KANSAS GEOLOGICAL SURVEY
OPEN-FILE REPORT 86-10

NATURE OF KANSAS GEOLOGY AND PRODUCTION

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Missing Figures #4 & #5

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Special Energy Loan Conference
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Hilton East, Wichita, Kansas

"Nature of Kansas Geology
and Production"
W. Lynn Watney and David Collins

I. Introduction

Objective: Review information about petroleum geology and engineering that are useful and even essential for the objective appraisal of producing oil and gas leases for cost-effective loan determination.

Procedure:
Discuss: 1) Economic and business considerations in lease evaluation;

2) Methods of reserve estimation and justification in lease appraisal;

3) Sources of information useful and essential in lease evaluation;

4) Illustration of the geologic variability of oil and gas reservoir rocks in Kansas and the resultant range in performance and costs of operation of leases;

5) Summary

II. Economic and business considerations in lease evaluation.

The oil market became more unpredictable when the Saudis abandoned their role in November as the swing producer. During the late 70's and early 80's they had continued to cut-back on production as world-wide additions to supply exceeded demand. Since November they have pressed for a larger market share by drastically lowering the spot prices for their crude oil. Markets in other producing countries could only follow suit. Much of the oil brought on stream under more favorable economic conditions since deregulation in 1981 is now becoming or approaching uneconomic levels in mature producing areas such as the Midcontinent. Kansas is no exception.

Figure 1. Kansas Rig Count

The plunge in price has sorely affected cash flow and required banks to react by accelerating loan schedules and increasing collateral in order to protect the principal. Adverse market conditions have also changed economic viability of petroleum development. Recent declines in the number of workable drilling opportunities is reflected in Figure 1 in the historical record of active drill rigs in the state. During downswings fewer loans are made and those applications are looked at with much greater scrutiny. How loans are evaluated becomes extremely important when the pool of loans becomes much smaller and the decline in the economy create a greater risk. Banks and operators have equally suffered and it is now time to begin picking up the pieces by planning for recovery when prices rebound.

Maintaining a successful business will be more difficult and future recovery will be slower for the banks and the industry if methods used for estimating loan value are not taylored to the lease conditions or to the operator's experience. The reliance on rules of thumb which represent only average lease conditions will not permit banks to develop experience factors based on the actual variability of leases nor will it provide a knowledge base from which to infer criteria for making better loans.

What can be done that will help limit the risk? We would suggest that categorizing risks based on objective geologic and engineering information will make it clearer for a bank to determine what went right or wrong and provide a database on which to justify a change in direction. Ideally, some form of reserve estimate and production schedule, economic and petroleum market forecast, and evaluation of the borrowers financial position should be used in arriving at maximum loan values. Then the bank can apply its own procedures to define the actual loan value based on the separate risks introduced by the economy, market, operator experience, and concentration of assets, etc.

It is common practice to compare loan value as a fraction of cash flow or reserves. Rules of thumb such as amount loaned per net barrels of reserves or loan value per net barrels of production rate are best suited as a comparison between loans. These rules are based on assumptions of the average nature of the reservoirs of the lease such as the decline schedule for production, plus economic conditions, and the available market for the product. These variables should however be analyzed separately, especially when economic and market conditions are subject to outside manipulation or have greater uncertainty. The production schedule could be seriously affected by declining oil price. The rule of thumb then becomes a poor guide.

Loan value is ultimately linked to fair market value of a lease which is related to the above mentioned variables. No one would argue that the optimum way to estimate fair market value includes determination of reserves and recovery schedule. Variation in the properties of the reservoirs in Kansas and the Midcontinent really necessitate reserve estimation in some form.

How far a small banker can go in lease appraisal utilizing reserve estimation such as hiring or retaining an engineer or geologist depends on the size and numbers of projects under consideration. The approach toward evaluating the lease performance can and should be considered nevertheless. Data are available from public sources which can assist in drawing analogies to nearby production and provide a means of comparing previous decisions in a logical manner.

III. Methods of reserve estimation and justification in lease appraisal

Considerations in reserve estimating include: 1) the fact that the estimates are no better than the data on which they are based and are subject to the experience of the estimator; 2) data available increases through the life of the project and improves the confidence in estimation as different methods are applied.

Figure 2. Life of a producing property.

The uncertainty of reserve estimating decreases with time until reserves are exhausted. Typically, leases offered as collateral for loans have a limited production history which permits, for example, the construction of production decline curves, one of the more accurate means of estimating reserves. The production is projected out to an economic limit where lease expenses (monthly) equal revenue (monthly). The area beneath the rate curve represents the ultimate production of the lease.

Figure 3. Production schedule interrupted by a large decline in oil price.

Obviously, the economic limit is dependent upon market conditions and can affect the production schedule. A large decline in the product price can cut short the life of the lease and result in early abandonment. In this uncomfortable situation cash flow is terminated and ultimate production was less than anticipated. The time when a price fall might occur relative to the projected life of the lease is crucial to assessing level of risk and jeopardy of the parties involved. A majority of leases in Kansas are in that sensitive stage.

The lower the rate of decline in production (that is the flatter the decline curve) the more sensitive the economic limit is to changes in oil price or operating costs. In this case a small change in market conditions will result in a significant change in the expected economic life of the lease. The market value of such a lease, with production rates close to the economic limit, might look very good under one price forecast, but look much worse with only a slightly more pessimistic price forecast. To state it somewhat differently, the flatter the curve and the closer to an existing economic limit, the greater the sensitivity to and risk associated with price fluctuations. The construction and analysis of decline curves from monthly production data and lease expense records permits this kind of assessment.

A logical compilation of and analysis of decline curves on nearby leases could be extremely useful in validating by analogy the assignment of risk to the lease in question. The level of sophistication and time and money spent in lease evaluation obviously is of concern in maintaining a competitive edge and must be taylored to the user's needs.

IV. Sources of information useful and essential in lease evaluation.

The geological attributes of petroleum reservoirs and the distribution of petroleum can be used as the initial criteria for establishing analogies between leases to permit a logical comparison for establishing loan value. Again we stress the kind and detail of information needed and professional services required are dependent on the size and conditions associated with the lease. Maps, summary reports, and lists of the distribution of petroleum reservoirs by location, age, depth, and rock types are available from the Kansas Geological Survey. These data can be used in comparing the lease being analyzed with nearby and analogous production. If anything, these data demonstrate the variability of properties which affect the loan value.

Significant variations which occur between reservoirs should make you aware of the element of risk in using simple rules of thumb to assess the value of a property. Reviewing these regional geological data to place a lease in some kind of perspective is analogous to examining the neighborhood before buying the house. You do not necessarily need to interview the occupants to get a good idea what is in store, but knowing someone living there would not hurt.

The Kansas Geological Survey also maintains lease production, and location, depth and age of reservoir rocks that are producing on the lease. Individual records of well completions are also kept on file together with wireline logs, cuttings, and some cores from the wells. The monthly production data could be used to generate performance records, i.e. the production decline curves. The accessibility of this data on the computer in a "user-friendly" form is not yet available through state agencies. However, it is available commercially. I anticipate that such a service could be extremely useful for banks and operators alike.

An upcoming report of the State Geological Survey which is now in final editing entitled, "Kansas Oil and Gas Production: Its Stratigraphic and Spacial Distribution" by David Newell, Lynn Watney, and Stephen Cheng will illustrate the variability of reservoirs in Kansas and include a compilation of available literature and a glossary on the subject. This should serve as an overview reference which would introduce the professional or lay person to the petroleum geology of the State.

Operators themselves can supply key geological and engineering information on the lease and perhaps surrounding leases for more detailed reserve estimation and lease comparisons. This information would include lease operating expenses which are tied to many variables including geology, production method, and operator experience and know-how. Some of these expenses are related to depth and reservoir energy and water cut or percent of fluid production from the lease, and include associated water disposal costs, lifting costs, costs of operation and maintenance of equipment, and production taxes. Seeking or providing reserve-based loans without this information does not represent prudent business practice.

V. Illustration of the geologic variability of oil and gas reservoir rocks in Kansas and the resultant range in performance and costs of operation of leases.

Figure 4. Slab of a core of a Pennsylvanian limestone reservoir from a northwestern western Kansas oil field. Oil in the reservoir occurs in similar large, irregularly-shaped, seemingly random but interconnected pores.

Figure 5. Slab of a core of another Pennsylvanian oil reservoir but in this instance a sandstone from southeastern Kansas containing much more evenly distributed and much finer pores. Other differences between these two Pennsylvanian reservoirs include area and thickness of the rock serving as the reservoir, the reservoir energy, fluid saturations and relative amounts of produced fluids. These later characteristics of the reservoir are obtained from other data. Together this information is related through mathematical formula to estimate oil recovery from the reservoir observed in the production decline curves.

Reservoirs are porous intervals of extensive rock layers found in the subsurface of the State and the Midcontinent. The units were deposited millions of years ago. The processes that were active during deposition and burial of these rocks determined the properties of the reservoir rock. Some reservoirs are noted for their variability such as the Pennsylvanian sandstones and limestones, while others are noted for their general uniformity, e.g. the Arbuckle Group. However, on a lease by lease basis even the seemingly homogeneous units vary.

Figure 6. Surface geological map of Kansas and east-west geological cross section.

