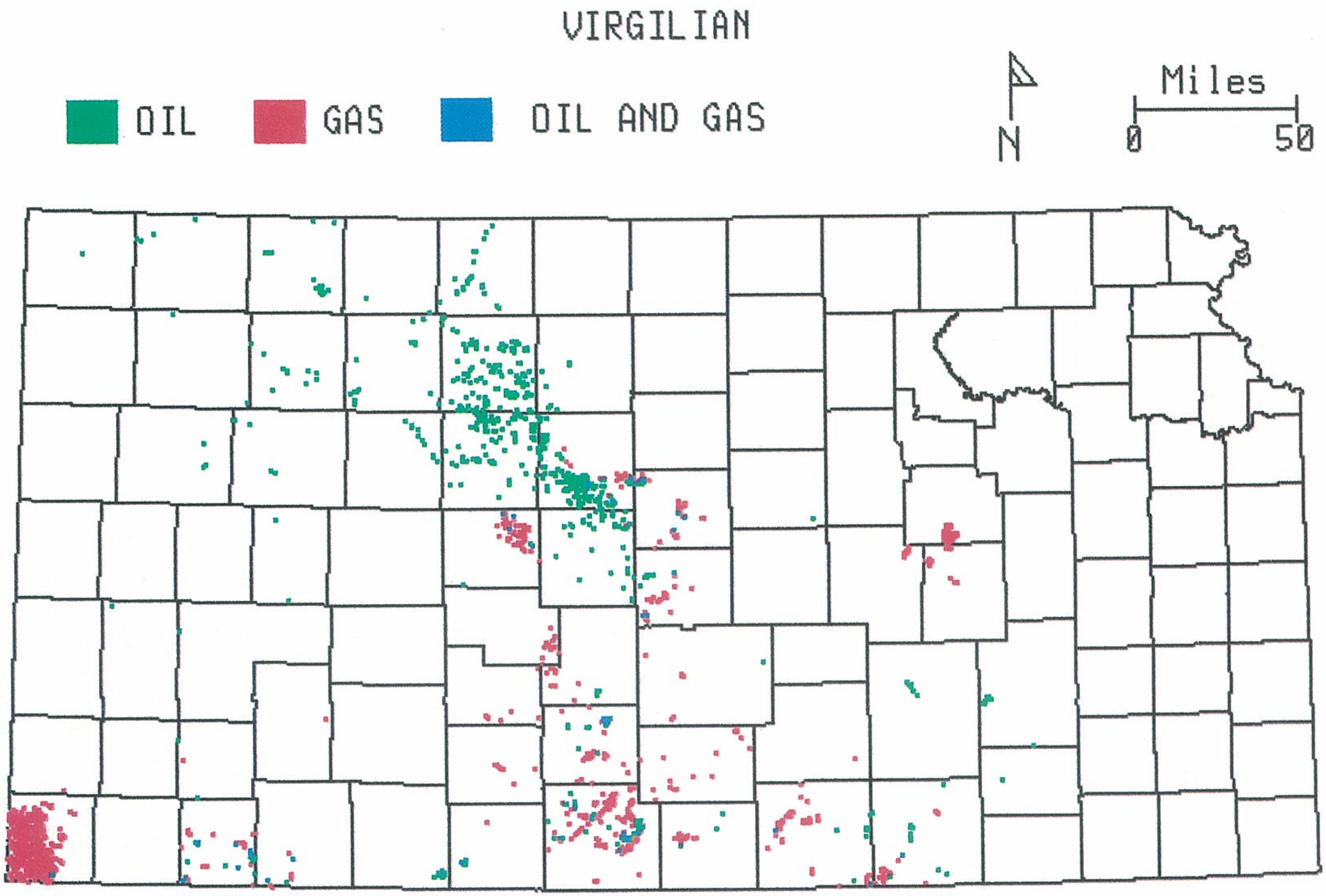


FIGURE 24—Douglas, Shawnee, and Wabaunsee production.

Admire, Council Grove, Chase, and Sumner
(Permian)

Permian strata serve as reservoirs for one of the largest gas accumulations in the western hemisphere, in the Panoma and Hugoton gas areas in southwestern Kansas (figure 25). These fields produce from the Council Grove or Chase groups, respectively. Small shallow Permian gas fields are also scattered across the southern Central Kansas uplift, Pratt anticline, over limited portions of the Nemaha uplift, and on local anticlines in the Sedgwick and southern Salina basins from the Chase, Council Grove, and Admire groups. Isolated occurrences of oil production are found on the Nemaha and Central Kansas uplifts, and in west-central Kansas from reservoirs in the Admire Group.

The Permian System of Kansas is a thick stratigraphic interval. It crops out at the surface along nearly a north-south line in eastern Kansas and reaches a thickness in excess of 3,500 ft (5,600 m) in southwestern Kansas (McKee and others, 1967). The Permian is divided from bottom to top into the Admire, Council Grove, Chase, Sumner, and Nippewalla groups (O'Connor and others, 1968). The Lower Permian Gearyan Stage, consisting of the lower three groups, accounts for essentially all of the reported Permian gas and oil production (figures 26, 27, and 28). A small amount of Sumner gas has been produced from Russell County on the Central Kansas uplift and scattered wells in southwestern Kansas (figure 29). The Hollenberg limestone of the lowermost portion of the Sumner Group has reported gas shows and may be locally producing in the Hugoton gas area (Paul, personal communication, 1986). The strata from the lower, most productive three groups are cyclic deposits of marine limestones, dolomites, and shales and nonmarine red silty shales and mudstones deposited during the waning stages of repetitive marine inundation of the Midcontinent during the late Paleozoic Era.

Reservoir-quality rocks in the Permian strata are commonly the uppermost, dolomitized regressive carbonates of each repetitive sequence. Secondary porosity such as skeletal and anhydrite molds, vugs, and intercrystalline porosity between dolomite crystals is most common and results in low, irregular permeability. These carbonate-dominated marine deposits are overlain and grade westward into continental red-bed clastics. This transition causes a porosity pinch out in western Kansas resulting in large stratigraphic traps in the giant Hugoton (Chase) and Panoma (Council Grove) gas areas. The Hugoton field is the largest gas accumulation in the western hemisphere (Hemsell, 1939; Page, 1940; Hinton, 1952; Kleen, 1956; White, 1981; Abdullah, 1983; Rascoe and Adler, 1983). The Hugoton stratigraphic trap may also be assisted by an east-directed hydrodynamic flow (Mason, 1968; Pippin, 1970). The Hugoton-Panhandle gas area of Kansas, Oklahoma, and Texas covers some 5 million productive acres from which an estimated 76.5 trillion ft^3 of gas will be ultimately produced. The combined thickness of the pay zones within the Chase Group averages 50-60 ft (15-18 m) in the Hugoton gas area of Kansas (Furbush, 1959). Gas accumulations in the Council Grove Group are scattered across western Kansas but are concentrated in the Panoma field which underlies Hugoton, but extends farther to the west (figure 27).

Shallow buried dolomite reservoirs of the Chase Group in central Kansas, such as in Rice County, result from secondary porosity in dolomitized limestone. Best porosity occurs in local accumulations of grain-supported carbonates where skeletal grains are dissolved (Glossa, 1982). The occurrence of this improved porosity appears to be closely related to structural highs (figure 28). Shallow Permian gas production also occurs in central Kansas in the Indian Cave sandstone of the Admire Group in similar positions on the crests of structures (figure 26). The Wilde, Wilsey, and Alta Vista fields in Morris and Chase counties produce from the Indian Cave sandstone in the Admire Group in structural-stratigraphic traps along the crest of the Nemaha uplift (Merriam, 1960; figure 26).

Outside of the giant-sized oil accumulation in the Panhandle field in the Texas panhandle, the Permian strata should continue to provide small, shallow gas reservoirs including bypassed and overlooked zones on structures with established deeper pay zones. Gas detection, readily available today but not originally used in early drilling, should provide many opportunities for additional gas reserves in central and western Kansas. The price and market for natural gas will determine the feasibility of this development.

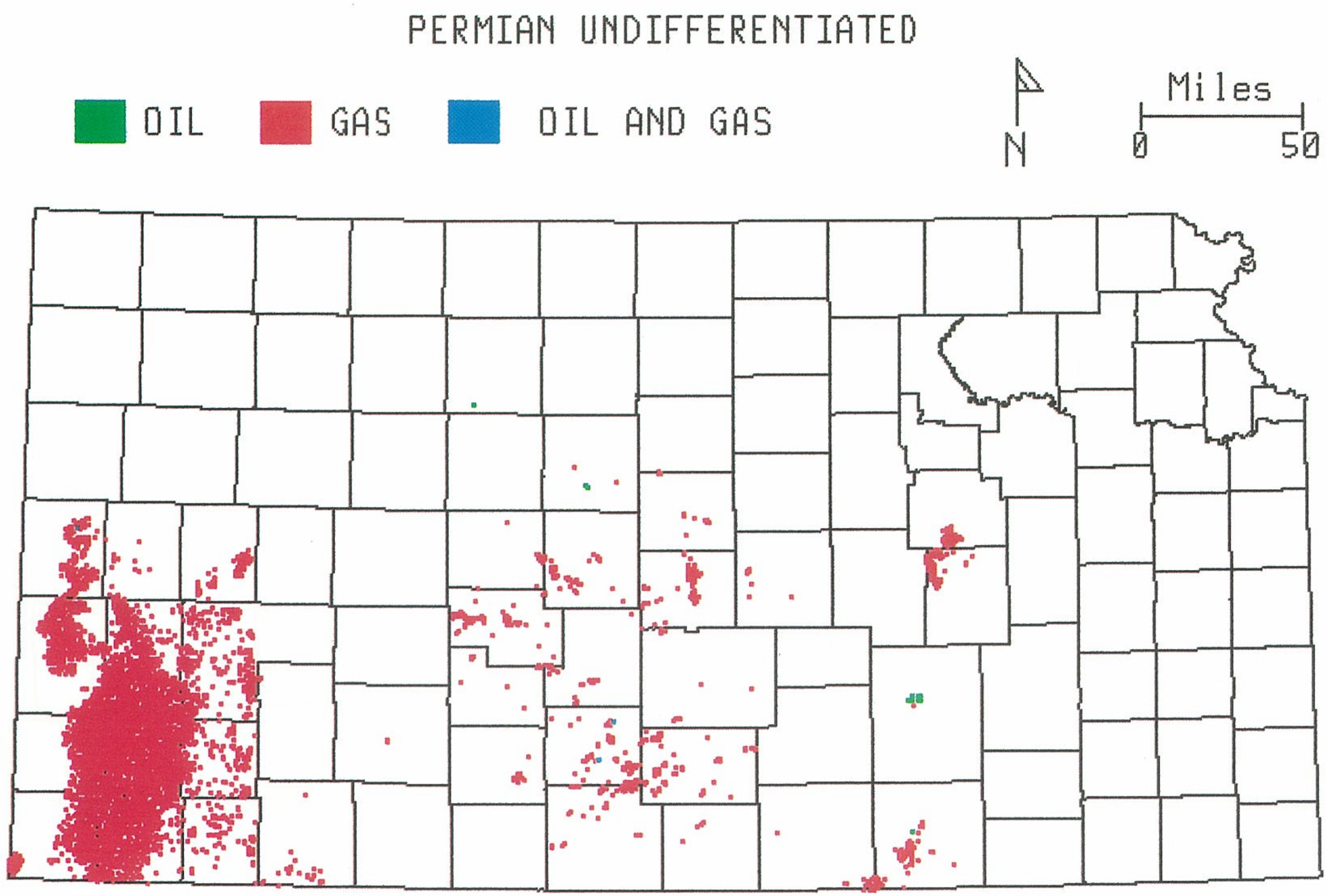


FIGURE 25—UNDIFFERENTIATED PERMIAN PRODUCTION.

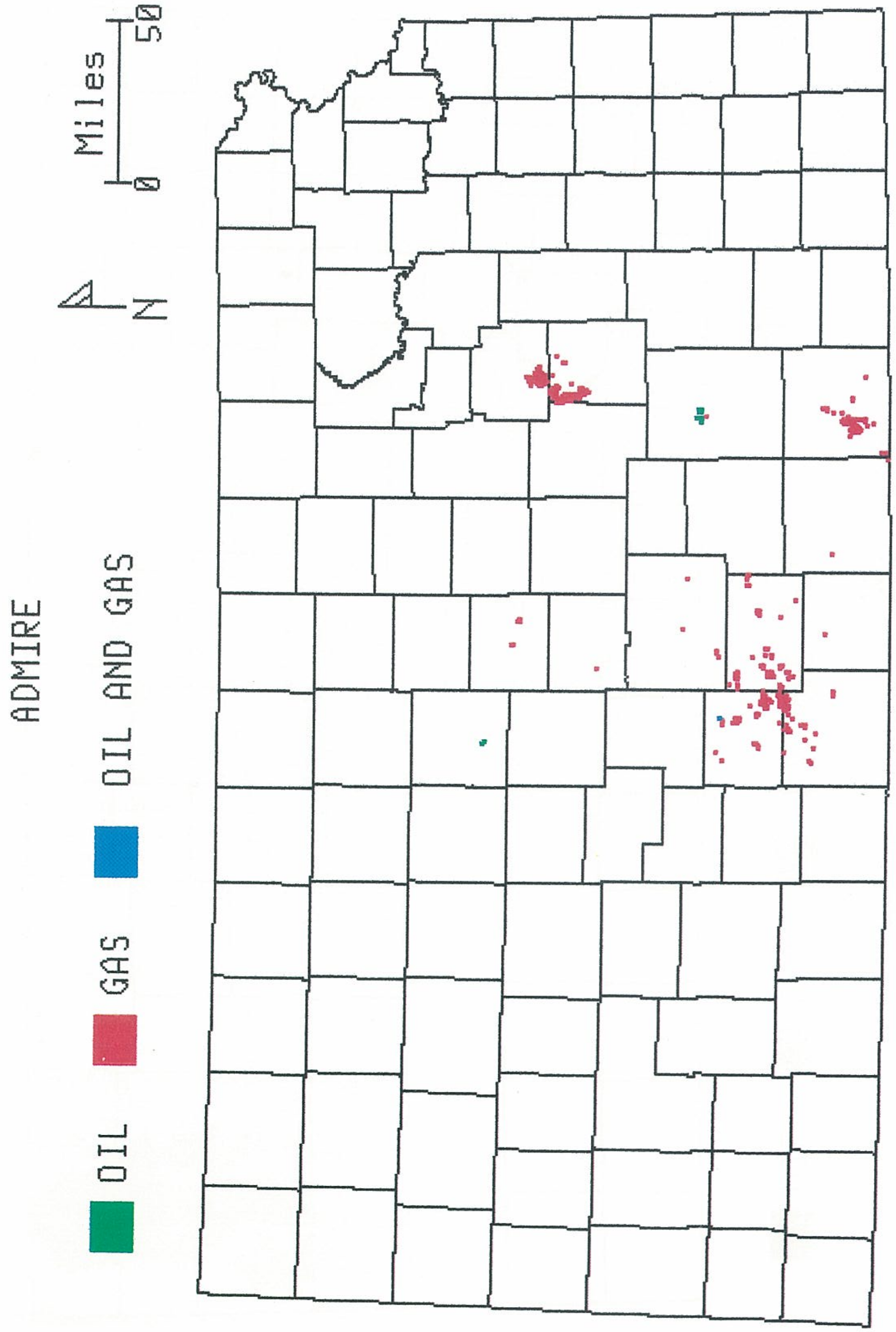


FIGURE 26—ADMIRE PRODUCTION.

