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AN ANALYSIS OF SURFACE AND SUBSURFACE LINEAMENTS AND FRACTURES FOR OIL AND GAS EXPLORATION IN THE MID-CONTINENT REGION

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March 1995

By
Genliang Guo
Stephen A. George

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ABSTRACT

An extensive literature search was conducted and geological and mathematical analyses were performed to investigate the significance of using surface lineaments and fractures for delineating oil and gas reservoirs in the Mid-Continent region. Tremendous amount of data were acquired including surface lineaments, surface major fracture zones, surface fracture traces, gravity and magnetic lineaments, and Precambrian basement fault systems. An orientation analysis of these surface and subsurface linear features was performed to detect the basic structural grains of the region. The correlation between surface linear features and subsurface oil and gas traps was assessed, and the implication of using surface lineament and fracture analysis for delineating hydrocarbon reservoirs in the Mid-Continent region discussed.

It was observed that the surface linear features were extremely consistent in orientation with the gravity and magnetic lineaments and the basement faults in the Mid-Continent region. They all consist of two major sets trending northeast and northwest, representing, therefore, the basic structural grains of the region. This consistency in orientation between the surface and subsurface linear features suggests that the systematic fault systems at the basement in the Mid-Continent region have probably been reactivated many times and have propagated upward all the way to the surface. They may have acted as the loci for the development of other geological structures, including oil and gas traps. Also observed was a strong association both in orientation and position between the surface linear features and the subsurface reservoirs in various parts of the region. As a result, surface lineament and fracture analysis can be used for delineating additional oil and gas reserves in the Mid-Continent region.

The results presented in this paper prove the validity and indicate the significance of using surface linear features for inferring subsurface oil and gas reservoirs in the Mid-Continent region. Any new potential oil and gas reservoirs in the Mid-Continent region, if they exist, will be likely associated with the northeast- and northwest-trending surface lineaments and fracture traces in the region.

ACKNOWLEDGMENTS

This work was sponsored by the U.S. Department of Energy under Work Request Number 95-A04. The authors wish to thank Rhonda Lindsey of the DOE Bartlesville Project Office for her support, counsel, and encouragement. The authors also acknowledge the contribution of the following BDM-Oklahoma employees: William Johnson and Wendy Troxell.

AN ANALYSIS OF SURFACE AND SUBSURFACE LINEAMENTS AND FRACTURES FOR OIL AND GAS EXPLORATION IN THE MID-CONTINENT REGION

1.0 INTRODUCTION

This report presents the results of our investigation on the significance of lineament and fracture analysis for oil and gas exploration in the Mid-Continent region. The investigation covers parts of Oklahoma, Kansas, Nebraska, South Dakota, Missouri, Iowa, and adjacent areas. Existing studies on surface and subsurface lineaments and fractures in the region were reviewed. Information on surface and subsurface lineaments and fractures interpreted from satellite images, aerial photographs, and gravity and magnetic surveys or through surface monoclinal analysis were collected, digitized, and analyzed. An orientation analysis was performed, and correlations between surface and subsurface lineaments as well as between surface lineaments and subsurface oil and gas traps were investigated. The significance of using surface lineament and fracture analysis for delineating additional traps in the Mid-Continent region was assessed.

2.0 A REVIEW OF SURFACE AND SUBSURFACE LINEAMENT STUDIES IN THE MID-CONTINENT REGION

An extensive literature search was conducted to collect information on surface and subsurface lineaments, major fracture zones, fractures, and faults in the Mid-Continent region. The surface lineaments collected were primarily interpreted from Landsat satellite images, the surface major fracture zones were obtained through surface monoclinal analysis, the surface fracture traces were interpreted from aerial photographs, and the subsurface lineaments collected in this report were interpreted from gravity and magnetic data. The basement fault systems, in most cases,, were delineated from integration of remote sensing, geophysical, and geological data. The surface and subsurface linear features are separately presented in the following two sections.

2.1 SURFACE LINEAMENTS, MAJOR FRACTURE ZONES, AND FRACTURE TRACES IN THE MID-CONTINENT REGION

Tremendous amounts of information are available in the literature on surface lineament and fracture analysis using satellite images and/or aerial photographs. Figure 2–1 shows those areas where information on surface lineaments, major fracture zones, and fracture traces were collected and digitized in the Mid-Continent region. A brief review of these individual studies is given as follows.

Figure 2–2 shows the surface lineaments in the Nemaha Uplift area (Burchett et al. 1983). These surface lineaments were used in the study to define the Precambrian basement fault systems in an effort to identify the relationships between seismicity and tectonic activities in the area. Additional surface lineament and fracture studies which focus on small parts of the Nemaha Uplift region also have been reported.