In general, the rock layers in Kansas gently dip to the west. The oldest rocks are exposed in the eastern portion of the state. These older rocks serve as petroleum reservoirs where they occur at depth beginning as shallow as several hundred feet in eastern Kansas. The distribution of the rock layers is affected by large-scale folding of the earth's crust including two large uplifts called the Central Kansas and Nemaha uplifts from which a good share of the oil production is found.

Figure 7. Configuration of the surface on the Precambrian in Kansas.

The uplifts and basins are illustrated on this map according the relative elevations on the surface of the rock units on which the major oil and gas reservoirs were deposited. This map provides an important means of relating and comparing production across the State.

Figure 8. Oil and Gas map of Kansas.

Field distribution is closely linked to the relative elevation of an area or structure on which the reservoir resides. Many new and old fields have also been found in basinal areas flanking these major uplifts. Kansas and much of the Midcontinent are part of a mature oil and gas producing province.

Over 75 million barrels of oil were produced in Kansas in 1985. The American Petroleum Institute estimates that over 16.5 billion barrels of oil were originally in place in Kansas. Some 11 billion barrels remain, only a fraction of which are recoverable. Proved reserves are now around 370 million barrels. 33% of Kansas is under lease amounting to over 17 million acres. There are 51,000 producing wells, 93% of them producing less than 10 barrels per day and are included in the stripper well category. Kansas has been recently ranked between first and third in number of wildcats drilled and third in total drilling.

Figure 9. Drilling density map.

Many of the 150,000+ wells in Kansas have been drilled on the Central Kansas uplift, in the Sedgwick basin, and in eastern Kansas. Other areas are surprisingly sparsely drilled, but with prices once again on track we should see activity in these areas and hopefully new successes. Viable and interested bankers will definitely be needed in realizing any success. The dense drilling and development in many areas provides a wealth of data for lease appraisal, but what is available to an individual bank is effectively limited by the time, expense, and knowledge required to compile the information.

Figure 10. Map of depths to deepest producing reservoirs in Kansas.

Depth of the reservoir beneath the surface significantly affects the cost of operations of a lease, e.g. lifting and drilling costs, and will affect the ultimate recovery and production schedule of oil and gas. Depth therefore serves as one obvious means of comparison. The shallowest reservoirs or pays are generally located in eastern Kansas.

Figure 11. Distribution of oil and gas wells producing from the Arbuckle Group.

Several examples from prominent reservoirs will illustrate that their variability is the rule rather than the exception. 48% of the original-oil-in-place is associated with Arbuckle reservoirs. Only a small fraction of new discoveries have Arbuckle pays. This reservoir is noted for its long producing life and accordingly, profitable operation of older Arbuckle leases continues today. The reservoir is widespread beneath Kansas, but the accumulations of oil and gas are most abundant on the major uplifts of the state such as the Central Kansas uplift.

Figure 12. Production decline curve for an Arbuckle lease from the Central Kansas uplift.

Production decline curves (rate vs. time) serve very well as a means for comparing different reservoirs. These data were provided by a producer. The example is a recently developed lease showing an initial rather rapid decline typical of oil wells in the State. The Arbuckle is almost always a water-driven reservoir. Water-driven means water encroaches into the reservoir as the oil is produced and replaces the fluid brought to the surface. Hence, the rate of decline flattens out at intermediate levels because the pressure is maintained. This is common for high porosity, water-driven reservoirs, which makes the Arbuckle stand out.

Figure 13. Decline curve for a long-time producing Arbuckle lease in El Dorado field.

This lease illustrates the flattened decline curve common to most Arbuckle leases after they have been produced over a considerable time. However, the production rate does not include the large volumes of water that are commonly extracted with the oil late in the life of these leases. The offsetting effect of the oil price and the lease operating expenses such as lifting and water disposal costs and production taxes would determine whether the production level stays above the economic limit.

Figure 14. Map of wells producing oil and gas from the Mississippian limestones in Kansas.

23% of the original-oil-in-place comes from Mississippian rocks in Kansas. The reservoir is absent over the Central Kansas uplift, thus the major reason for the gap in the producing area. Major producing areas of the Mississippi Lime are nearly mutually exclusive with Arbuckle production in most parts of the state. Four successive, but distinctively different layers of limestone comprise this interval and are often simply referred to as the Mississippi lime.

Figure 15. Production decline curve for a Mississippi lime lease in western Kansas.

The decline curve for an operating lease from a Mississippian reservoir in western Kansas shows a greater rate of decline compared to the Arbuckle because of differences in both the properties of the reservoir and the natural energy available to maintain pressure in the reservoir. This particular lease has a combination gas and water drive in a reservoir with less extensive porosity development. However, Mississippian reservoirs in and among the four divisions have notable variations in type of reservoir and accordingly the decline curves vary from area to area according to depth, whether they are gas or water drive, and the properties of the rock.

Figure 16. Map of wells producing oil and gas from the Cherokee Group (Des Moines Pennsylvanian) in Kansas.

The Pennsylvanian is comprised of literally dozens of separate and distinct pay zones. The Cherokee Group produces from several sandstone units in eastern Kansas while in western Kansas production is from both limestones and sandstones. The two areas of western and eastern Kansas are not recommended for comparison of production nor can they be easily compared in western Kansas.

Figure 17. Map of wells producing oil and gas from the Lansing and Kansas City groups (LKC, Missourian) in Kansas.

The LKC is a succession of thin limestones and alone contains 12 possible producing zones. This commonly reported classification combines all of these pays together just as is done in the Cherokee Group. The LKC is noted for the discontinuous nature of its reservoirs. Only one or two zones commonly produce on any one lease on which only some of the wells are actually productive.

Figure 18. Production decline curve for a LKC lease in western Kansas exhibiting multiple zone production in the LKC.

Typically, the LKC pay zones are noted for their very rapid decline rate especially during the first year (approximately 60%). This rate of decline levels off to around 20% per year which results in a shorter life of these leases compared to Mississippian and Arbuckle pays. There are some notable exceptions and an expected rate of decline for LKC will not always hold true.

Figure 19. Production decline curve for a single fractured limestone pay from another LKC lease in western Kansas.

The rate of decline in this fractured LKC limestone pay is even greater. The lease was near its economic limit after only several years of production. The main source of primary energy in this reservoir apparently is dissolved gas in the oil which together with the small reservoir volume contribute to this rapid decline because of rapid pressure drop in the reservoir. Nevertheless, the production was initially high enough so that the wells paid out. The production schedule and ultimate recovery from this example would probably be appreciably different from the others.

The rapid rate of decline is generally greater for the Pennsylvanian pays than other zones. These reservoirs are particularly suited to secondary recovery where water is injected to increase pressure or perhaps designed to sweep additional oil from the reservoir. Other enhanced recovery methods may be employed to get what may be two-thirds or so of the oil not extracted during primary recovery.

The Pennsylvanian pays including the Morrow sandstones in southwestern Kansas, eastern Colorado, and Oklahoma and together account for over half of the new oil found in discovery wells during the last five years in Kansas. This success is in part due to the number of prospective zones and the elusive nature of their distribution which are only now being found as new and more costly exploration methods are employed. Projects such as this are ones where funds are and will be sought.

We hope from this discussion that it is apparent that simple rules of thumb may or may not be successfully applied to lease appraisal, but vary according to the complexity of the reservoir.

Table 1. Range of lease operating expenses (LOE) in Kansas required to calculate a lease's economic limit (EL).

Estimates of Monthly Lease Operating Expenses (LOE) in Kansas

Estimate	Gas	Oil
low	600	900
average	900	1200
high	1200	1500

lifting costs, chemical treatment, maintenance costs, workover costs, production taxes (ad valorem, severance)

e.g., <u>low</u> cost: low water cut, lighter oil, shallow depths. <u>high</u> cost: high water cut, deep, unusual oil properties needing treatment

(Table 1 continued)

ECONOMIC LIMIT (EL)
Barrels Oil Per Day

$$EL = \frac{LOE}{30.4 \times \text{price} \times (1-\text{state tax}) \times NRI/WI}$$

NRI, net revenue interest
LOE, lease operating expense

As previously discussed, an important factor in lease appraisal is the determination of the economic limit. The LOE are varied in amount and type by reservoir, location, and depth. LOE for oil producing units in Kansas, in general, range from \$900.00 to \$1500.00 per month with a monthly average of \$1200.00.

Table 2. Three examples of LOE for leases in central Kansas and calculation of the economic limit compared to actual production and market price for the oil.

Kansas Examples of <u>LOE</u> and <u>EL</u>

January-May, 1986

Example Lease		Jan	Feb	Mar	Apr	May
(1)	LOE($)	1202	1282	1791	1188	1160
	bbls prod.	3090	2710	2372	1887	1584
(2)	LOE($)	6340	4036	3983	3867	3565
	bbls prod.	682	606	692	588	603
(3)	LOE($)	1768	2055	1410	1328	1256
	bbls prod.	188	152	145	149	143

(1) and (3) similar expenses but contrasting production

Darcies Law
Darcy's Law

(Table 2 continued)

	Ave. BOPD	$9	Economic BOPD $12	Limit $14
(1) LOE($) bbls prod.	77	5.9	4.4	3.8
(2) LOE($) bbls prod.	21	20.3	15.3	13.1
(3) LOE($) bbls prod.	5	7.3	5.5	4.7

(1) and (3) similar expenses but contrasting production

Actual LOE on Leases 2 and 3 indicate that these are in trouble if the price does not increase soon as they are barely able to pay for themselves. The high operating costs of lease 2 may be due to high lifting costs associated with high water cut. As lease 1 shows, its high producing rate provides a comfortable margin between the revenue on that lease over the cost of operating the lease. A lease with this wide margin in Kansas should not be in jeopardy if the price falls further, but is an exception rather than the rule.