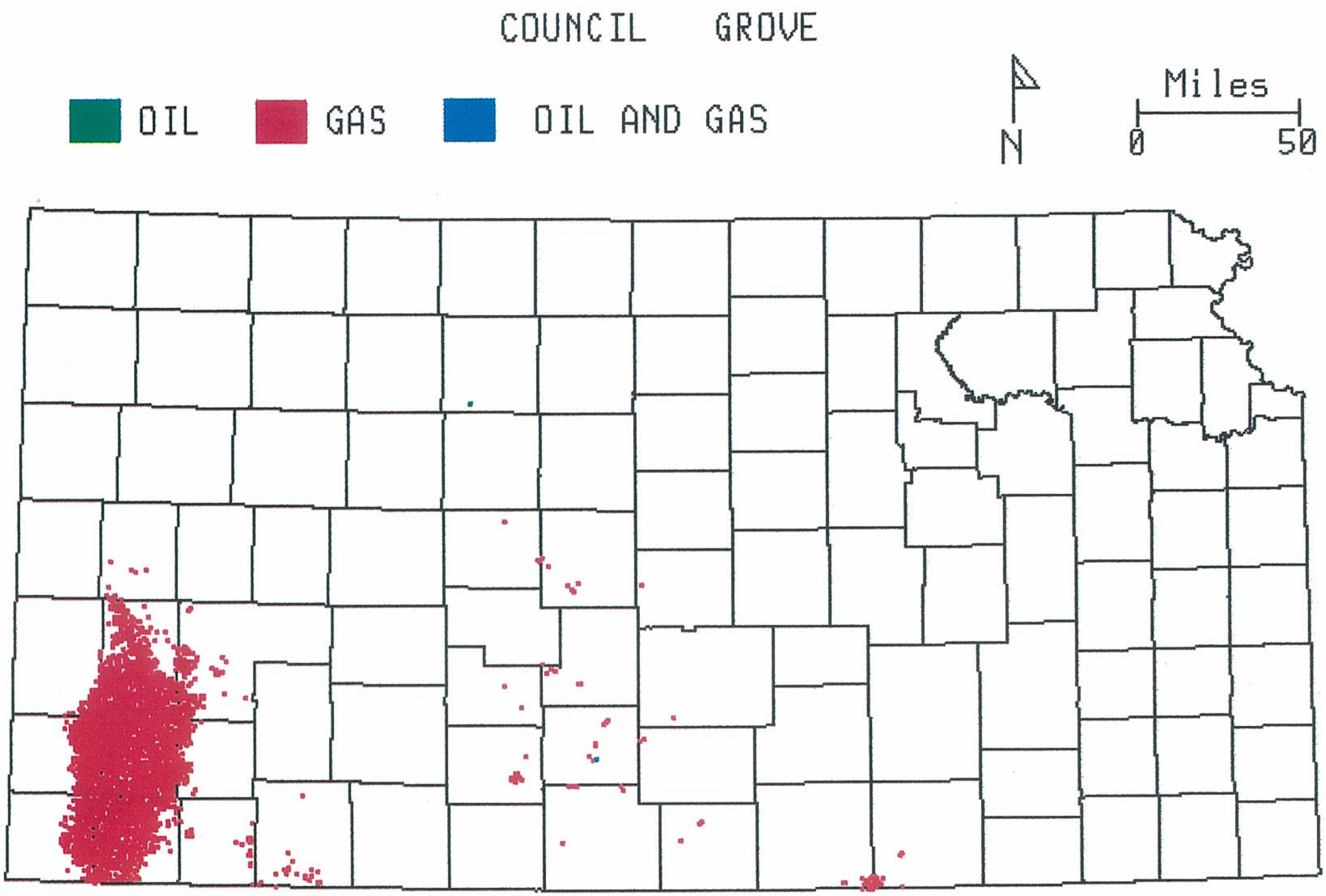


FIGURE 27—COUNCIL GROVE PRODUCTION.

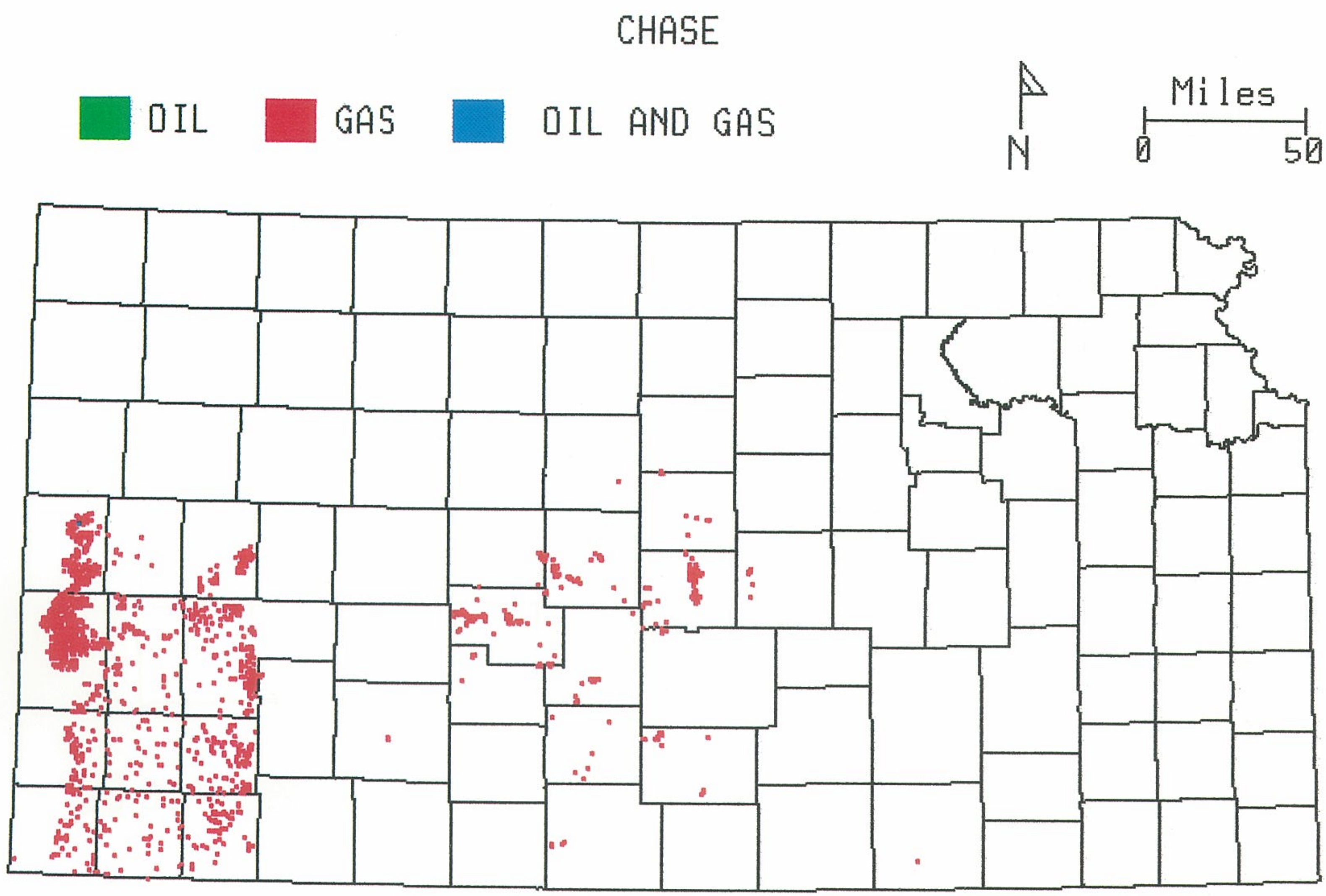


FIGURE 28—CHASE PRODUCTION.

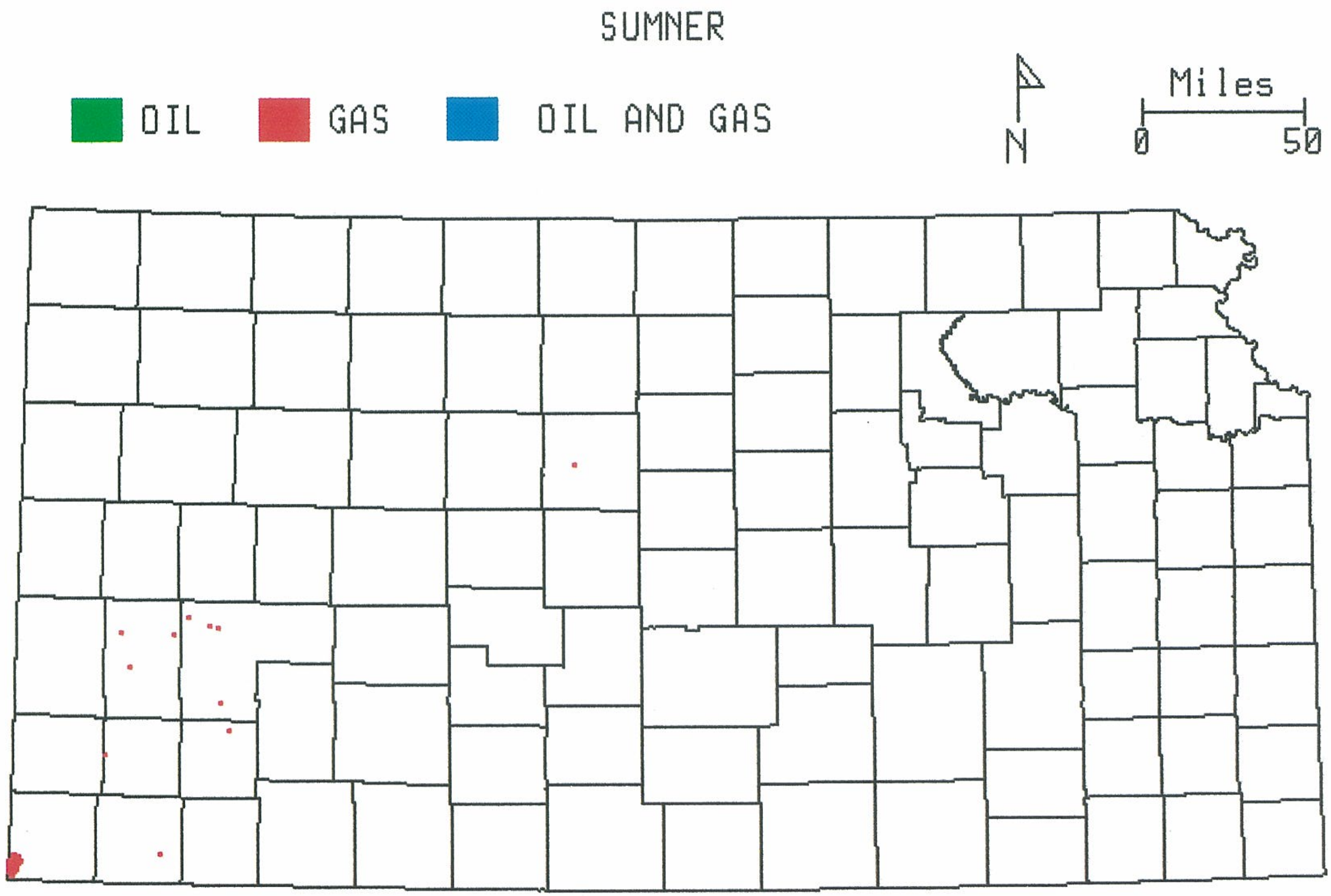


FIGURE 29—SUMNER PRODUCTION.

Niobrara
(Mesozoic)

The Upper Cretaceous chalks of the Niobrara Formation account for virtually all the Mesozoic gas production (figure 30); a single exception being an abandoned well that produced gas in western Sheridan County from the Codell sandstone member of the Carlile Shale which immediately underlies the Niobrara. Niobrara production in Kansas is presently limited to a small area in northwestern Kansas, including Cheyenne, Rawlins, Sherman, Thomas, Sheridan, Wallace, and Logan counties. The porous chalk that constitutes the reservoir rock was deposited during a major transgression of the sea. The Niobrara Chalk is divided into two members—the Fort Hays Member and the overlying Smoky Hill Member (O'Connor, 1968). The Fort Hays Member, named after an area of outcrop in central Kansas, is a clean chalk averaging 40-85 ft (12-25 m) thick. The most productive gas zones are in the Smoky Hill Member, which is also referred to as the Beecher Island Zone. The Smoky Hill Member averages some 600 ft (180 m) in thickness (Hattin, 1981).

The gas in the Niobrara is biogenic, having formed at temperatures less than 75° C by anaerobic-bacterial decay of organic matter apparently indigenous to the Niobrara itself (Rice and Claypool, 1981). Active exploration for these gas deposits has included eastern flanks of the Denver basin, immediately east of the Rocky Mountains and the Los Animas arch in eastern Colorado, and along the Chadron-Cambridge arch in northwest Kansas, northeast Colorado, and western Nebraska.

Late Cretaceous and Early Tertiary deformation associated with the uplift of the Rocky Mountains produced many small faults and low-relief anticlines and domes which led to gas entrapment (Brown and others, 1982). Although the chalk is highly porous, it has very low permeability. However, the chalk is brittle and it fractures during folding and faulting, thereby enhancing its reservoir characteristics. The gas accumulations are therefore primarily in structural traps with rates of production strongly controlled by local fracturing. Matrix porosity in chalks varies directly with depth. Porosities over 40% are present at the shallow depths in Kansas and contribute favorably to reservoir development (900-1,200 ft [275-375 m]; Lockridge and Scholle, 1978). Hydraulic fracturing with foam during well completion has significantly improved the recovery and economics of the Niobrara reservoirs (Hanley and Van Horn, 1982).

Natural gas was discovered in the Niobrara near Goodland, Kansas, in 1912, which led to the development of the Goodland gas area. With rising gas prices and the new foam-fracture stimulation in the mid-1970s, a flourish of discoveries occurred as small fields throughout northwest Kansas and adjacent areas in Colorado and Nebraska were developed (Brown and others, 1982). Exploration has been limited to areas of shallow burial where matrix porosity is high. Additional exploration and development of these shallow gas deposits will be encouraged with a favorable price and market for the gas.

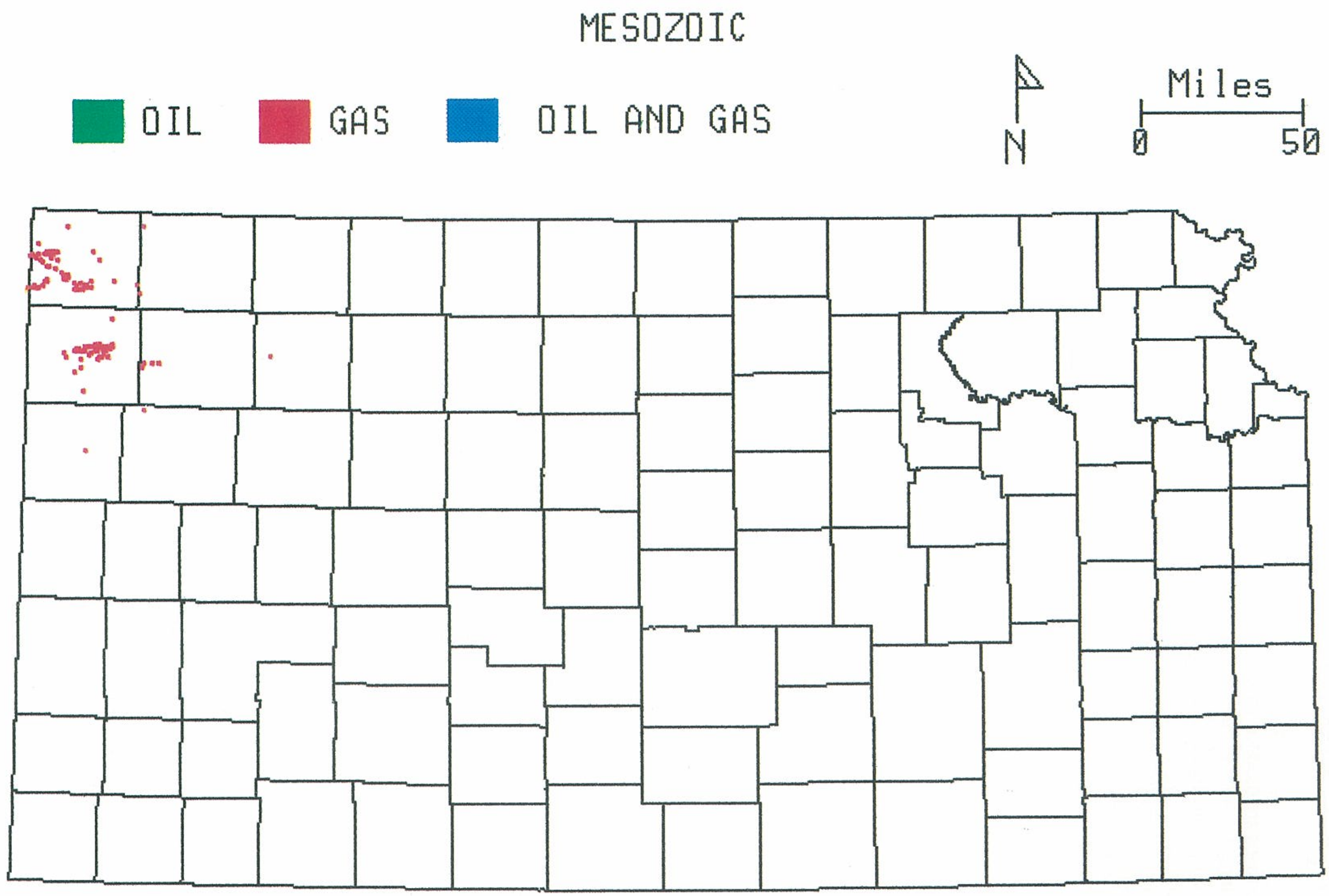


FIGURE 30—NIOBRARA PRODUCTION.