I. Summary

1. Reserve estimates are an important component in determining collateral value of a producing lease and the associated loan schedule. The uncertainties in present economic and market climate provide little tolerance for error. However, even in good times the prudent handling of lease appraisal is good operating procedure. Admittedly, reserve estimation involves uncertainty, but it should be distinguished from other forms of risk in order to provide realistic appraisals. Some form of reserve or performance estimate, perhaps simply a collection of factual geologic and engineering information on a lease will help to evaluate the variables which lead to good loans and lead to even greater success.

2. The assignment of a risk factor to the present value of the lease determines actual loan value of the property. This assignment of risk conforming with bank practices should consider in addition to circumstances and experience of borrower and degree of uncertainty and economic forecasts, the appraisal of reserves and cash flow available for debt service.

Rules of thumb on loan value with stable market conditions make good comparisons and incorporate many factors, but the reliance on these numbers contributes little to understanding the sensitivity of variables that led to the success or failure of the loan. The fluctuation of price, for example, would have a much greater impact on some leases due to geologic and engineering parameters. Their introduction in some form into the formula for lease appraisal would be instructive.

3. State organizations are interested and capable of providing information that can assist in making at least initial, first- approximation reserve appraisals. The reports on oil and gas production and their distribution are useful for integrating the lease with associated production trends. The answers to key questions about the lease or the awareness needed to recognize the need for additional information from the operator for validating the reservoir characteristics on the lease may be provided by the maps and reports. An engineer or geologist could be retained at some point to assist in collecting and analyzing this data. If the project is substantial, the retention of an engineer or geologist for a comprehensive reserve estimate may be needed to determine the expected performance of a lease and to translate the information into useful indices for the bank officers to use in later analysis.

4. It is essential that all parties work together and at least think about how we can quickly, but carefully revive and strengthen the industry for the next round when economic conditions improve. The ability to address basic geological and engineering factors crucial in lease appraisal may alleviate some of the problems that bankers have been facing. We would recommend further education opportunities focused on the subject of reserve appraisal taylored to the needs of small and intermediate-sized banking institutions.

Acknowledgments

Appreciation is extended to Kent Crisler, Tom Hansen, and Larry Richardson for their informative discussion and to Jennifer Sims and Stephen Wai Leung Cheng for their assistance with the computer graphics. Thanks is given to John Charlton for photographic work and Lea Ann Millikan for word-processing.

Attachment: List of selected figures as numbered in text.

HUGHES TOOL COMPANY RIG COUNTS

ACTIVE ROTARY RIGS IN KANSAS: 1970 - 1986

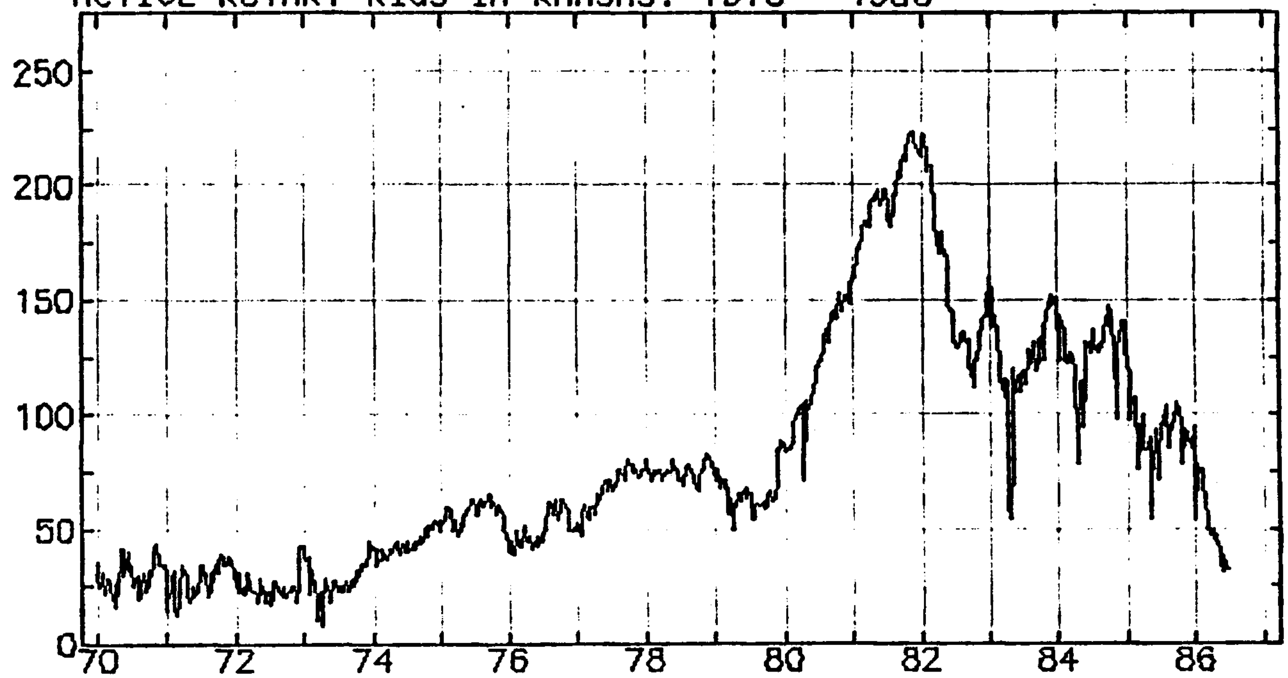

FIGURE 1

KANSAS GEOLOGICAL SURVEY

RESERVE ESTIMATES - STABLE PRICE FORECAST

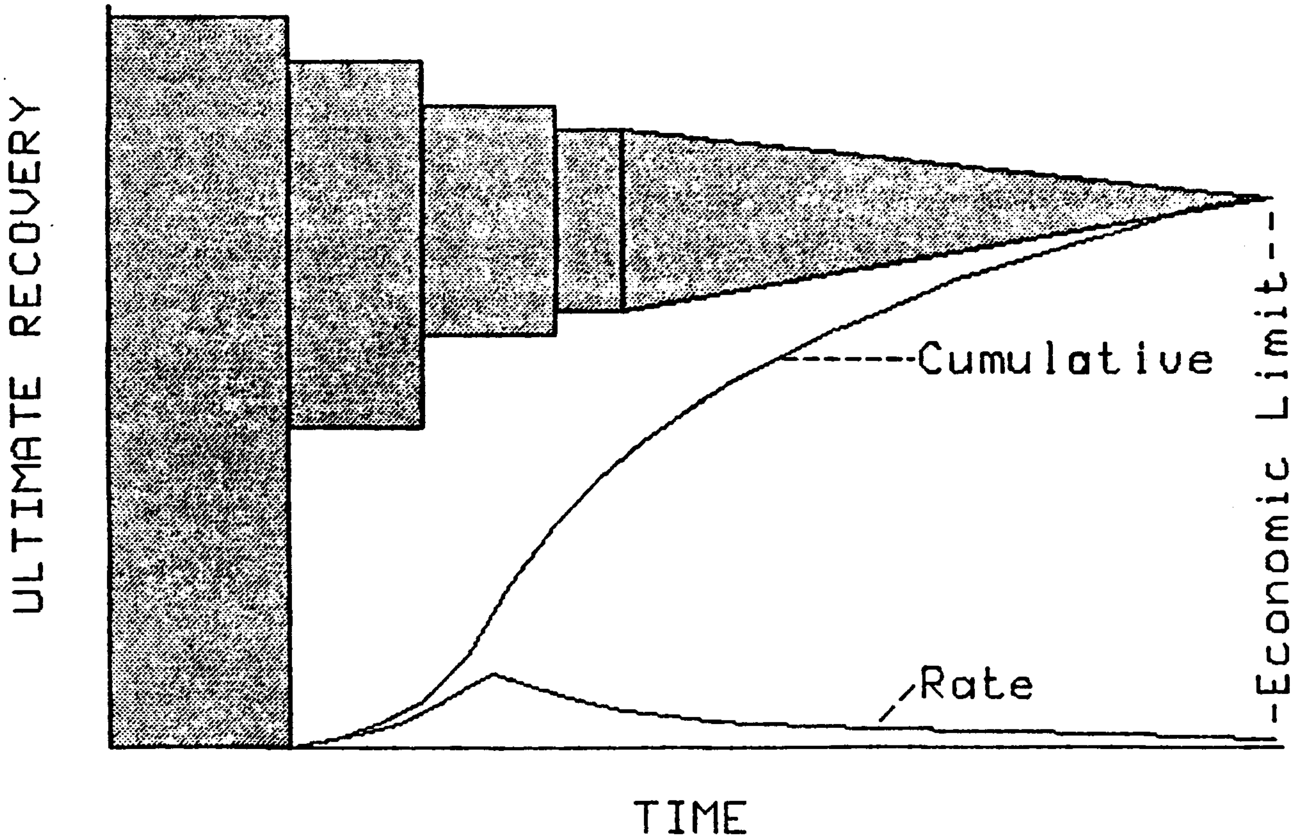

FIGURE 2

RESERVE ESTIMATES - UNEXPECTED PRICE DROP

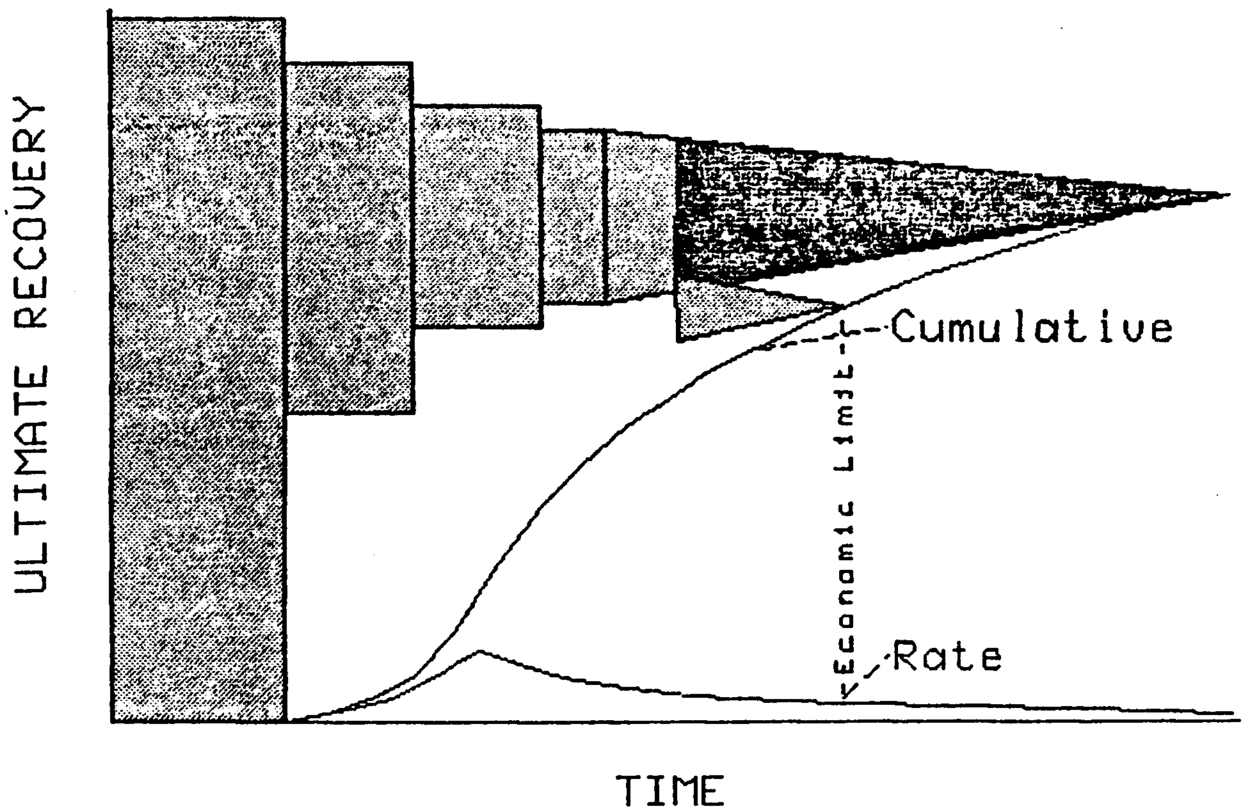

FIGURE 3

Kansas Geological Survey

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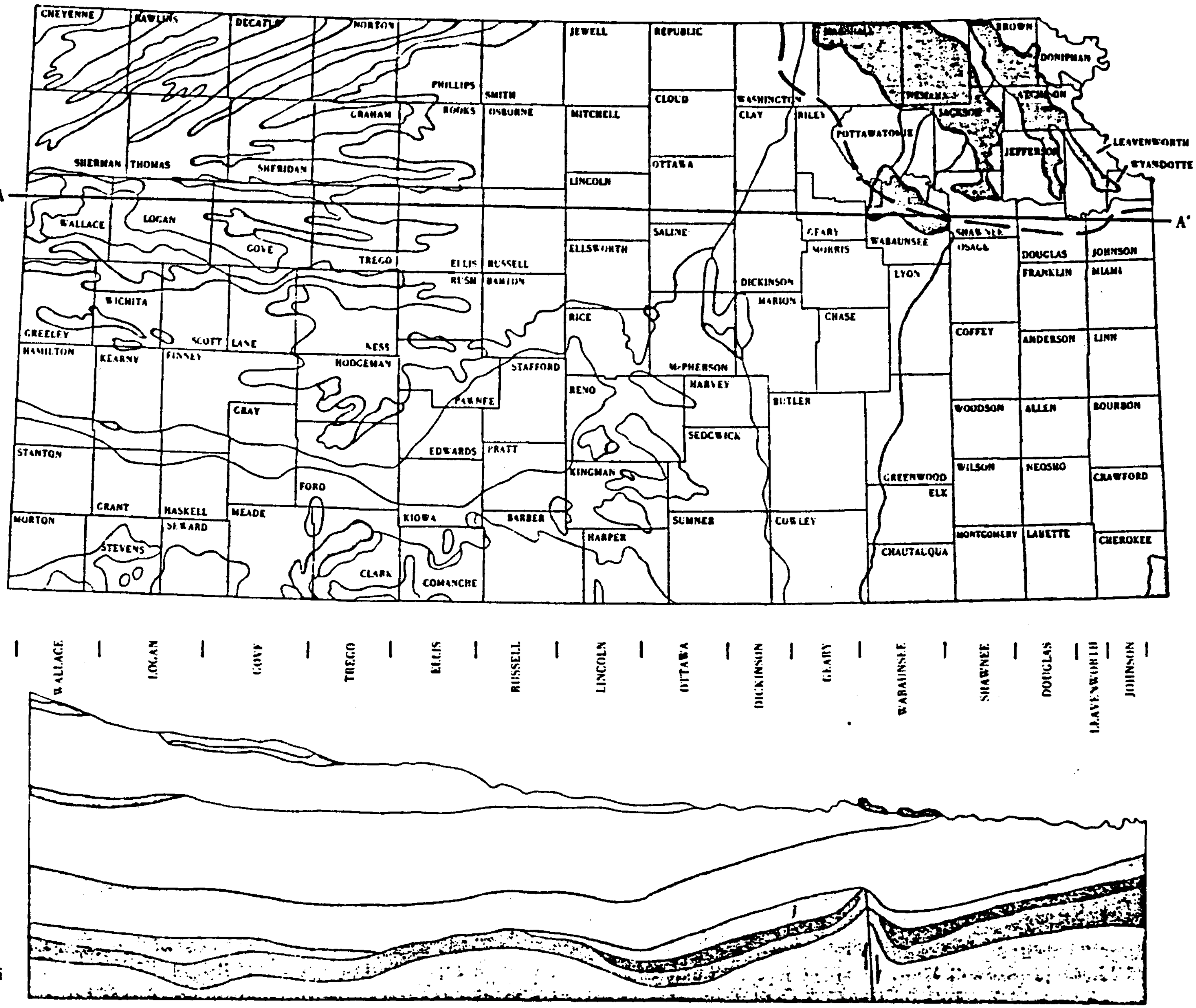
Generalized Geologic Map of Kansas

EXPLANATION

- QUATERNARY SYSTEM
  - Loess and river valley deposits
  - Sand dunes
  - Glacial drift deposits
  - Limit of Kansan Glacier
- TERTIARY SYSTEM
- CRETACEOUS SYSTEM
- JURASSIC SYSTEM
- PERMIAN SYSTEM
- PENNSYLVANIAN SYSTEM
- MISSISSIPPIAN SYSTEM
- SILURIAN-DEVONIAN SYSTEMS
- CAMBRIAN-ORDOVICIAN SYSTEMS
- PRECAMBRIAN SYSTEM
- A—A' Line of cross section