Number of producing zones per 1/4 township

Three maps are used to summarize the number of locally producing pay zones in the state; these maps are the number of oil-producing zones (figure 31), the number of gas-producing zones (figure 32), and the total number of producing zones regardless of whether they produce oil or gas (figure 33). About one-half of the 3,900 producing fields in the state are single-pay fields. These fields account for about one-fifth of the cumulative production in Kansas (Ebanks, 1975). All major fields in Kansas have multiple pay zones; however, one is usually more important than the others (Merriam and Goebel, 1959). Several fields with multiple zones are on the Central Kansas uplift. Other areas with several pay zones, either stacked atop each other in a single field or in close geographic proximity to each other in separate fields, include the Pratt anticline, the Hugoton basin in the vicinity of Seward and Meade counties, and the Nemaha uplift in the vicinity of Butler and Cowley counties. Gas-producing areas are largely limited to the south-central and southwestern part of the state, with minor production also extending up through eastern Kansas. The maximum number of gas pay zones producing in close proximity to each other (figure 32), like the maximum number of oil pay zones (figure 31), are located over the Pratt anticline in south-central Kansas. In areas such as the Pratt anticline, the Sedgwick basin, and Cherokee basin, gas production is generally spatially coincident and associated with oil production. Gas production dominates in the Hugoton embayment while oil production is more prevalent in the central and northern reaches of the Central Kansas uplift.

The maps showing the number of producing zones were produced by a computer search that counted the number of pay zones in each well in the data base and added this total to other zones counted in any wells within a distance of 3 mi (an area approximately equal to 1/4 township). A maximum number of 12 producing zones are possible at any given locality. These zones correspond to the individual pay zones in this report. The Arbuckle and sub-Arbuckle zones were combined as a single zone for this computer search, as were all the Permian zones.

Many factors may influence the pattern on these maps. For example, some fields may have a pay horizon developed as a weathered zone beneath an unconformity. If this unconformity is an angular unconformity such as the sub-Pennsylvanian unconformity, several units may crop out beneath the unconformity. If these units produce oil along the unconformity, each of them would probably be reported as an individual producing zone, even though, in reality, the field consists of only one weathered, porous zone that transects several separate units. The El Dorado field in Butler County is susceptible to this type of counting error in that the Stapleton zone, a major pay horizon in this field, is partly a weathered zone developed underneath the sub-Pennsylvanian unconformity. The Arbuckle, Simpson, and Viola all crop out beneath this unconformity and produce oil and are counted as three separate zones. However, instead of being three separate producing zones, they are in effect only components of a single zone.

Several productive zones could also be counted as only one of the pay zones in this report. The pay-zone categories used in this report may comprise a considerable thickness of strata, and several potential reservoir units could be productive within each of these intervals. For example, the Lansing Group, which is included as a Lansing-Kansas City-Pleasanton pay zone in this report, can contain several separate pay zones within it. However, regardless of how many Lansing pay zones an individual well may pump, the computer search would only recognize them as a single Lansing-Kansas City-Pleasanton pay zone. This situation occurs on the Central Kansas uplift, where numerous fields commonly contain several stacked Lansing-Kansas City pay zones. Similarly, several separate Cherokee shoestring sandstone bodies could produce oil in a given field in eastern Kansas, but in the data base these zones would be categorized only as undifferentiated Cherokee-Marmaton production.

The number of pay zones in a given area is not only a function of the geology and computer-search technique but also of the exploration maturity of an area. A greater number of pay zones would be expected in more densely drilled areas because there would be less chance of minor pay zones being overlooked. Optimistically, several recently discovered fields with only one pay zone will, with time, have new pay zones discovered either by deeper drilling or by outpost, infill, and other nearby exploratory or production drilling. Exploration activities concentrated along trends defined by the number of pay zones may possibly prove fruitful, particularly if a trend appears "underdeveloped" (i.e. with relatively few pay zones) compared to other nearby trends.

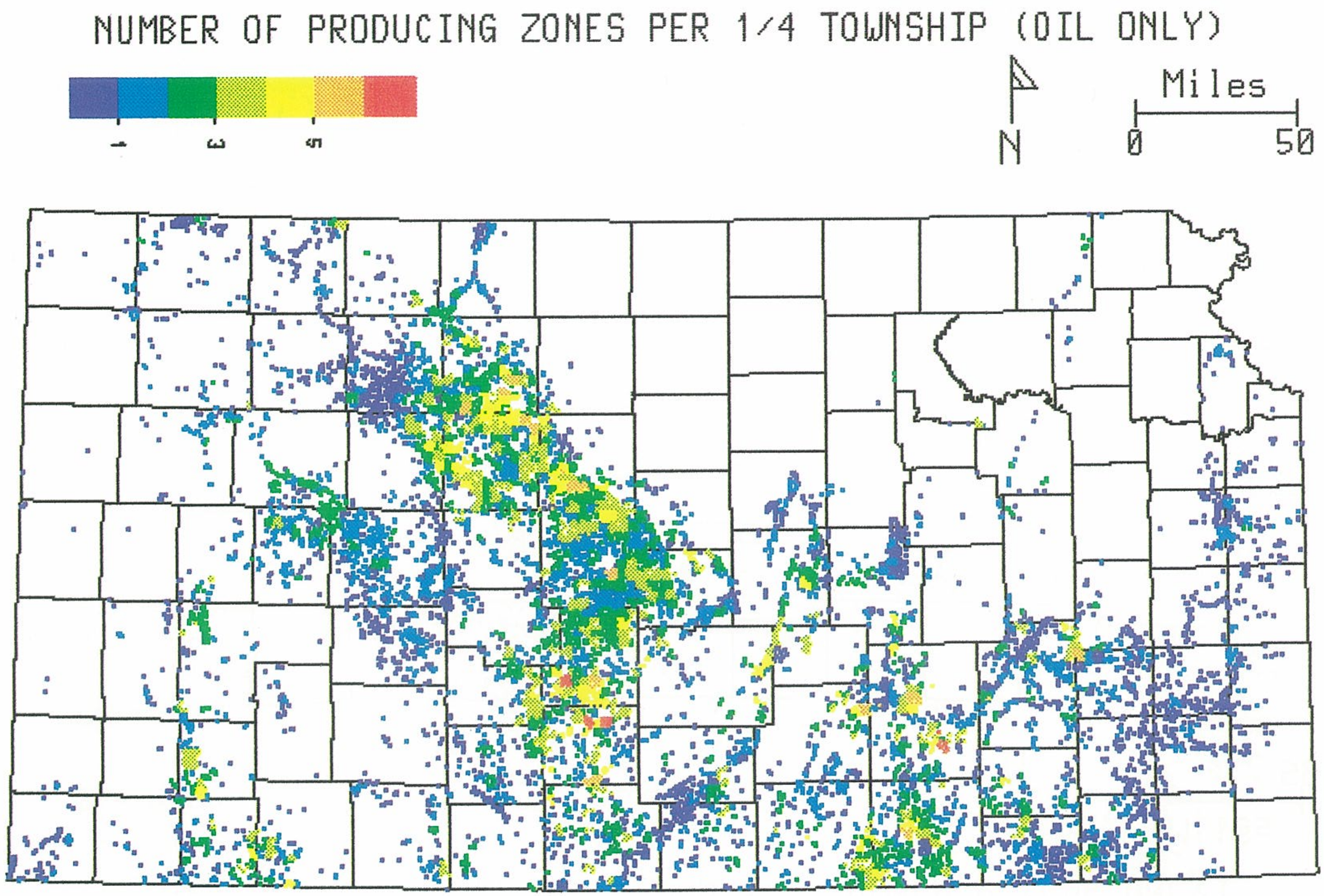


FIGURE 31—NUMBER OF PRODUCING ZONES PER 1/4 TOWNSHIP (OIL ONLY).

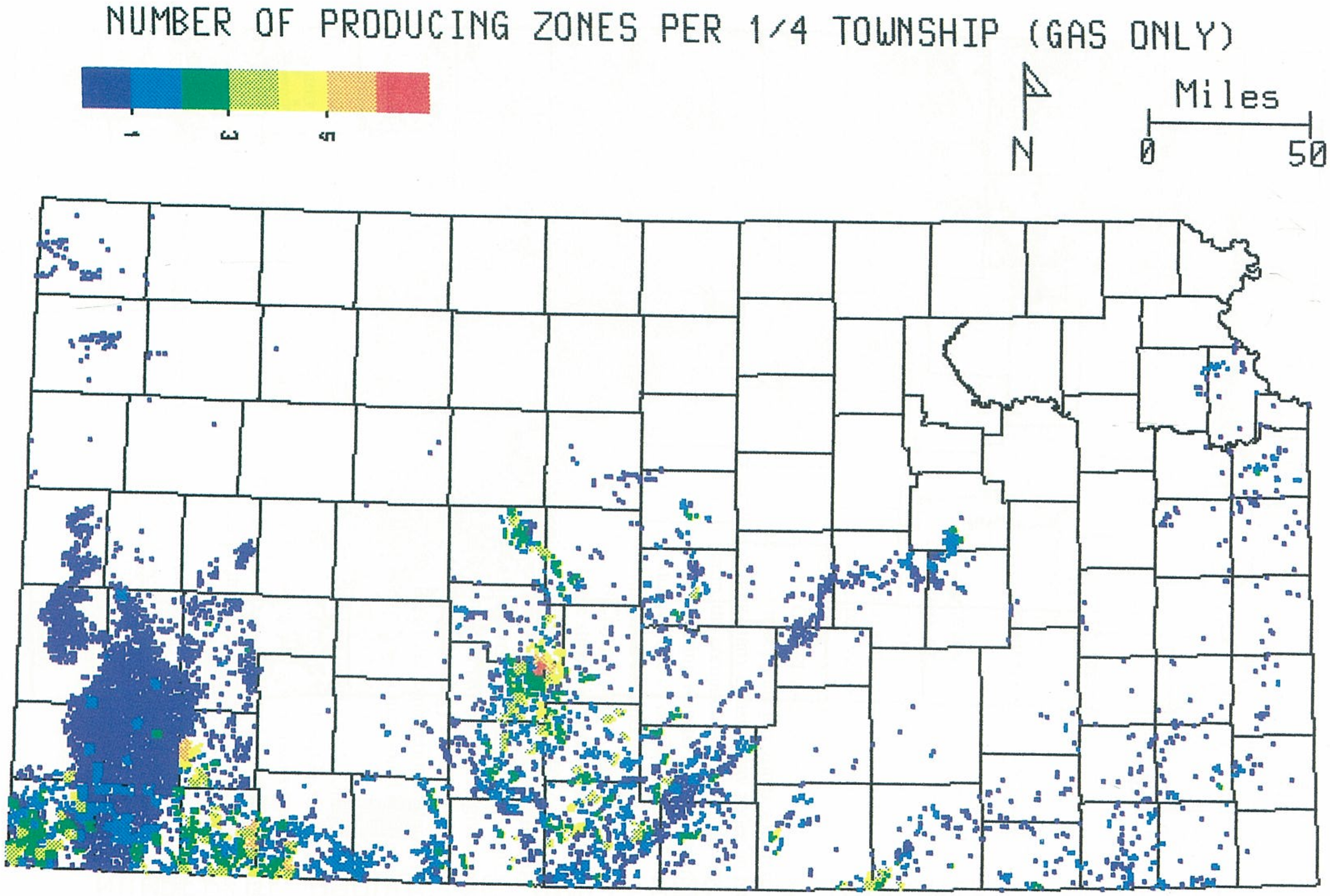


FIGURE 32—NUMBER OF PRODUCING ZONES PER 1/4 TOWNSHIP (GAS ONLY).

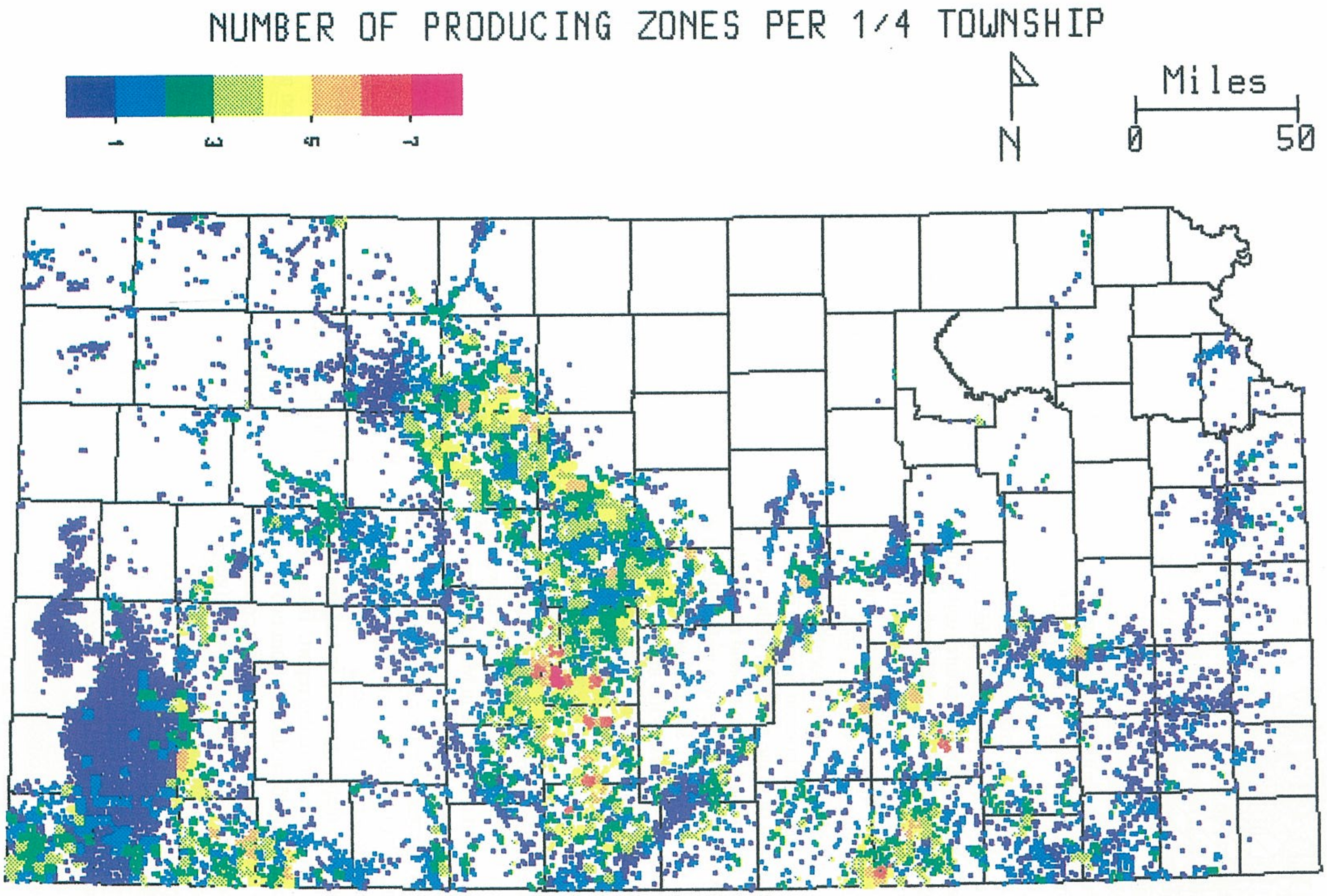


FIGURE 33—NUMBER OF PRODUCING ZONES PER 1/4 TOWNSHIP.

Depth of pay zones

Another way to examine oil and gas production in the state is to look at it from the perspective of depth rather than number of producing zones or stratigraphic horizon. Geologic strata can be regionally deformed into basins and uplifts, or locally deformed into anticlines and synclines (figure 34). Therefore, petroleum production from a given pay zone will be found at widely varying depths in different parts of the state.

Both subsurface and subsea depths can be considered when examining petroleum production. Geologists usually map geologic structures using subsea depths, but engineers and investors, who look closely at drilling costs and logistics, are also interested in the depths potential pay zones are below ground level. Conversion between subsea and subsurface depths is simple. A subsea depth for a geologic horizon at a well locality is obtained by subtracting the depth that horizon is below ground level (the subsurface depth) from the elevation of the well (the surface datum). For example, a unit found at a depth of 3,000 ft (915 m) below the surface by a well drilled at a locality 2,000 ft (610 m) above sea level would therefore be at a subsea depth of -1,000 ft (-305 m).

Ground-level elevations in Kansas can be quite variable, but in general, elevations increase westward toward the Rocky Mountains. The highest point in Kansas is Mount Sunflower (4,039 ft; 1,232 m) in Wallace County; the lowest point (approximately 680 ft; 207 m) is along the banks of the Verdigris River where its waters leave the southeast part of the state in Montgomery County. Subsurface depths of a given producing formation will generally increase westward in Kansas due to the general westward tilt of the geologic strata and the general westward increase in surface elevation.

A subsurface map (figure 35) and a subsea depth map (figure 36) are presented in this report. Inasmuch as a well can have commingled production from two or more zones, only the deepest producing zone was considered in generating these maps. The type of production (gas, oil, oil and gas) is not differentiated by color on figures 35 and 36 as they are on the pay-zone maps (figures 13, 15-30). Instead, color is used in the depth maps to correspond to depth intervals, with greater depths corresponding to hotter colors (red, orange, yellow) and cooler colors (purple, blue, green) corresponding to shallower depths.

The map with pay zones displayed according to subsea depths (figure 36) has fewer data points than the map showing subsurface depths (figure 35). The reason for this is that several wells in the data base were reported without their surface elevations from which subsea depths could be calculated. Some interesting features are revealed by comparing the subsurface and subsea depth maps. If subsea depths are considered (figure 36), the deepest production in Kansas is in Meade and Clark counties. However, if subsurface depths are considered (figure 35), the deepest production is farthest west, in Seward and Stevens counties. The reason for this is that Seward and Stevens counties generally have a higher elevation than Meade and Clark counties.

Permian gas production in the Hugoton field in southwestern Kansas is found between +500 and -500 ft below sea level (figure 36). This depth interval is comparable to the subsea-depth interval at which Pennsylvanian oil and gas is found in eastern Kansas. However, the Hugoton production is much deeper when subsurface depths are considered (figure 35). Conversely, the Cretaceous shallow-gas production in northwestern Kansas is comparable to the eastern Kansas Pennsylvanian production when considering subsurface depths. With respect to sea level, however, the northwestern Kansas Cretaceous production is 1,500 ft above sea level, considerably higher than the eastern Kansas production.

In order that the distribution of oil and gas production versus drilling (subsurface) depth (figure 35) can be observed, a series of seven depth-slice maps are presented (figures 37a-43a). Each slice represents a 1,000-ft depth interval. Hydrocarbon-producing wells in this series of maps are color-differentiated with respect to type of production (oil, gas, or oil and gas). The distribution of data points on these maps is both a function of the geologic structure and overlying surface topography. The deepest production in the state occurs in southwestern Kansas in the Hugoton basin. The shallowest production is in eastern Kansas in the Cherokee basin. Another series of depth-slice maps (figures 37b-43b) that categorize production according to geologic horizon are also presented with the production depth-slice maps (figures 37a-43a). Comparison of the two series of maps will help the user identify the type of production in a given area, its approximate subsurface depth, and the producing formation. Such comparisons may be useful to those who may want to quickly evaluate the merits of several different exploration plays in terms of production costs and profitability of oil versus gas.

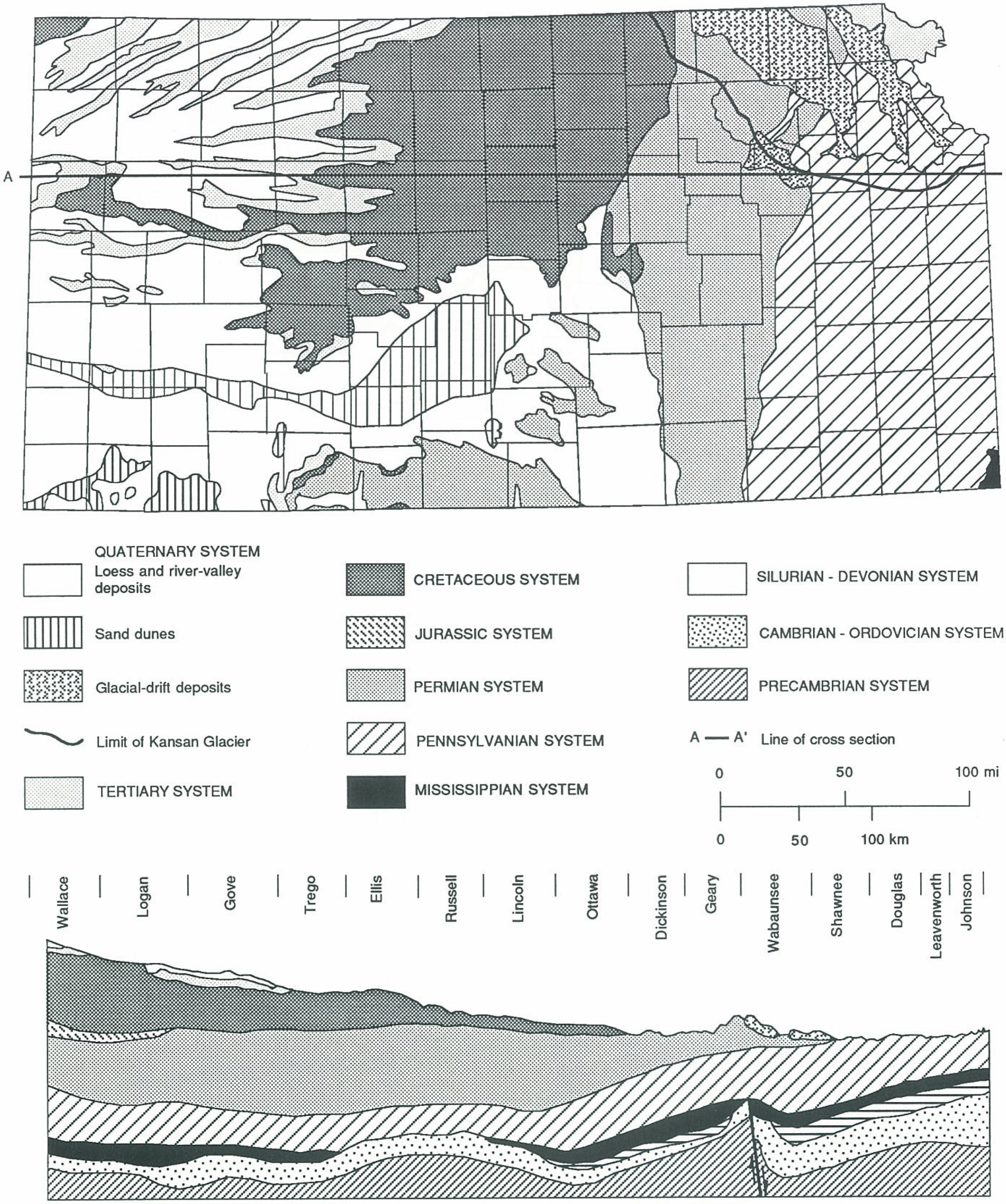


FIGURE 34—Geologic map and cross section of Kansas.

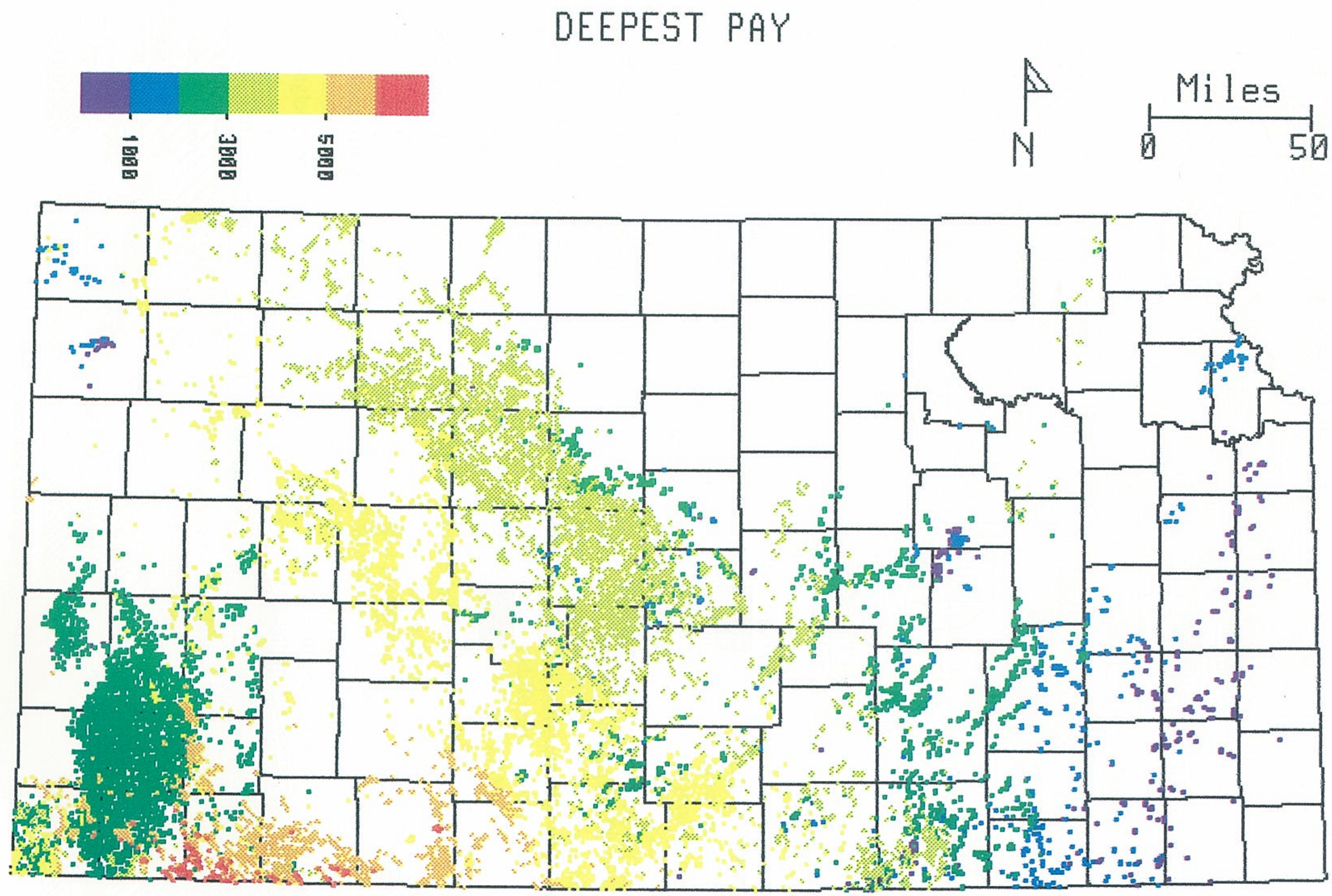


FIGURE 35—DEPTH FROM SURFACE TO DEEPEST PAY ZONE.

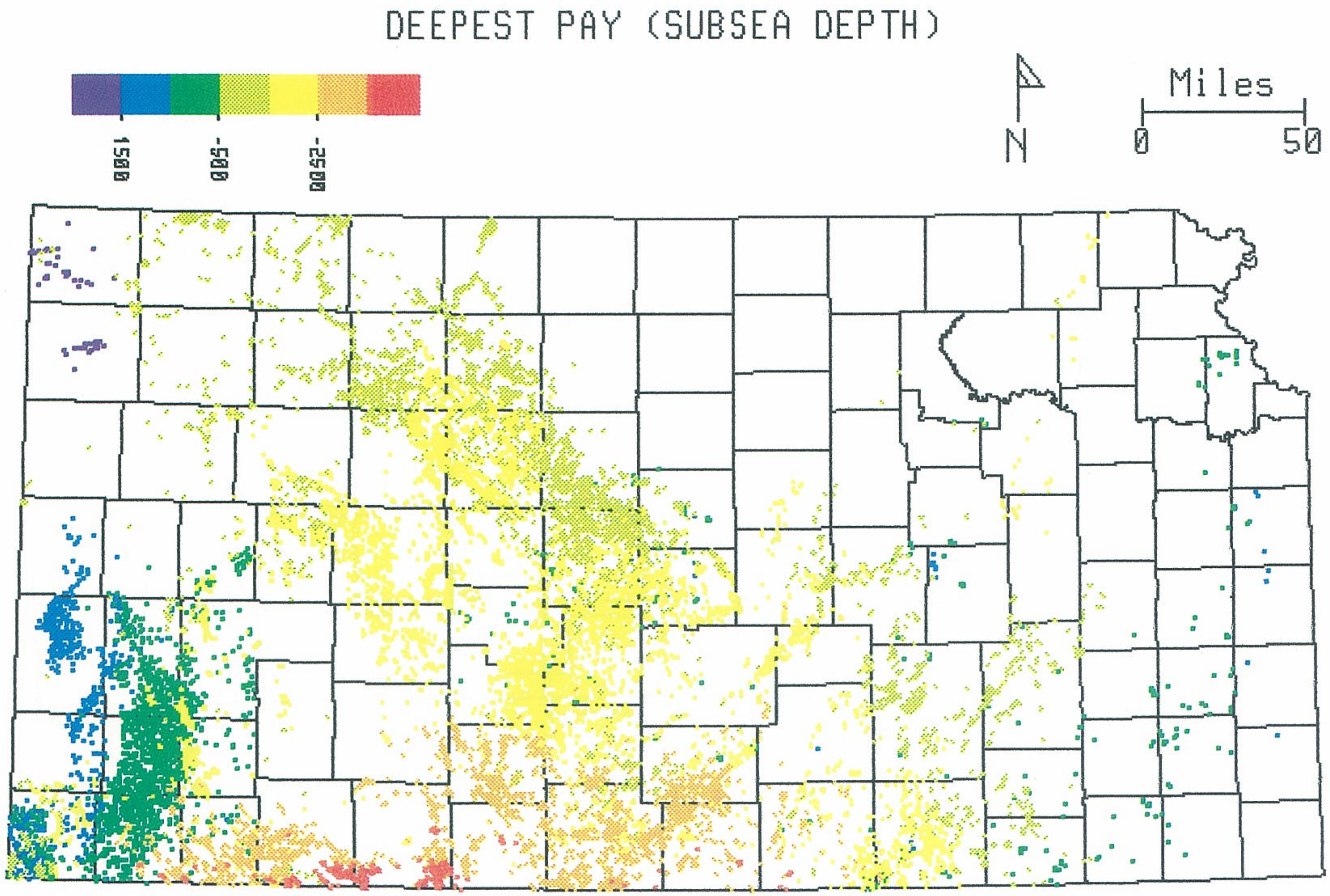
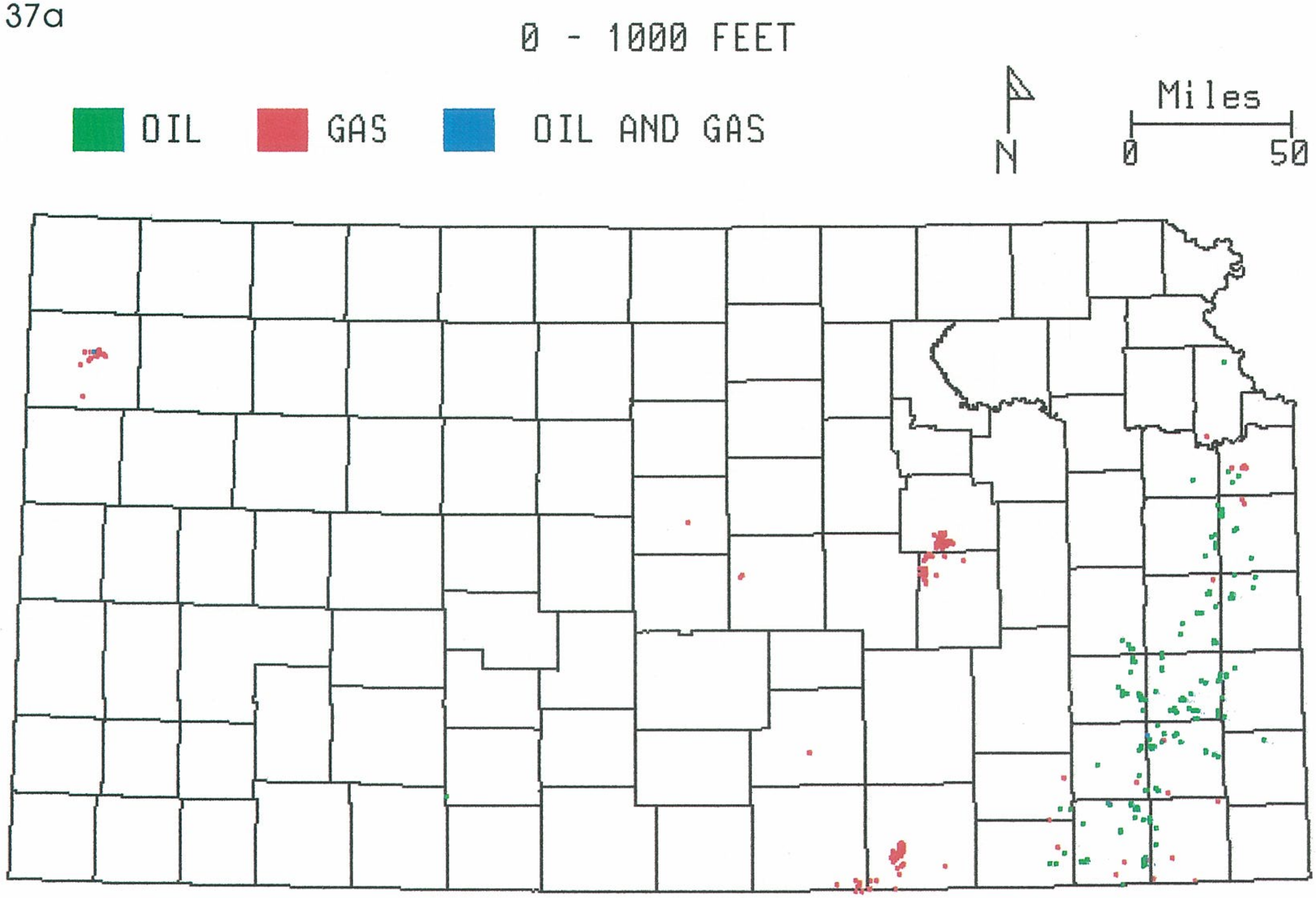