0 50 100 mi

0 50 100 km



Geologic cross section below I-70

KANSAS GEOLOGICAL SURVEY

FIGURE 6

Configuration of Kansas Basement

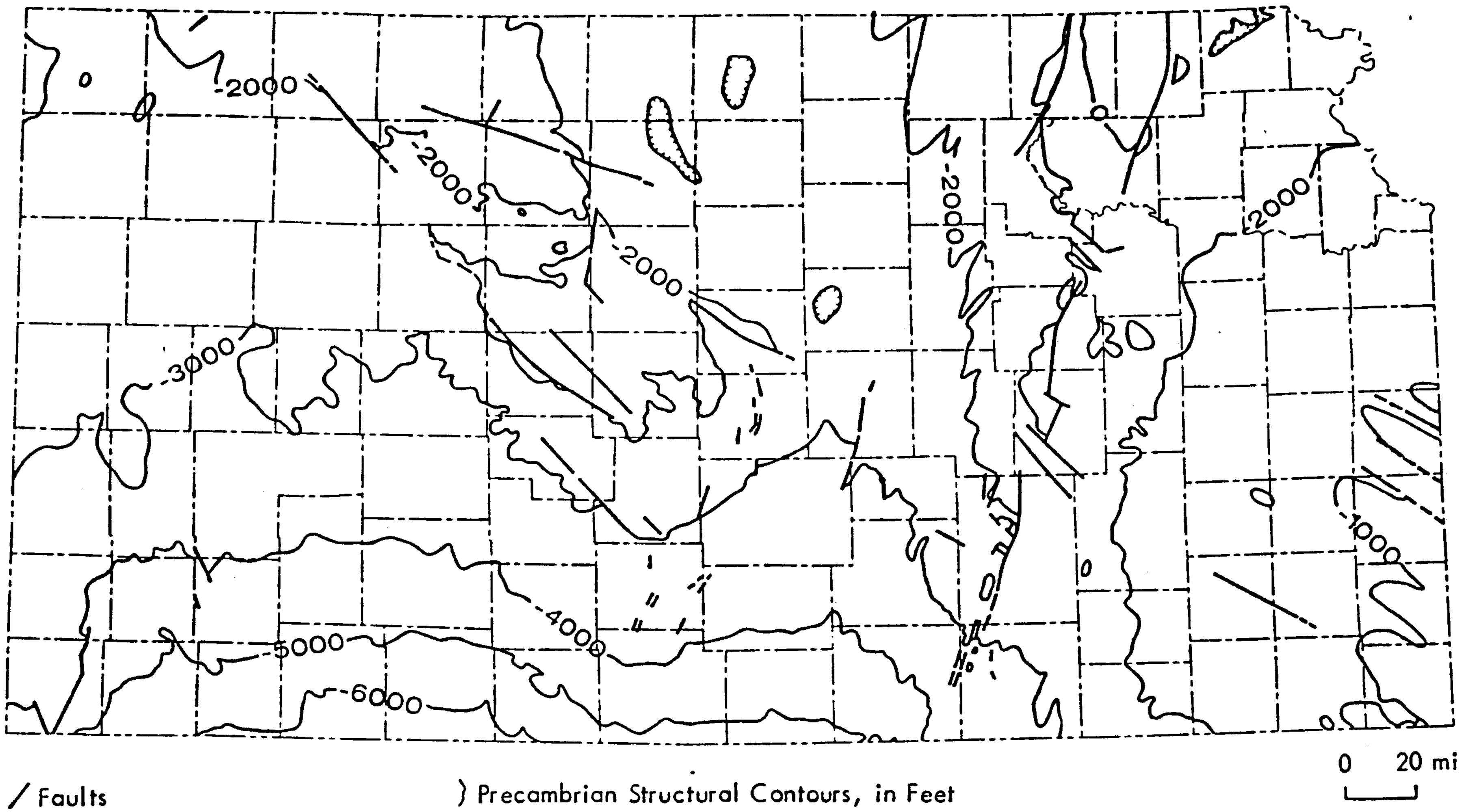


FIGURE 7

KANSAS GEOLOGICAL SURVEY

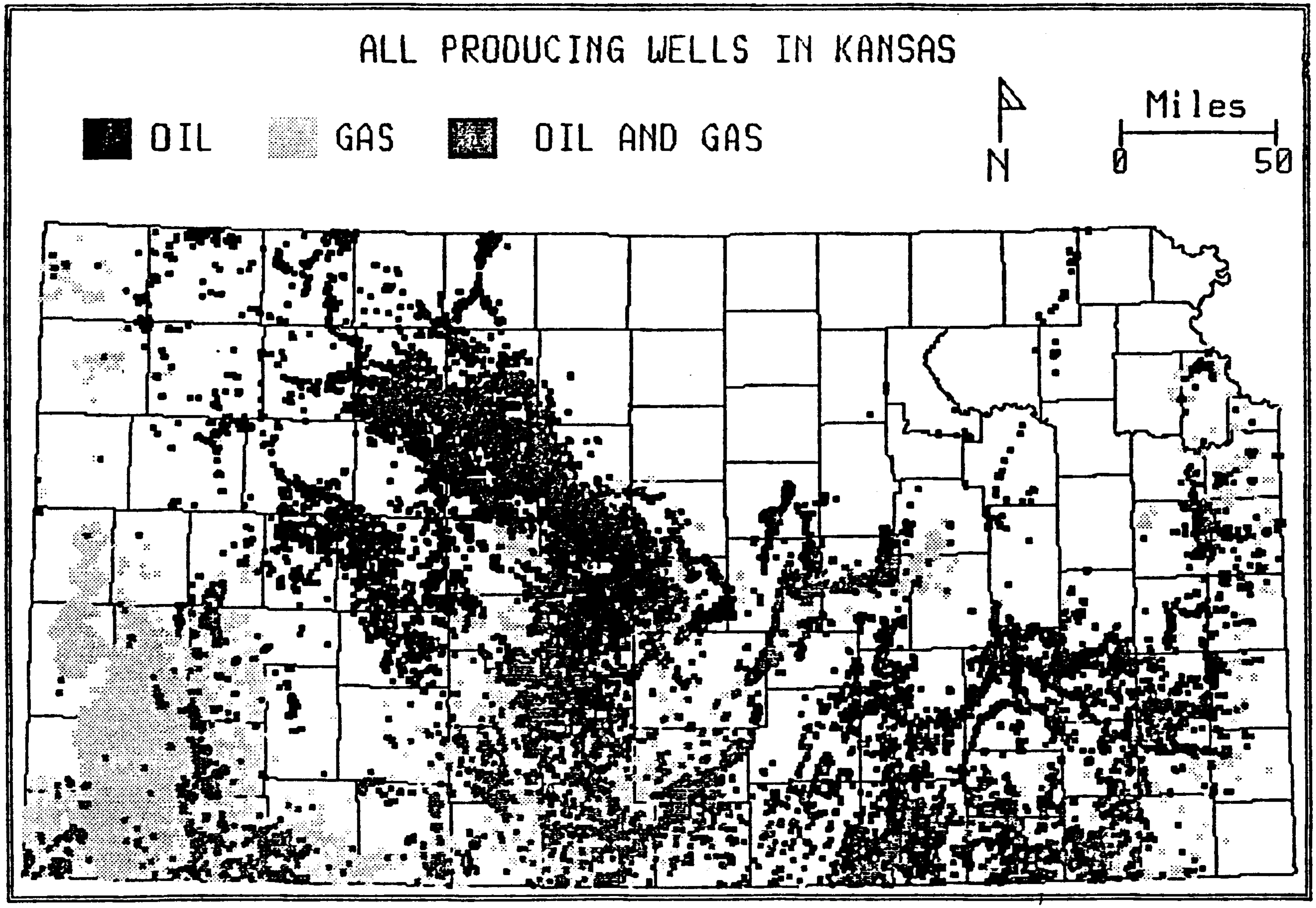
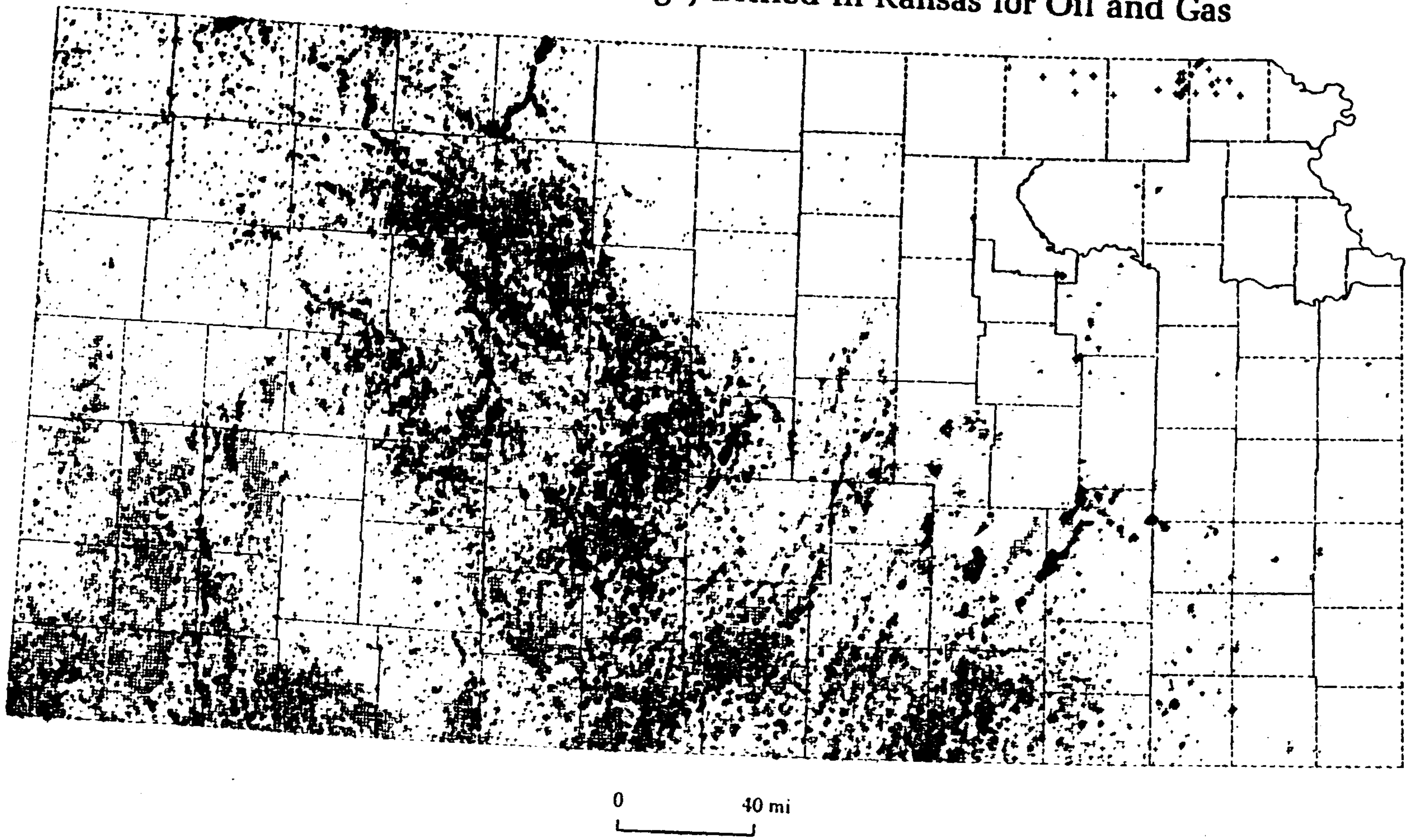


FIGURE 8

Holes (with geophysical logs) Drilled in Kansas for Oil and Gas



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KANSAS GEOLOGICAL SURVEY

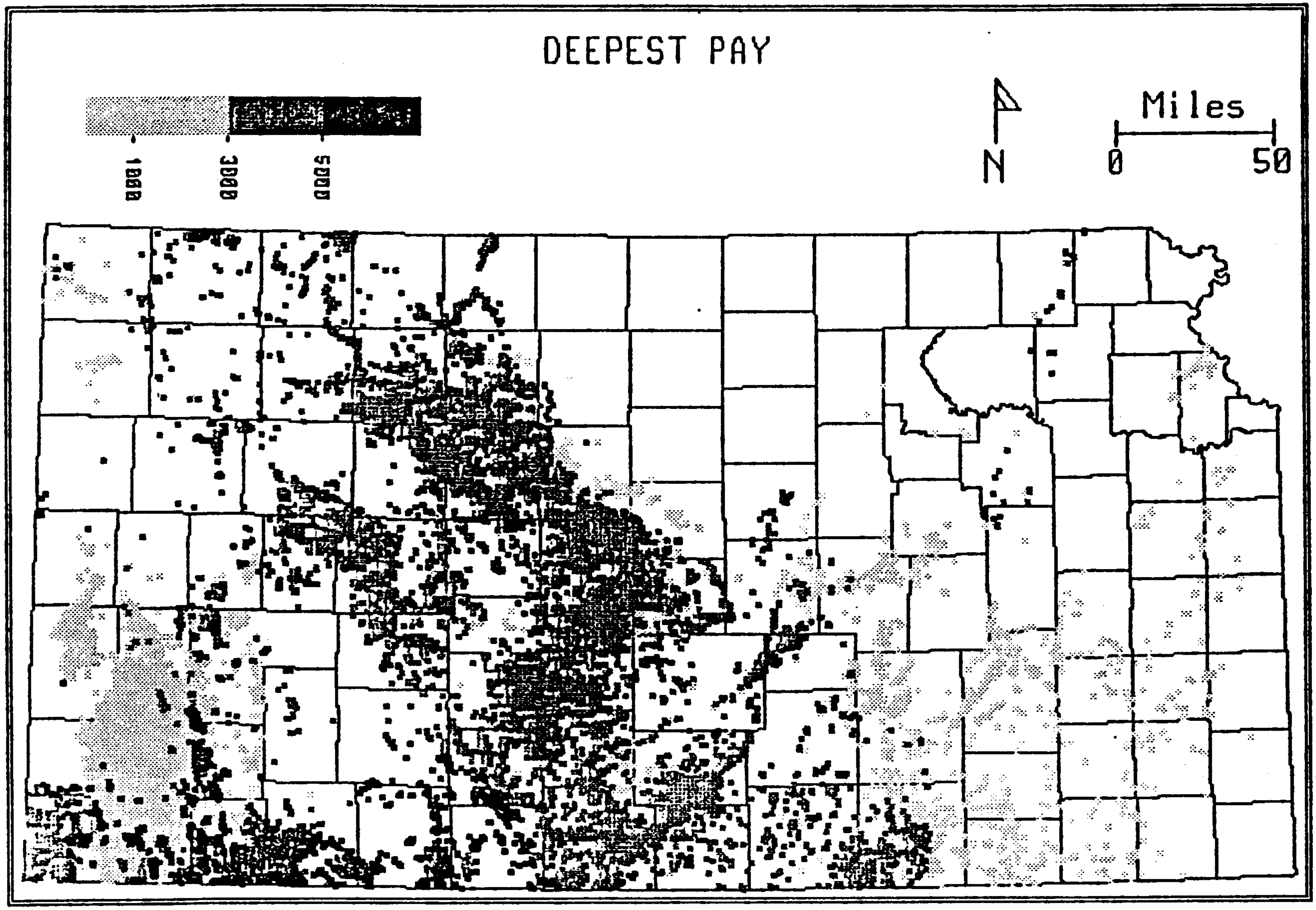
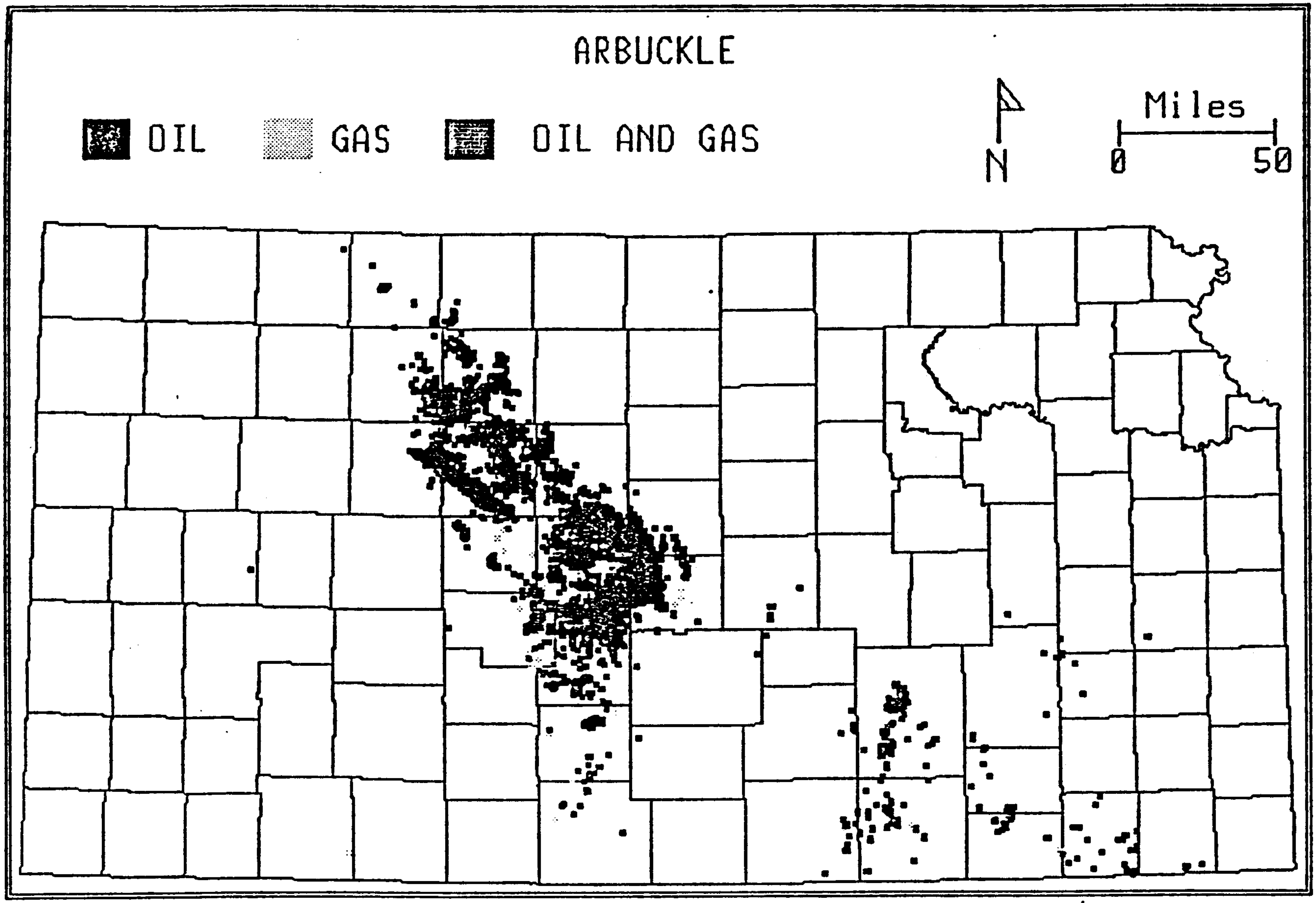