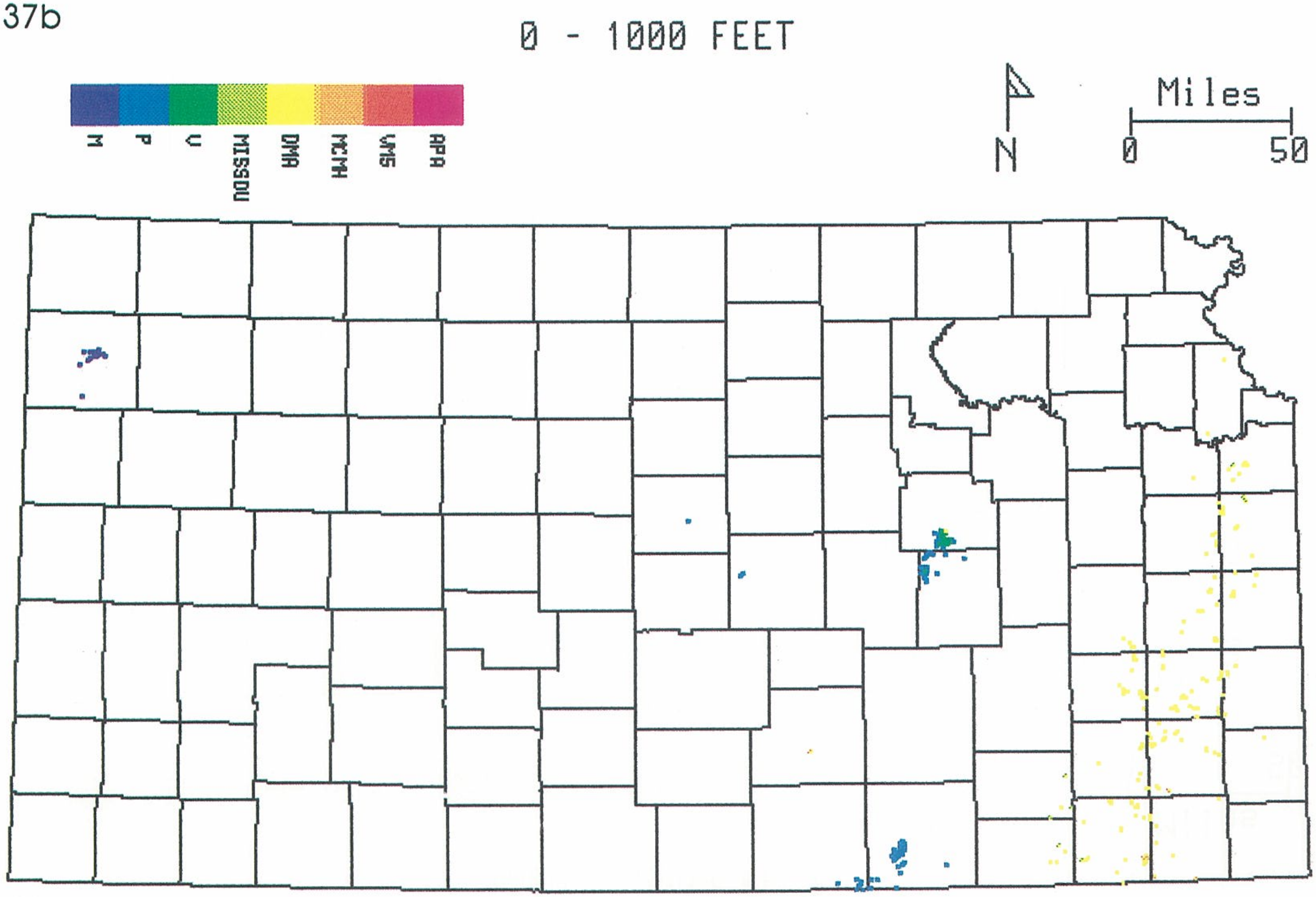
FIGURE 36—SUBSEA DEPTH OF DEEPEST PAY ZONE.

37a



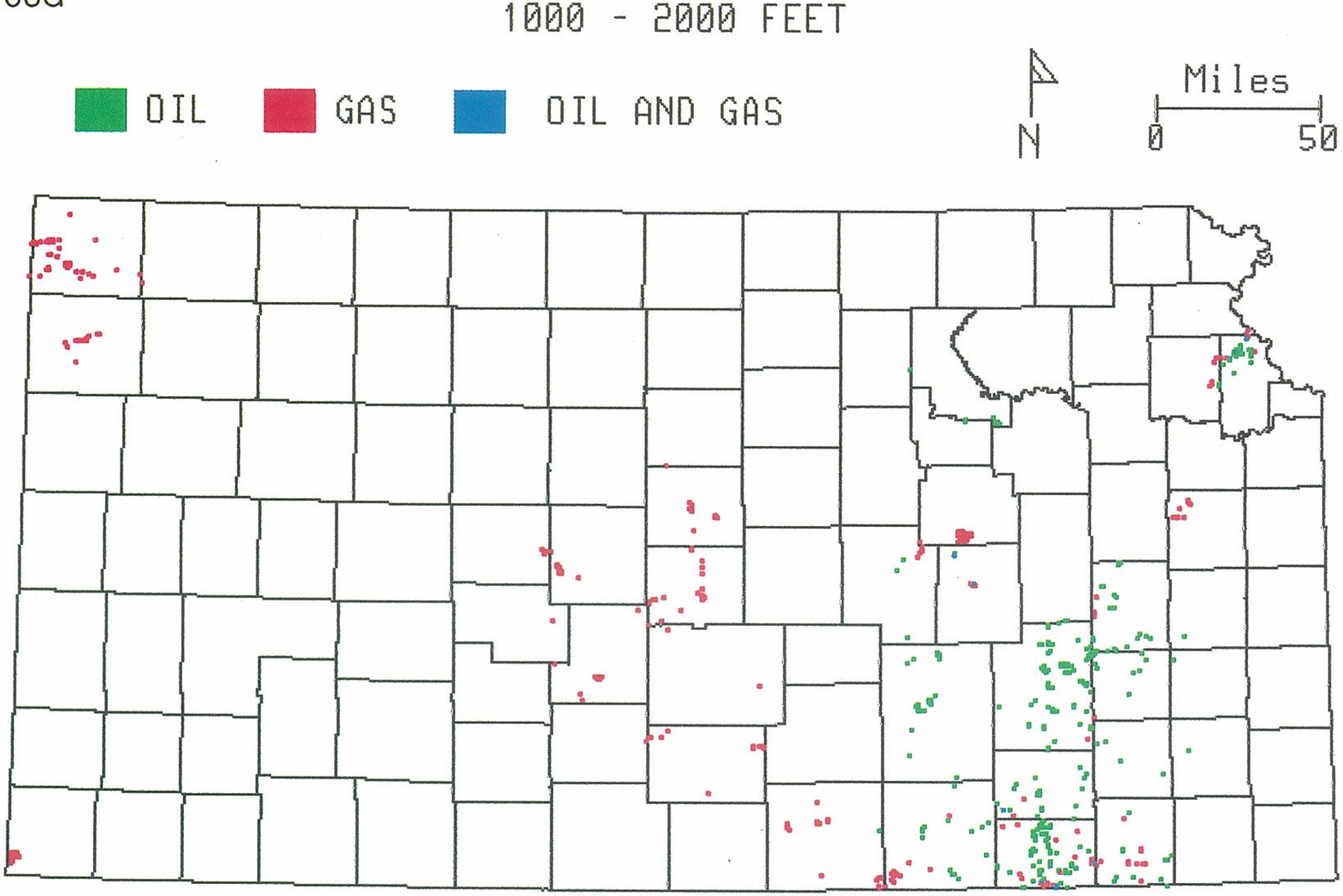
FIGURES 37A-43A—KANSAS PETROLEUM PRODUCTION DIFFERENTIATED BY TYPE OF PRODUCTION FOR 1,000-FT DEPTH SLICES. Depths are subsurface depths.

37b



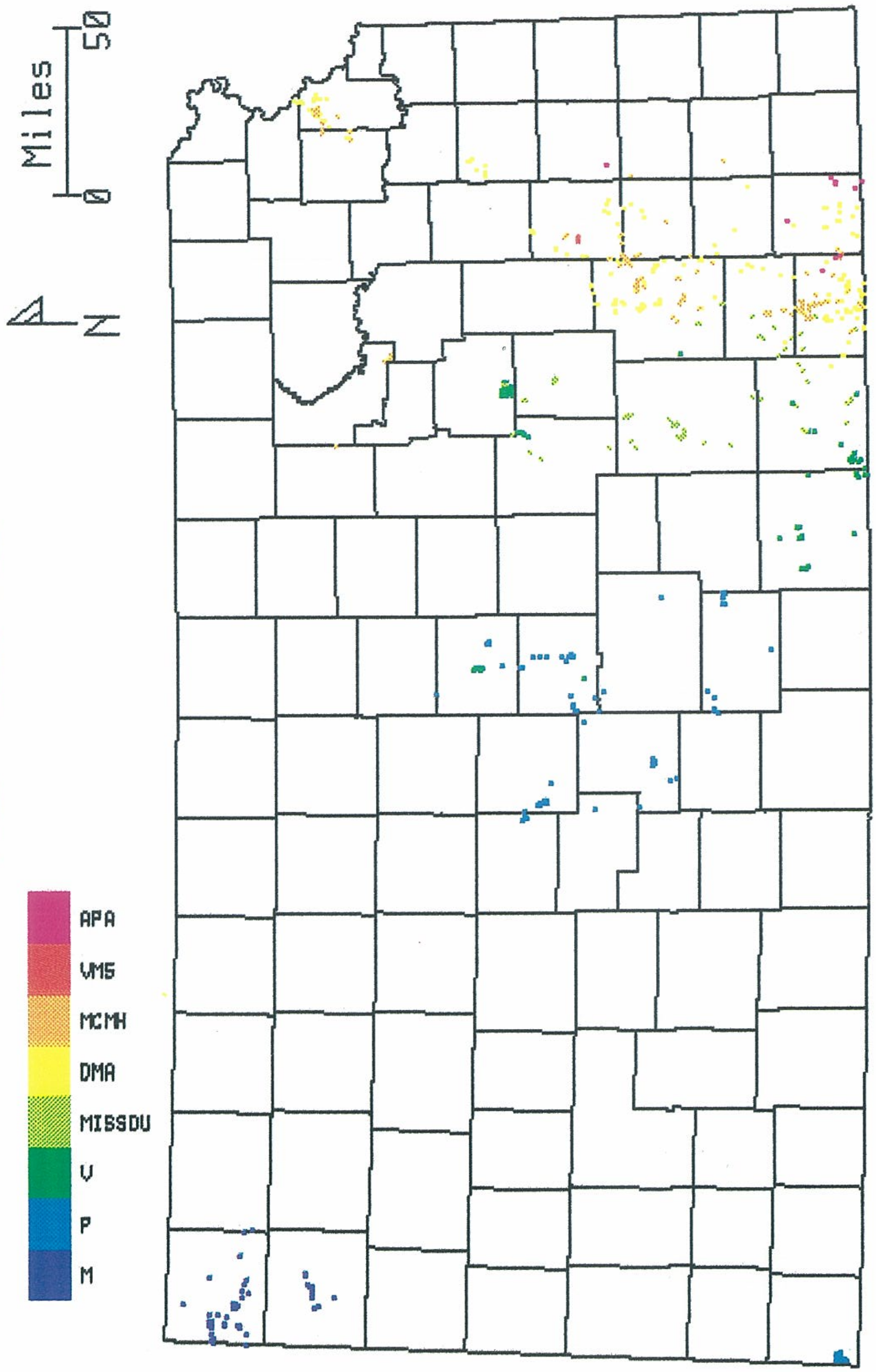
FIGURES 37B-43B —KANSAS PETROLEUM PRODUCTION DIFFERENTIATED BY PRODUCING ZONE FOR 1,000-FT DEPTH SLICES. Depths are subsurface depths. Producing zones are color coded; abbreviations correspond to various colors as follows: APA, Arbuckle, sub-Arbuckle; VMS, Simpson, Viola, Maquoketa; MCMH, Silurian-Devonian limestones Misener, Chattanooga, Mississippian limestones; DMA, Morrow, Atoka, Cherokee, Marmaton; MISSOU, Pleasanton, Lansing, Kansas City; V, Douglas, Shawnee, Wabaunsee; P, Permian; and M, Niobrara.