FIGURE 10

KANSAS GEOLOGICAL SURVEY



GURE 11

KANSAS GEOLOGICAL SURVEY

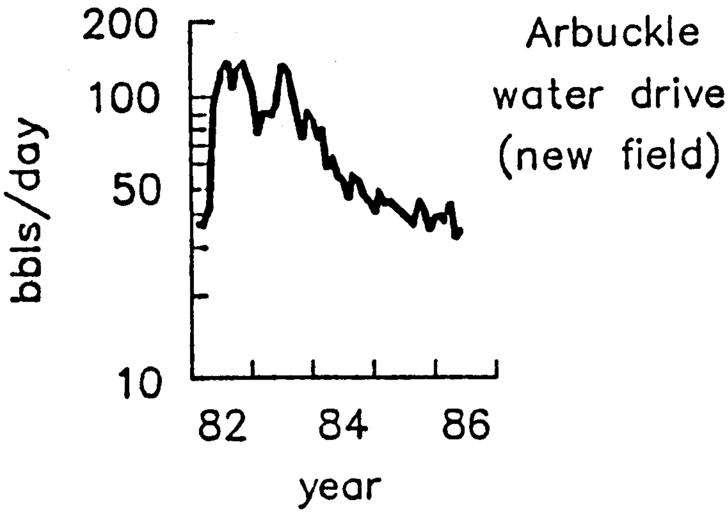


FIGURE 12

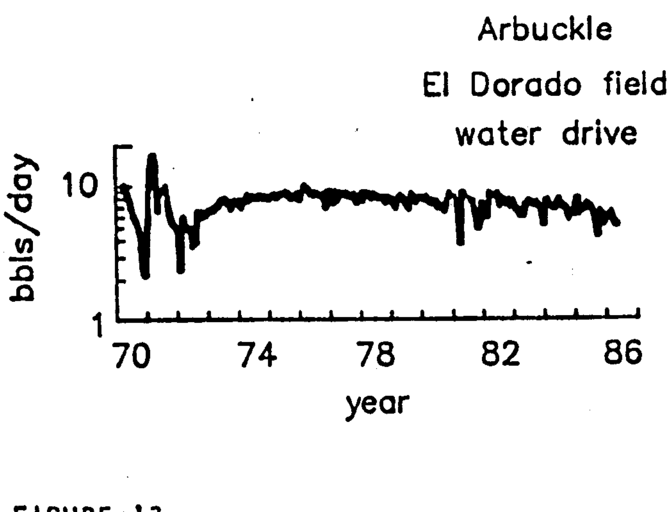
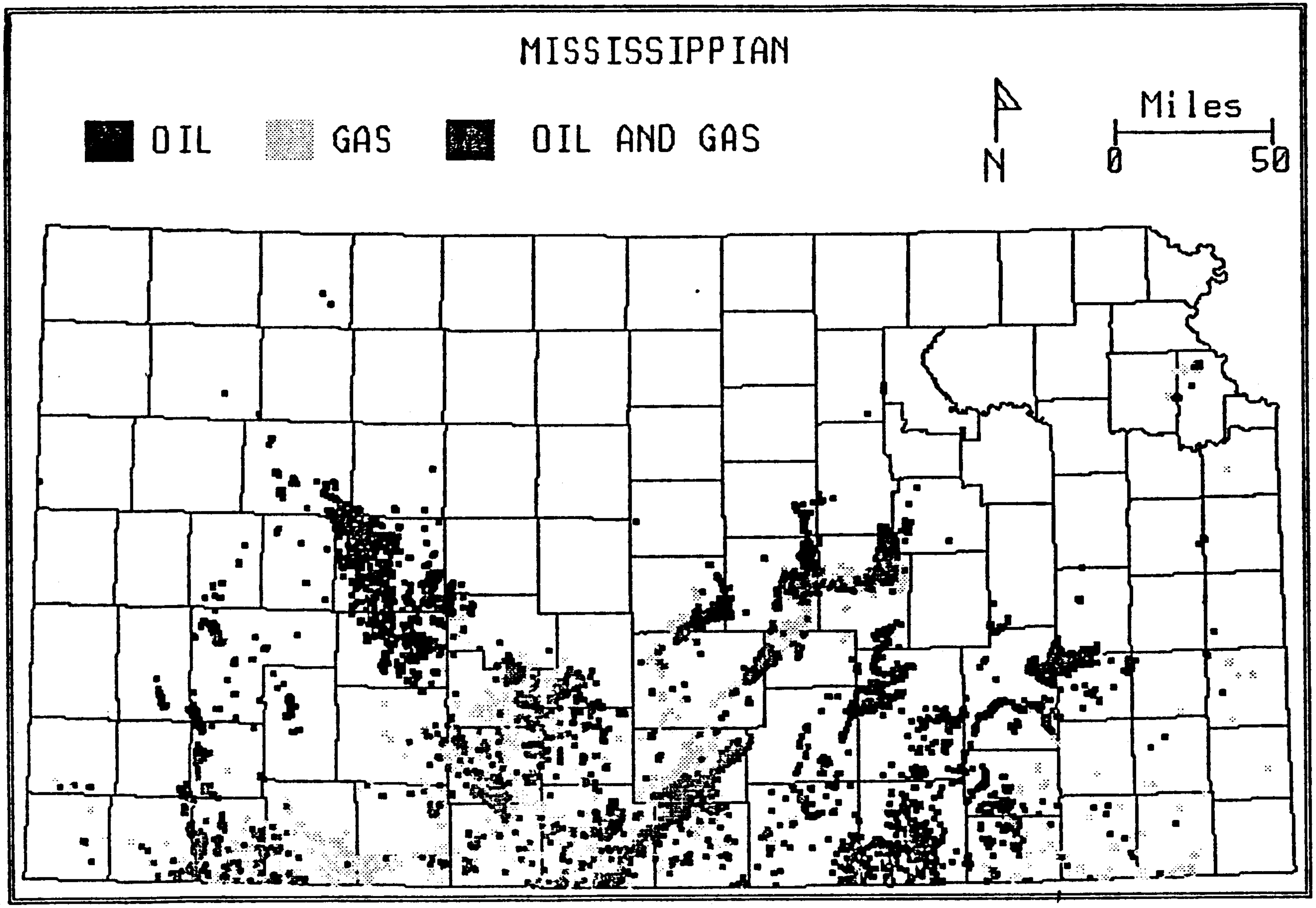
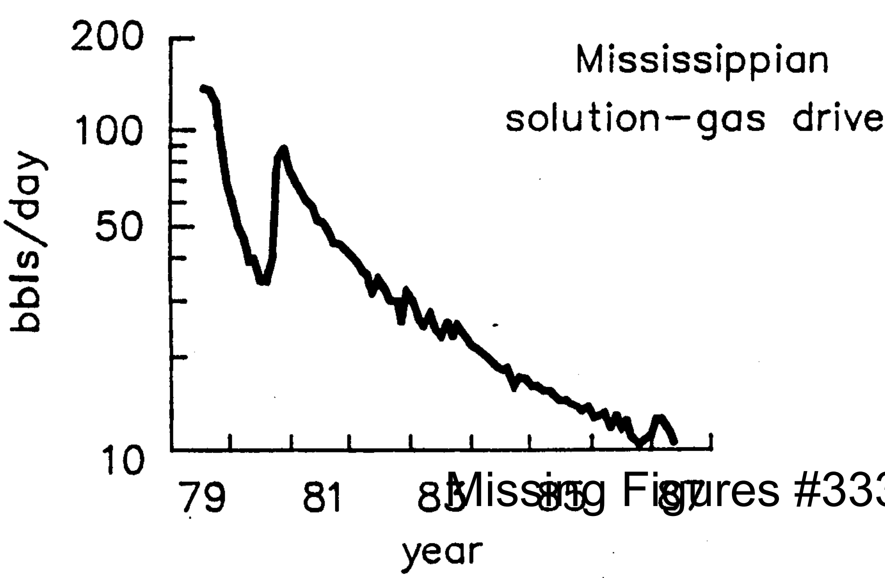


FIGURE 13



KANSAS GEOLOGICAL SURVEY

FIGURE 14



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KANSAS GEOLOGICAL SURVEY

FIGURE 15

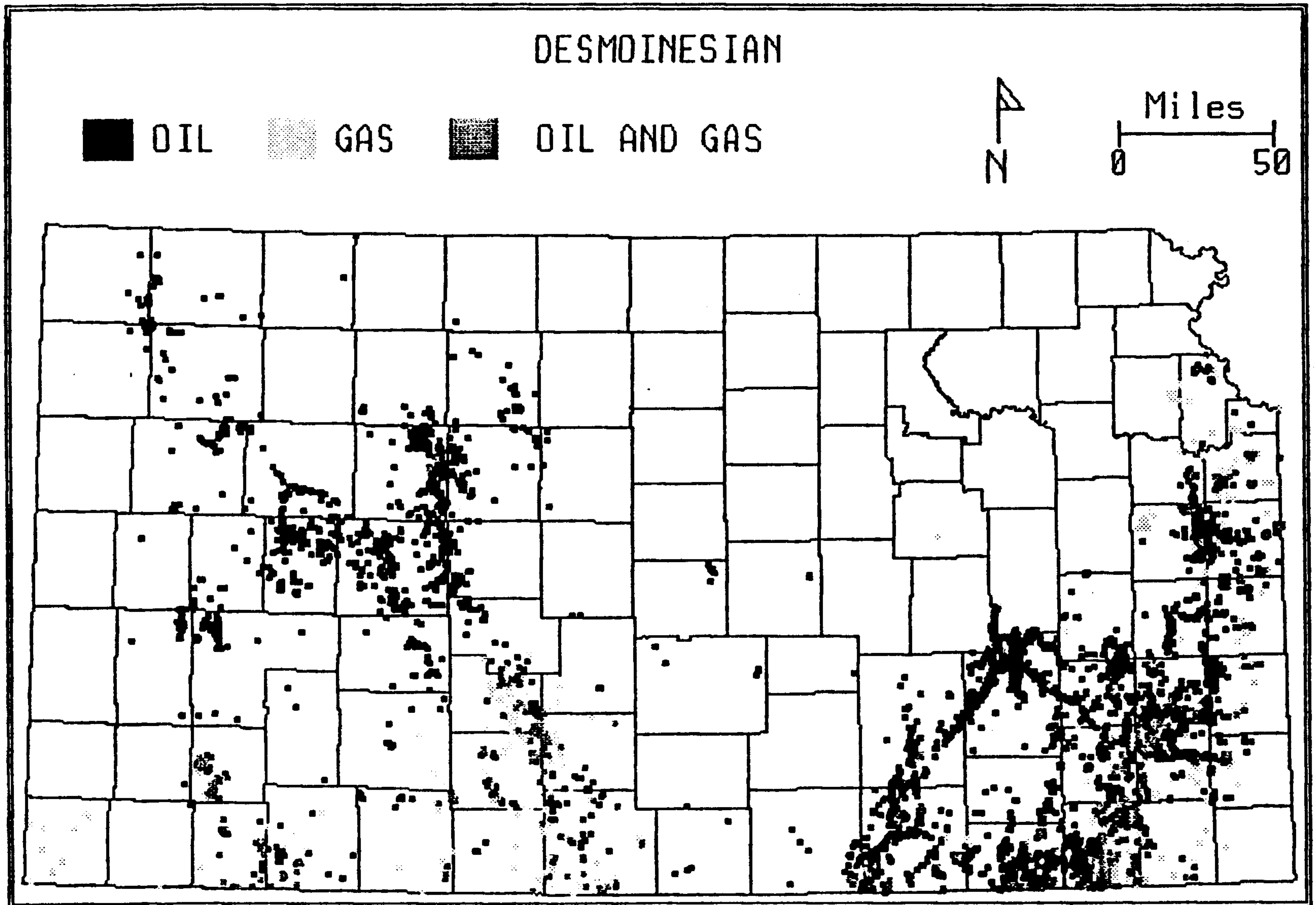
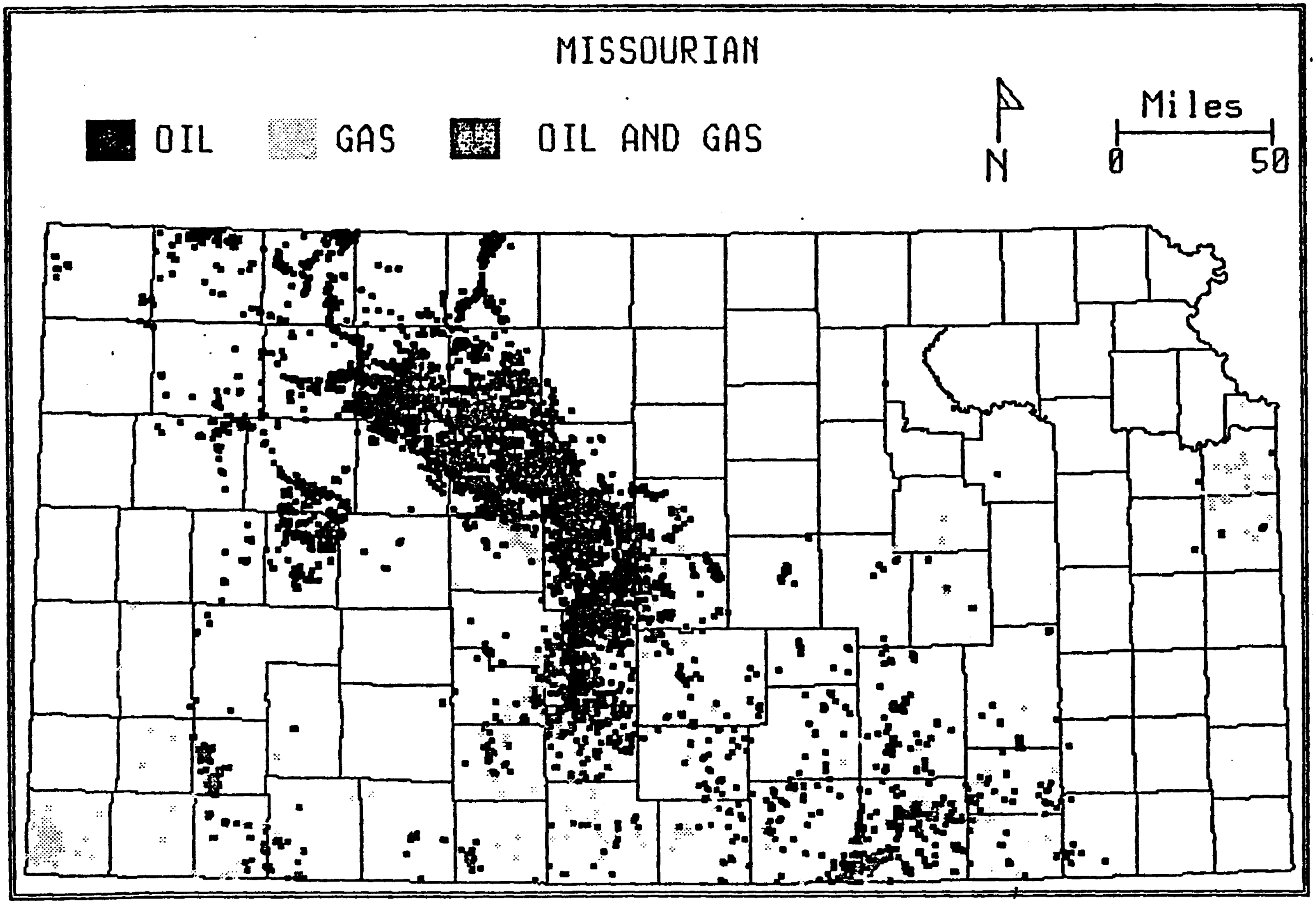


FIGURE 16

KANSAS GEOLOGICAL SURVEY



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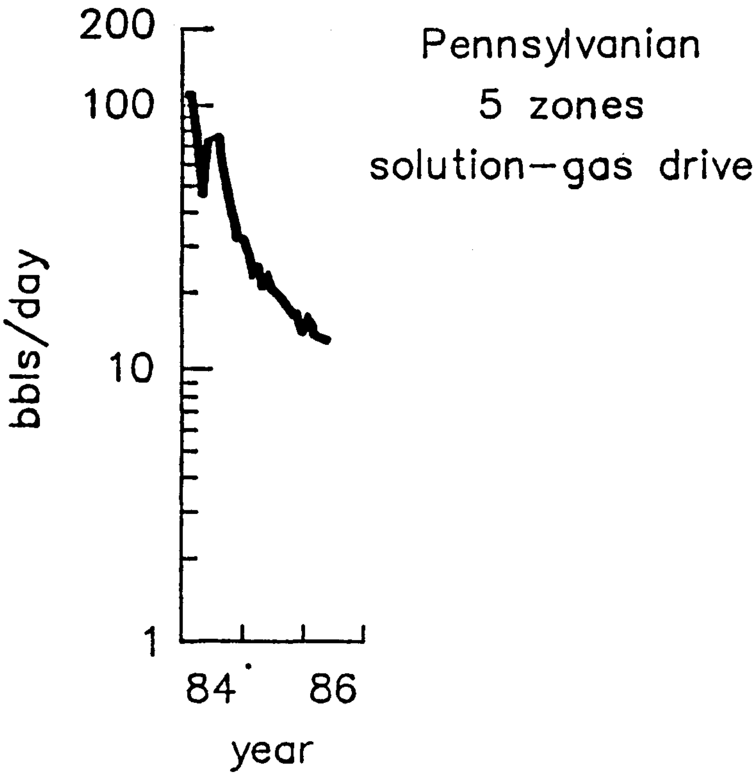
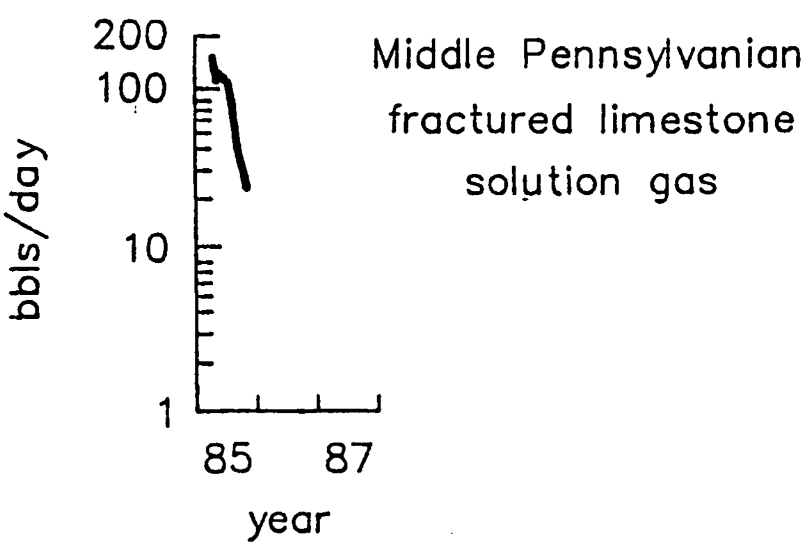

Pennsylvanian
5 zones
solution-gas drive
bbls/day
200
100
10
1
84
86
year

FIGURE 18


Middle Pennsylvanian
fractured limestone
solution gas
bbls/day
200
100
10
1
85
87
year