38a



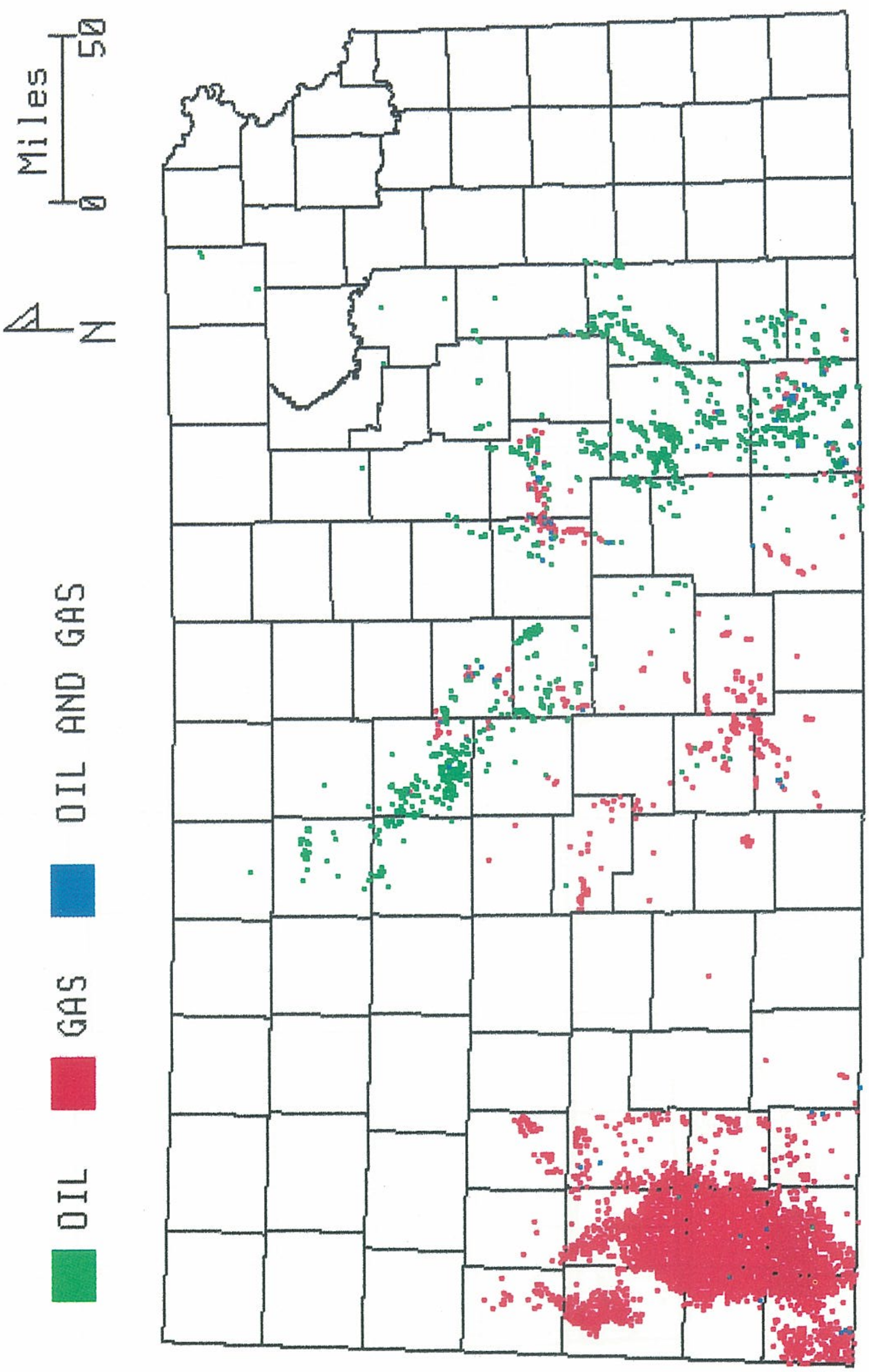
38b

1000 - 2000 FEET

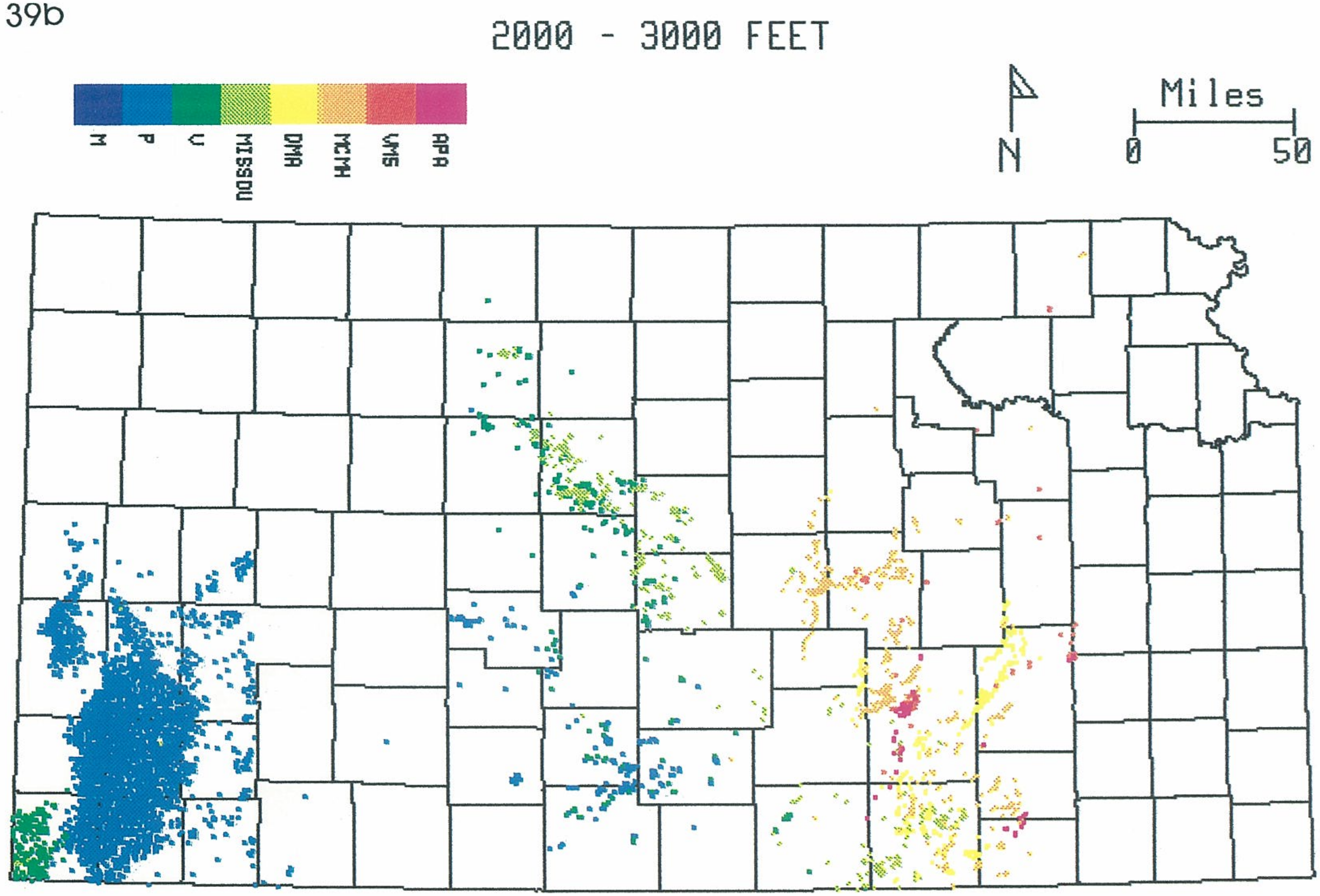


39a

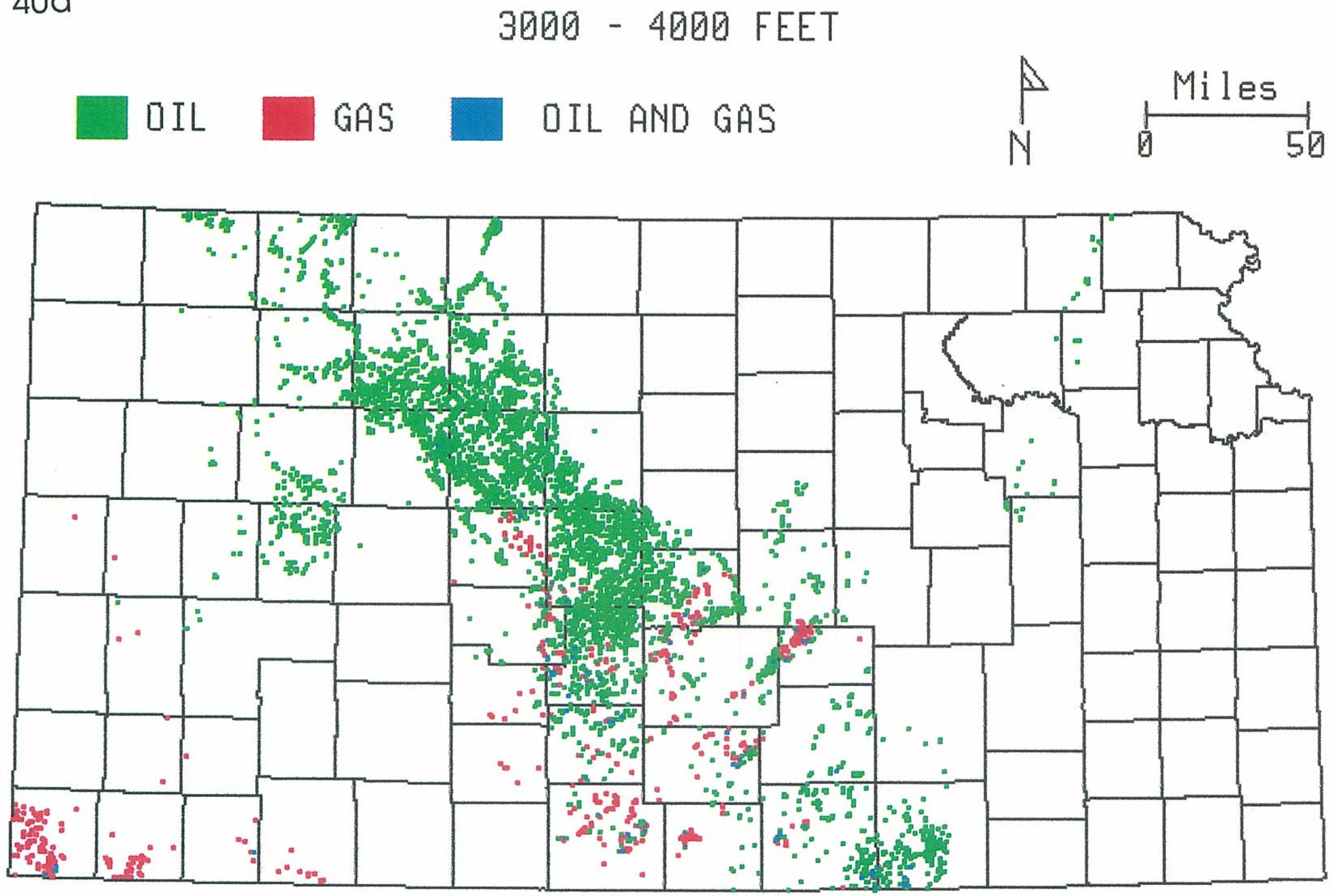
2000 - 3000 FEET



39b

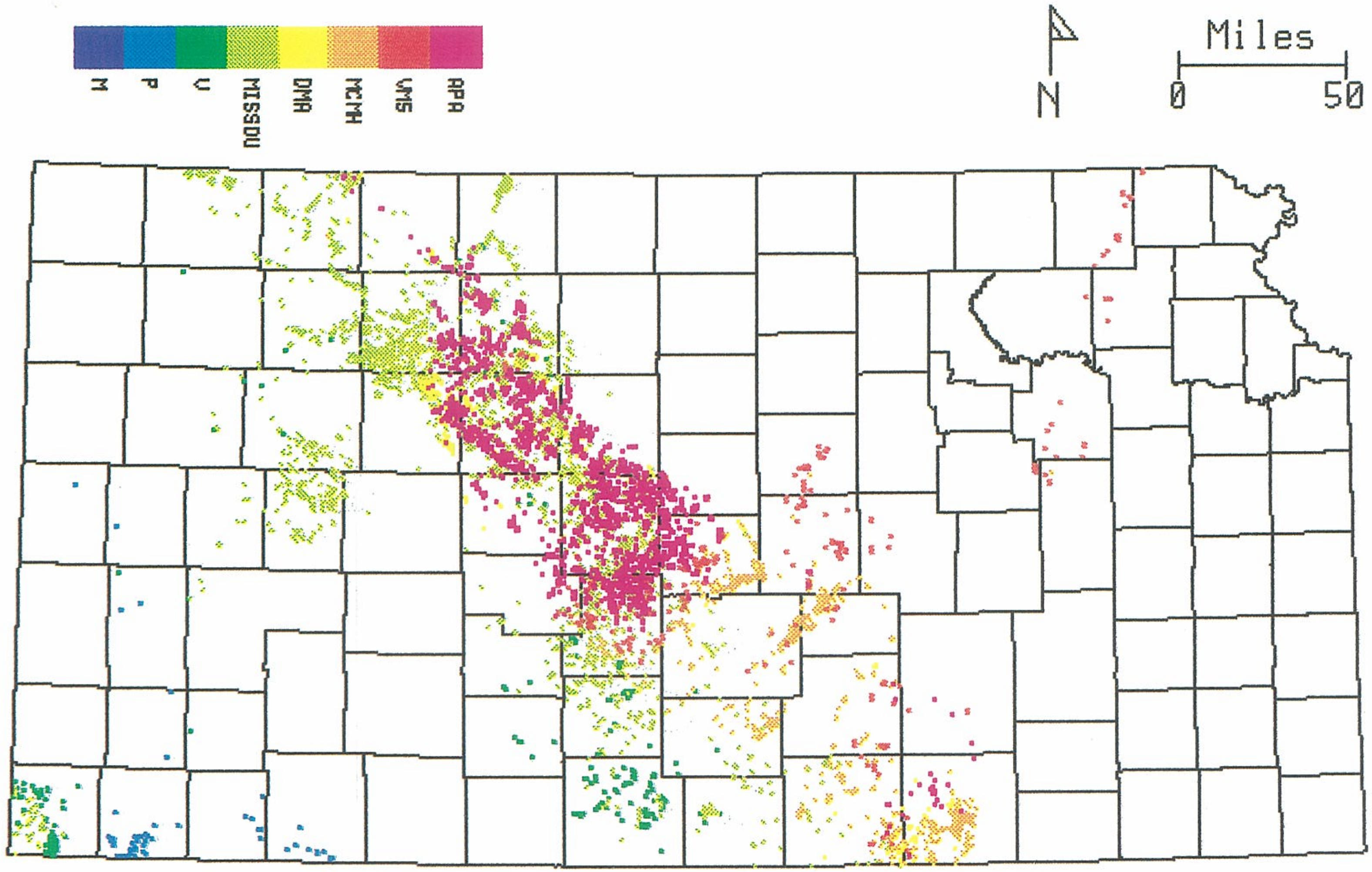


40a

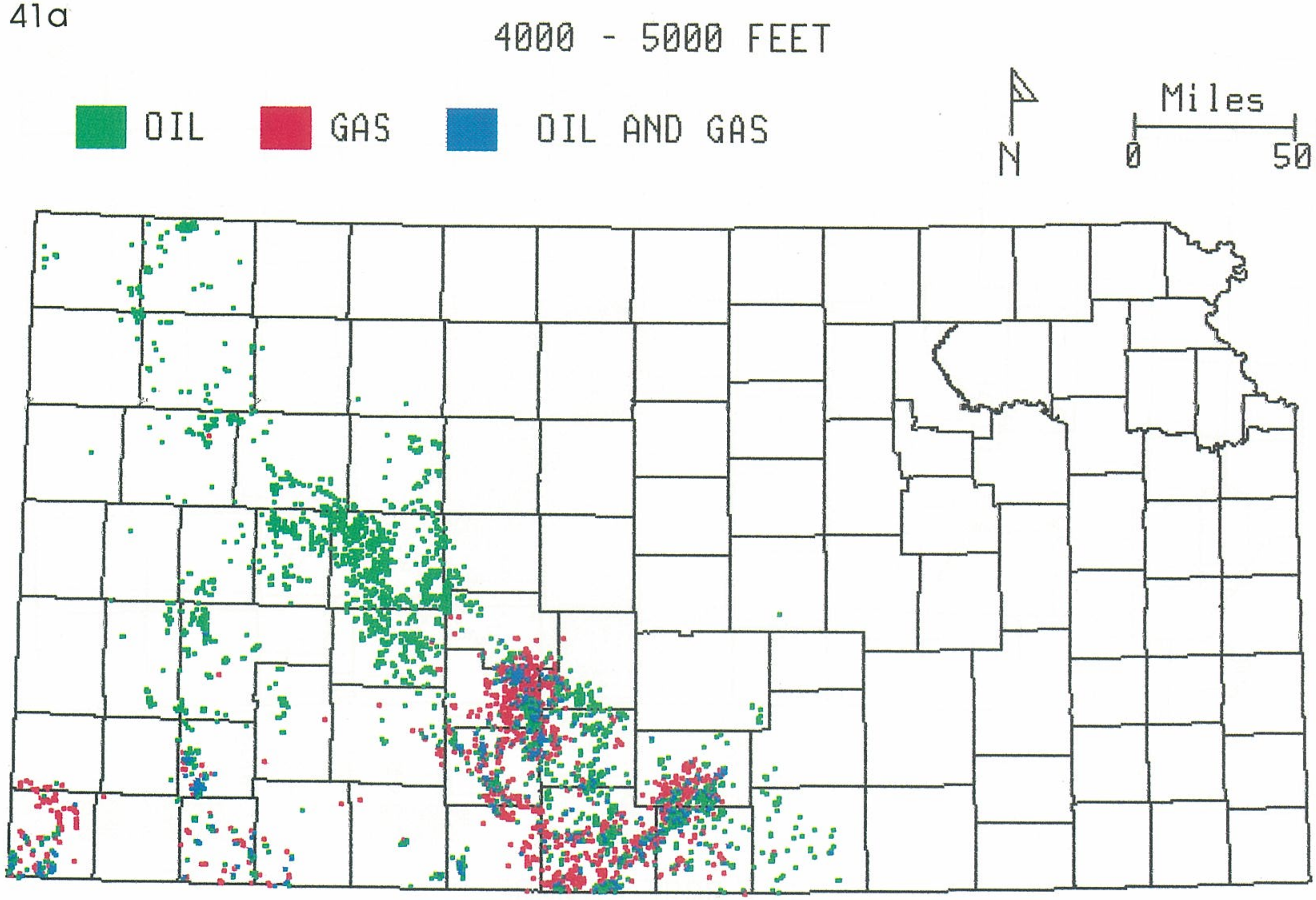


40b

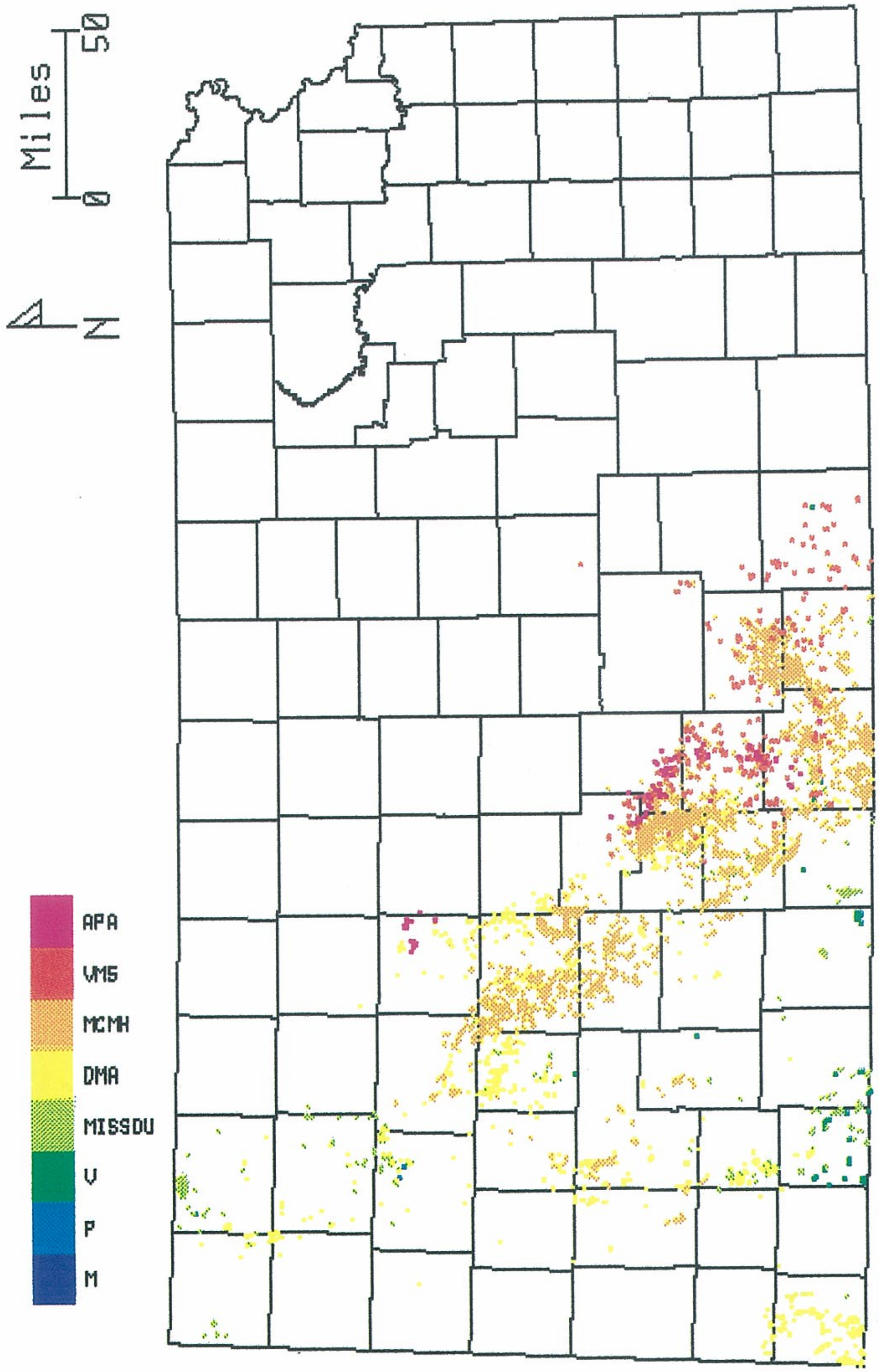
3000 - 4000 FEET



41a



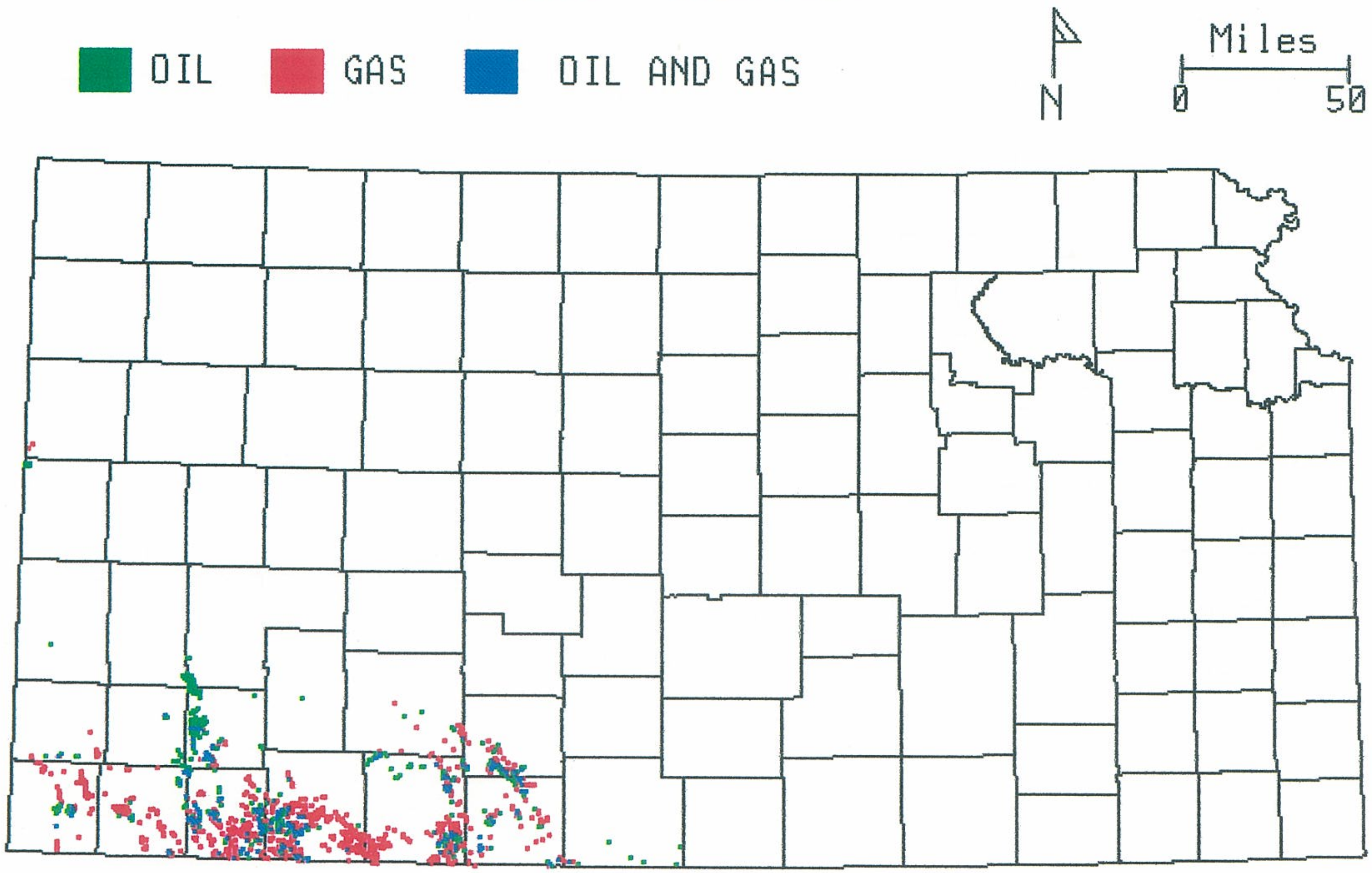
4000 - 5000 FEET



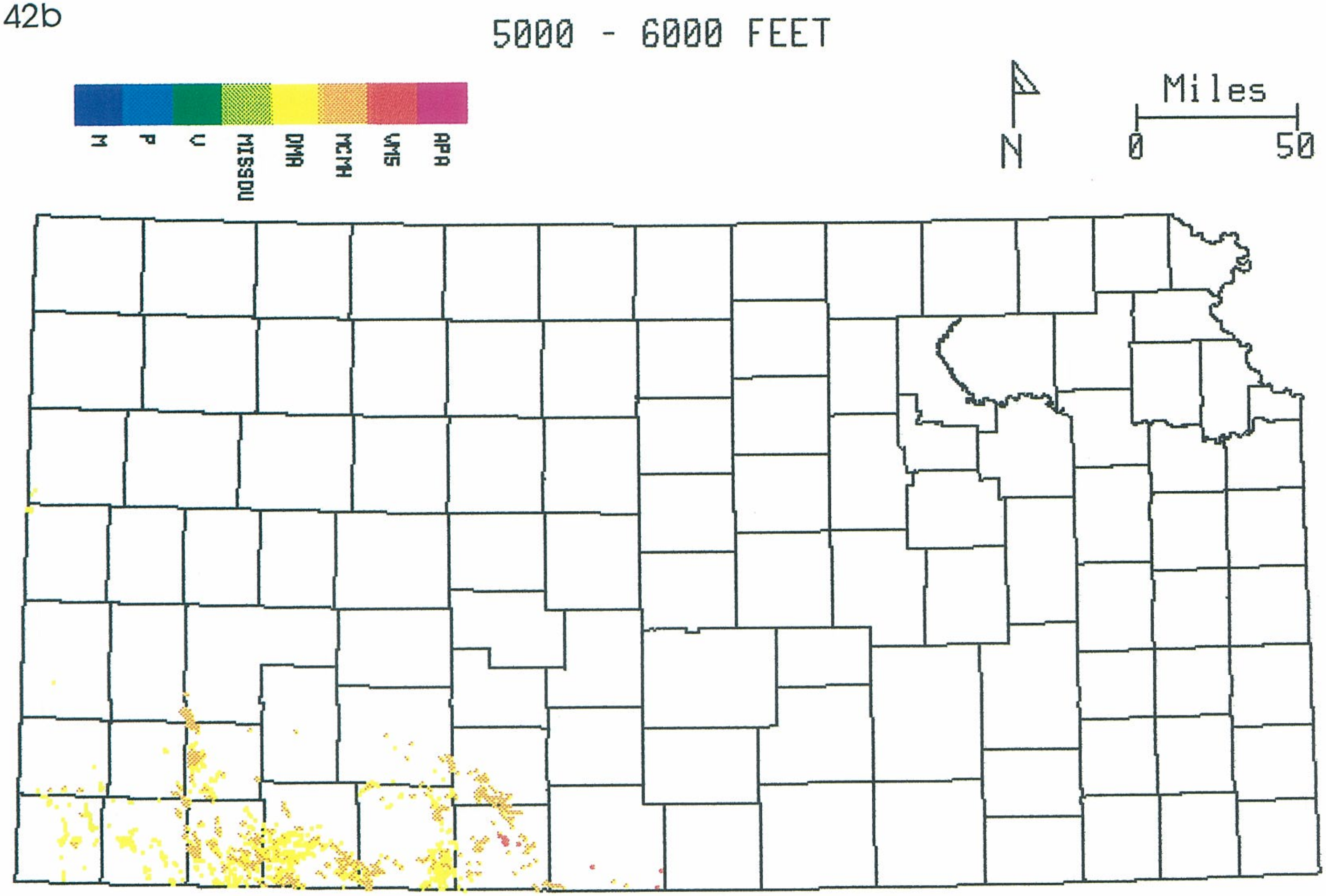
41b

42a

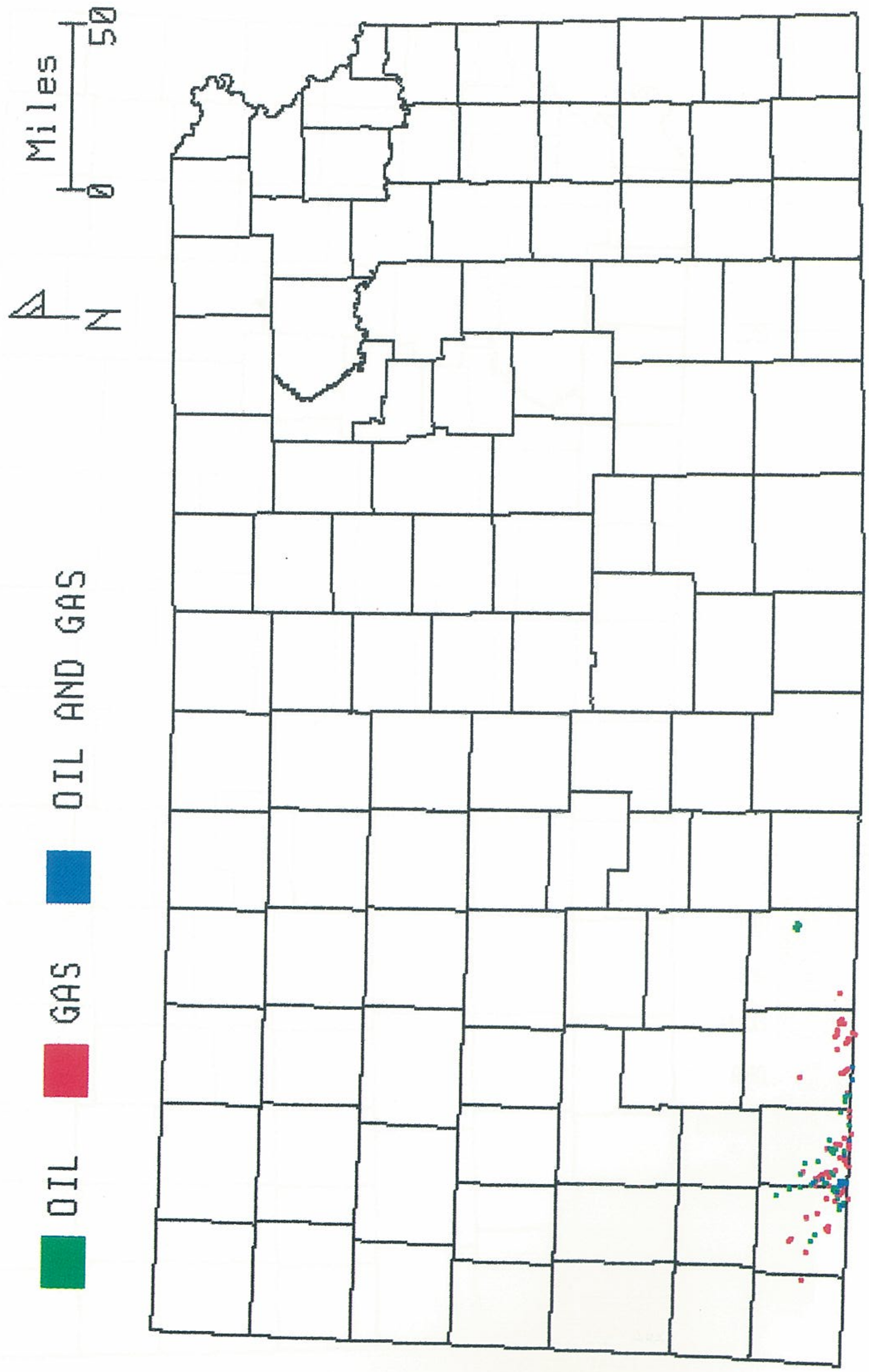
5000 - 6000 FEET

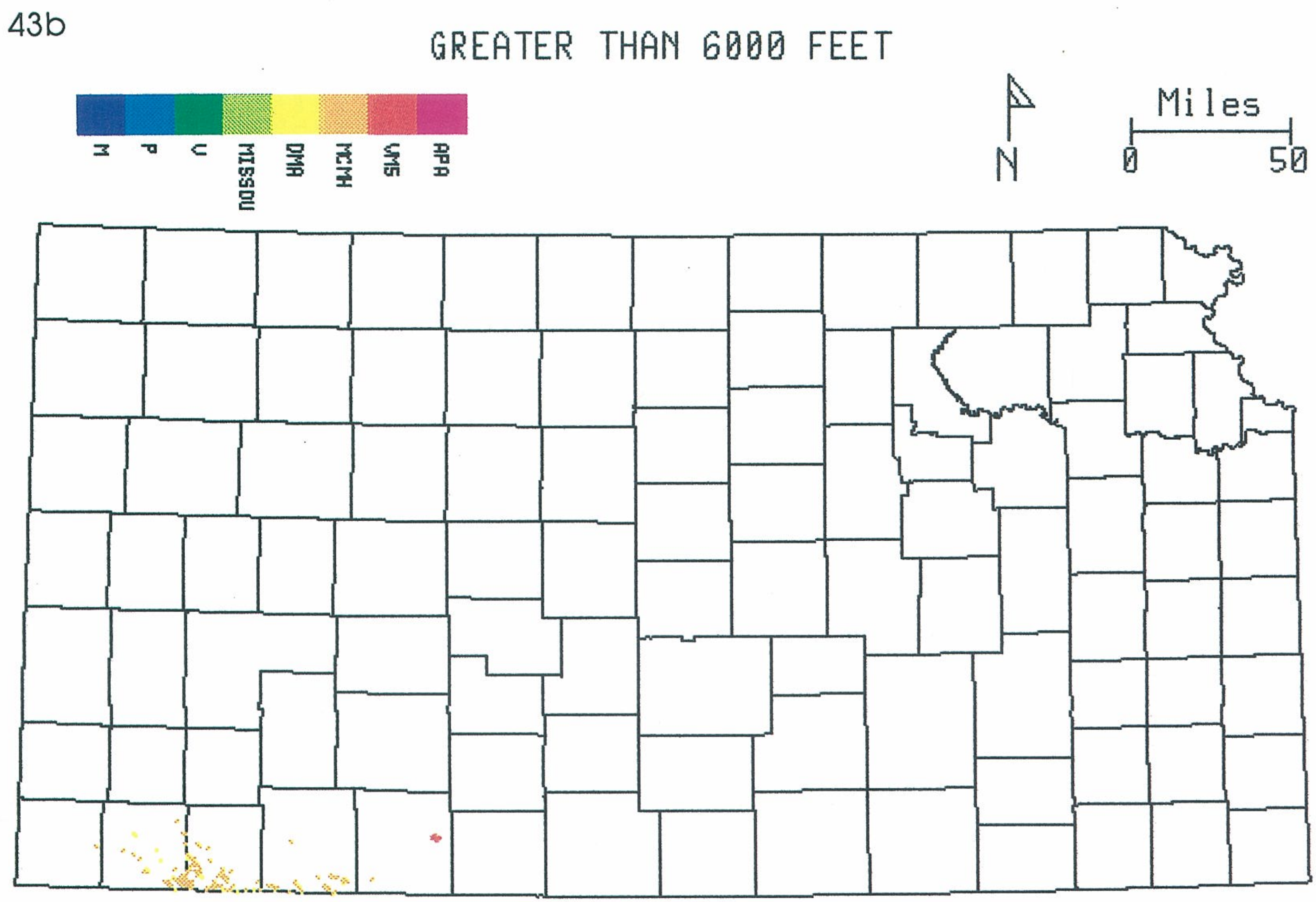


42b



43a




43b
GREATER THAN 6000 FEET
M
P
V
MISSDU
DMA
MCMH
VM5
APA
N
Miles
0
50

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Glossary

ANTICLINE	A convex-upward fold. Anticlines are commonly elongate features that can, in effect, resemble ripples on a carpet in a layered sedimentary sequence. They are the product of either compressive forces or differential vertical uplift. Anticlines can be quite complexly faulted in severely deformed areas, but they are generally very subtle features in Kansas, with their flanks gently dipping at less than 15° from horizontal. (*Also see* arch, basin, syncline).
ARCH	A large upwarp in the earth's crust that may be tens or hundreds of kilometers across. Arches may have smaller anticlines superimposed on them. If an arch is a round feature with virtually no elongation, it may be called a *dome*. Both arches and domes (and the basins they separate) can be extremely long-lived features that form very slowly over many millions of years. (*Also see* basin).
ARKOSE	A type of sandstone that is rich in feldspar and granitic rock fragments. It is usually poorly sorted and is derived from weathered granites or high-grade metamorphic rocks such as gneiss.
BARREL	Barrels are the traditional volumetric measurement of petroleum and its products in the United States. One barrel is equal to 42 US gallons.
BASAL SANDSTONE	The sedimentary rocks deposited at the beginning of a transgression usually include a basal sandstone or conglomerate, which is an expression of a nearshore or shore-line high-energy depositional environment. As the name implies, the position of the sandstone is at the base of the sedimentary-rock sequence laid down by the transgression. Sandstones in the lower part of the Middle Ordovician Simpson Group and the lower part of the Cambrian Reagan Sandstone are the basal sandstones of two separate major transgressions; others are also present in the Kansas rock column. (*Also see* transgression.)
BASEMENT ROCKS	In the Midcontinent, the dense, hard Precambrian metamorphic and igneous rocks that underlie the sedimentary-rock sequence are called the basement rocks. These rocks are extremely deformed and consist of granites, schists, and gneisses that may be older than 1 billion years.
BASIN	A broad downwarp in the earth's crust. Basins, like arches, can be very broad features that are many hundreds of kilometers across. Folds and other types of traps within basins and archs are areas where petroleum may accumulate. Sedimentary layers are generally thicker in basins than on adjacent arches.
BIOGENIC GAS	Natural gas (methane) formed by an anaerobic (without oxygen) fermentation process where forms of organic matter such as carbohydrates are reduced by bacteria to form methane. The process is associated with low temperature (less than 75° C). In contrast, thermal cracking of organic matter occurs at elevated temperatures to form other hydrocarbons including methane. Biogenic and thermogenic methane can be differentiated through examination of their carbon and hydrogen isotopes.

CAMBRIDGE ARCH	Northwest-southeast-trending uplift present in northwestern Kansas in Norton and Decatur counties. This arch is separated from the Central Kansas uplift by a structural saddle in Graham and Rooks counties. Vertical movement and uplift of the arch are most pronounced in pre-Mississippian, post Mississippian, pre-Pennsylvanian, and Mesozoic time.
CHALK	Widespread deposits composed of very small fossils of calcite called coccoliths. These were floating algae once abundant in the open sea that covered most of the west-central United States during Cretaceous time.
CHLORITE	Clay mineral composed of aluminum, iron, and magnesium silicate.
CLASTIC	Term describing rocks that are made up of fragments of other rocks, fossils, or various types of minerals (such as quartz or feldspar sand grains).
COCCOLITHS	Buttonlike calcite plates of algae around 3 micrometers (3×10^{-6} m) in diameter. Algae are floating plankton found in temperate and tropical waters. Remains are commonly found in Mesozoic chalk deposits and deep-sea ooze.
COMMINGLED PRODUCTION	Oil or gas produced from the mixing of two or more separate zones in a single well.
CONGLOMERATE	Coarse-grained sedimentary rock composed of rounded fragments larger than 2 mm in diameter. Particles include pebbles, cobbles, and boulders. Matrix (the material found between the clasts) is usually composed of sand and silt-sized particles.
CUTTINGS	Chips of rock typically less than 2 cm across, broken from strata encountered by a drill bit. Cuttings are produced by a rotary bit with three toothed wheels which rotate as drill pipe is turned. Drilling mud circulated down through drill pipe is ejected through ports on the bit. Mud then carries the cuttings to the surface as it moves between the drill pipe and borehole wall. Geologists can inspect these cuttings to determine rock lithology and presence of oil shows.
CYCLOTHEM	A vertically repeating sequence of sedimentary rocks a few meters to tens of meters thick, originally defined as those found in Pennsylvanian strata. Origin has been controversial and continues to stimulate research.
CREVASSE SPLAY	A fan-shaped sand body deposited in a lagoon or swamp adjacent to a distributary channel where levee has been breached.
DIAGENESIS	The processes of lithification which are responsible for making newly deposited sediments into rocks. Diagenesis includes (but is not limited to) the processes of compaction, cementation, and recrystallization.
DIP	The angle at which a bed or rock layer is inclined from the horizontal.
DOLOMITE	A rock such as limestone that is composed of $Ca,Mg(CO_3)_2$. Most limestones are composed of $CaCO_3$ (calcite). Many dolomites in the rock record were originally limestones. The magnesium was introduced during the long processes of lithification of the limestones.

EMBAYMENT	An indentation along the continental margin that underwent subsidence during sedimentation, resulting in a thickened sequence of sedimentary rocks. Commonly an extension of a basin which underwent even greater subsidence and filling by sedimentary rocks. The Sedgwick and Hugoton basins in Kansas are commonly referred to as embayments off the Anadarko basin.
ENHANCED OIL RECOVERY (EOR)	The additional oil that can be economically recovered from a petroleum reservoir after oil recovered by primary and secondary methods of production has been produced. Primary-recovery methods rely on the natural energy of the reservoir to produce oil, whereas secondary methods include techniques such as injection of water or gas to maintain reservoir pressure. EOR techniques include methods such as steam flooding and carbon dioxide injection. It is an expensive process, but more fields in Kansas will be subject to EOR. Since EOR is expensive, oil prices are very crucial to decisions to initiate such projects.
FLUVIAL	Adjective describing sediments that have been deposited by rivers or streams. Other terms commonly used to describe other types of depositional environments or processes include *marine* (pertaining to oceans), *eolian* (pertaining to wind), and *lacustrine* (pertaining to lakes).
GAMMA RADIATION	Radiation emitted by rocks in generally small amounts which can be measured in a borehole by a gamma-ray wireline log. Logs record radiation intensity plotted against depth. In turn, this information can be used to define strata encountered in borehole for correlation and delineating shale content. (*Also see* wireline log).
GLAUCONITE	A green mineral composed of potassium iron silicate commonly occurring in marine sedimentary rocks.
INSOLUBLE RESIDUE	The material remaining after a limestone sample has been dissolved in hydrochloric or acetic acid. This material comprises siliceous material such as quartz-sand grains, chert, phosphatic material, and silicified fossils. Stratigraphic zonation of limestone units (such as the Arbuckle) has been achieved by insoluble-residue studies.
KAOLINITE	An abundant aluminum silicate clay mineral, commonly called fire clay.
LITHOLOGY	The physical characteristics of a rock that can be determined by observation, either by the naked eye or a low-power microscope. Correlations of rock layers (geologic formations) over distances between two or more wells (or outcrops) are usually made on the basis of lithology.
LAS ANIMAS ARCH	Northeast-southwest-trending arch extending from southeastern Colorado through northwestern Kansas and into southwestern Nebraska. The Las Animas arch forms thewestern border of Hugoton embayment in western Kansas. Movement began in Late Pennsylvanian and extended into Cenozoic.
OIL-IN-PLACE	The total quantity of oil trapped in a reservoir of an oil field is described as oil-in-place. Generally, only 10-35% of this oil-in-place can be produced by primary-recovery techniques. Hence, enhanced oil-recovery (EOR) techniques will become increasingly important in producing the oil remaining in old or abandoned oil fields.

OÖLITE — Nearly spherical sand-sized grain (0.25-2 mm in diameter) composed of an interior nucleus that is covered by outer concentric laminations. The concentric laminations are commonly composed of calcium carbonate and less commonly iron oxide or silica. An interior nucleus is commonly a quartz grain or shell fragment. Carbonate oölites are most often formed in warm, shallow, agitated marine waters.

PALEOTOPOGRAPHY — Topography (hills and valleys) that has been buried by a younger overlying sedimentary strata. Buried hills of Precambrian basement rock in the Central Kansas uplift form paleotopographic traps in Barton, Russell, Rice, and Stafford counties in Kansas. Fractures in the basement rock usually form the porosity that holds the oil.

PAY ZONE — The stratigraphic interval, or reservoir rock, that produces oil or gas in commercial quantities in an oil field.

PERMEABILITY — The ability of a rock to allow fluids to pass through it. In effect, rocks with high permeability have well-developed connections between pore spaces, whereas rocks with low permeability have either no porosity or isolated pores which are not connected to each other. (*Also see* porosity).

PETROLEUM — Petroleum is a catch-all term for any hydrocarbons that can be produced through a drill-pipe and, as such, includes crude oil, natural gas, and condensates.

POROSITY — The amount of void space in a rock that can either be filled by brine, oil, water, or gas. (*Also see* permeability, reservoir rock.)

PROSPECT — A name given to a location which is identified as a likely site of petroleum occurrence and one which may be tested by the drill.

REGRESSION — A relative fall in sea level. A regression is expressed by rocks displaying characteristics of progressively shallower environments of deposition. Subaerial exposure and possible erosion can ultimately result from regression expressed in the rock record as an unconformity. (*Also see* transgression, unconformity.)

RESERVES — The amount of discovered oil that is presently *economically* producible under current economic conditions and present technology. (*Also see* resource.)

RESERVOIR ROCK — A rock layer that is capable of holding oil, gas, or water in its pore system. The pore system, or porosity, of a reservoir rock can be composed of different types of porosity such as that between sand grains, e. g., quartz and oölite grains, (intergranular porosity), between crystals in a recrystallized limestone or dolomite (intercrystalline porosity), small solution cavities (vugular porosity), or even dissolved shells of fossils (moldic porosity). A reservoir rock usually averages approximately 10-35% porosity, although greater and lesser amounts of porosity can also occur. (*Also see* pay zone, permeability, porosity.)

RESOURCE — The amount of oil that may eventually be producible and useful to society. Resources include not only reserves but also inferred and undiscovered oil fields. Resources also include known subeconomic reservoirs that may be producible with future technology and techniques, or if the material being produced eventually commands a higher price. (*Also see* reserves.)

SHOESTRING SANDSTONE	A sandstone body that is long and narrow, usually surrounded by shale. Shoestring sandstones are very important stratigraphic traps in the Cherokee Group of eastern Kansas. The dimensions of such reservoirs are highly variable but they can be on the order of 100-300 m wide, several kilometers long, and several meters thick.
SOURCE ROCK	A rock that is organic-rich and capable of generating petroleum. Source rocks generally contain greater than 0.5% finely disseminated organic matter and are generally dark-colored shales and limestones.
SPILLPOINT	*See* trap.
STRATIGRAPHIC TRAP	A trap for hydrocarbons that is produced by depositional characteristics of the rock layer holding and surrounding an accumulation of hydrocarbons. There are several types of stratigraphic traps. Channel sands or lenticular sand bodies are particularly important types of stratigraphic traps found in eastern Kansas. Thick accumulations of chert fragments (chat) are particularly important traps in central Kansas at the top of the Mississippian limestones. (*Also see* structural trap, trap.)
STRUCTURAL CLOSURE	Vertical distance between a structure's highest point and its lowest elevation contour that encloses itself. A structural closure is also a more general term for an anticline or faulted anticline.
STRUCTURAL TRAP	A trap for hydrocarbons caused by deformation of rock strata. The simplest type of structural trap is a dome. Some structural traps can be quite complex, particularly those associated with severely deformed and faulted anticlines. Structural traps are found all over Kansas and can be detected by shallow core drilling, subsurface or surface geologic studies, and geophysics. (*Also see* anticline, stratigraphic trap, structural closure, trap.)
SUBCROP	The map trace of a unit truncated by an unconformity. Subcrop maps are essentially paleogeologic maps which show the spatial distribution of geologic units at some time in the past before subsequently deposited rock units covered the outcrops. Subcrop maps are useful in locating buried geologic structures which may hold oil.
SYNCLINE	A convex-downward fold. Synclines, like anticlines, are commonly elongate and are found between anticlines. (*Also see* anticline).
TOWNSHIP	Government land surveys in the United States and Canada parcel land into a gridded pattern. A fundamental unit in such a land grid is the township that is generally a rectangle 6 by 6 mi. Thirty-six sections, each about 1 mi^2, comprise a township. In turn, each square mile is composed of 640 acres.
TRANSCONTINENTAL ARCH	Broad, persistent uplift traced between Wisconsin and Arizona extending through northern and western Nebraska and northeastern Colorado. The transcontinental arch was periodically uplifted during the Phanerozoic (the span of time encompassing the last 570 m.y.). It is referred to as "continental backbone" because of its central location and persistence.

TRANSGRESSION	A relative rise of sea level. Several major transgressions have occurred on the North American continent over geologic time and some are recorded in the rocks of Kansas. (*Also see* basal sandstone, regression).
TRAP	A trap is any set or combination of physical conditions that encourages the accumulation of significant quantities of hydrocarbons. A trap usually consists of a porous reservoir rock that contains hydrocarbons and a surrounding impermeable rock that keeps the hydrocarbons from leaking out of the reservoir rock. Traps can be further differentiated into stratigraphic or structural traps . . . or even combination traps that are hybrids involving both stratigraphic and structural characteristics. The size of a trap can be given in terms of its *closure,* which either can be its areal extent or its maximum vertical dimension between its highest (shallowest) and lowest (deepest) points. The highest part of a trap is called its *culmination* or *crest.* The lowest point to which hydrocarbons can accumulate in a trap is called the *spillpoint.* Inasmuch as the usual type of fluid found in rock pores is water (usually brine), any gas or oil generated by organic matter will rise by buoyancy to the culmination of the trap (because oil is less dense than water). (*Also see* stratigraphic trap, structural trap.)
UNCONFORMITY	An unconformity is a buried, ancient, erosional surface sandwiched between rock layers of different ages. There are several types of unconformities that are defined by the structure and type of rocks lying above and below the unconformity. An *angular unconformity* occurs where the sedimentary layers above and below the unconformity are tilted at different angles. The older strata on which the unconformity is developed are generally tilted at a steeper angle than the younger strata above the unconformity. In Kansas, the difference in tilt between strata below and above an angular unconformity is generally not great—usually less than 10°. A *disconformity* occurs where there is no appreciable difference in tilt between the rocks above and below an unconformity. A *nonconformity* is an unconformity in which stratified rocks, such as sandstones, limestones, or shale, lie above an erosional surface developed on igneous or metamorphic rocks. The unconformity developed over the Precambrian basement in Kansas is a nonconformity and represents a vast gap in time of at least 500 million years.
VUG	*See* reservoir rock.
WIRELINE LOGS	Instruments that are suspended on a cable and lowered into the borehole to measure such properties as resistivity, natural gamma radiation, acoustic (sound) travel time, and other physical characteristics of rock along the bore-hole wall. One or more surveys are made in a typical oil well to help the geologist correlate between wells and to determine porosity, presence of petroleum, and even composition of the rock, provided appropriate combinations of tools are used.

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