Figure 2–3 shows the surface fracture traces mapped from the northern Forest City Basin in southwestern part of Iowa (Herman et al. 1986). The surface fracture traces were integrated with geophysical data to delineate preliminary structural leads for more detailed exploration methods (such as seismic and structural testing) in the prospect area.

DuBois (1978) correlated surface lineaments and fractures to subsurface tectonic features using data in Nemaha County, Kansas. The location and the surface lineaments and fractures are shown in Figure 2–4. The surface lineaments and fracture traces in this county were mapped based on surface drainage patterns. It was concluded from this analysis that many of the present stream valleys (i.e., many of the surface lineaments and fracture traces) likely follow directional weakness faulting which has been shown to breach the bedrock surface along the Humbolt fault zone, one of the major subsurface tectonic features in the county.

Johnsgard (1983) investigated the potential for hydrogen gas in north-central Kansas in a study which integrated different types of information: surface lineaments and fractures, surface soil gas measurements, and gravity and magnetic surveys . The location of this study and the surface lineaments and fracture traces used in the study are shown in Figure 2–5. The study concluded the surface lineaments and drainage patterns, gravity and magnetic lineaments, and subsurface fault systems are basically consistent among each other. This conclusion was also obtained from another study in eastern Kansas (Berendsen et al. 1983). The surface lineaments and fracture traces used in his study (see Fig. 2–6) were interpreted from surface drainage patterns. The surface lineaments and fracture traces in western Kansas were also mapped, as shown in Figure 2–7 (Cooley 1984).

A more recent and more detailed study on the correlation between surface lineaments and fracture traces, and subsurface geological features was reported in Osage County, Oklahoma (Guo and Carroll 1995). The surface lineaments and fracture traces are shown in Figure 2–8.

In the study, subsurface structures were mapped and their strikes compared with the orientations of the surface lineaments and fracture traces. It was observed that surface lineaments and fracture traces, and subsurface structures were exceptionally consistent in orientation. The surface lineaments and fracture traces were subsequently used for developing additional exploration leads in the area.

Figure 2–9 shows the surface lineaments and fracture traces mapped from Landsat images in the Anadarko Basin in western Oklahoma (Collins et al. 1974). The purpose of the study was to verify the applicability of using satellite image analysis for oil exploration.

Another very interesting study applied Landsat images to map surface lineaments and fracture traces for oil and gas exploration in Hugoton gas fields in southwestern Kansas and the Oklahoma Panhandle (Swanson and Shannon 1990). Landsat images were interpreted for mapping surface lineaments and fracture traces (see Fig. 2–10). The study observed that structural interpretation made from Landsat images can be a valuable, inexpensive supplement to the usual geological and geophysical studies carried out for petroleum exploration in the Mid-Continent region, and fracture trends interpreted from Landsat lineaments and drainage anomalies can be used to direct seismic programs and to select deeper exploration candidates below shallow infill-drilling programs in an area.

Perry and Lee (1986), the results of an investigation in the northern Denver Basin, is similar to the study of the Hugoton gas field. The surface lineaments mapped in this area are shown in Figure 2–11. In the study, the surface lineaments interpreted from Landsat images were found to correlate to known hydrocarbon accumulations. It was concluded that surface lineaments can be used in extending present production trends and in prospecting for new reservoirs.

Figure 2–12 shows the surface lineaments interpreted from Landsat images in western South Dakota (Shurr 1983). The analysis indicated that the surface lineaments there can be interpreted as basement-block boundaries. They may also be used as an exploration tool in the search for shallow gas.

Different from most lineament studies in which Landsat images or aerial photographs were used for mapping surface lineaments and fracture traces, Stix (1982) used Seasat images for mapping surface linear features in an effort to search for geothermal resources in western Nebraska. The study found that Seasat data do indicate surface manifestations of subtle basement structures, particularly faults and joints. The surface lineaments mapped in the study are shown in Figure 2–13.

Surface lineament and fracture analysis has also been used as a tool for environmental investigations, such as in a study in northeastern Iowa (Chen 1992). The surface lineaments and fracture traces used in this investigation are shown in Figure 2–14.

Kisvarsanyi and Martin (1977) integrated surface geological analysis with a study of surface lineaments and fracture traces for general mineral exploration in Missouri. The surface lineaments and fracture zones are shown in Figure 2–15. Kisvarsanyi and Martin concluded that the lineaments in Missouri are, in general, expressed on the ground as combinations of geomorphologic features, faults, fracture zones, escarpments, and axes of synclines and anticlines. The lineaments often express major Precambrian zones of tectonic weakness and provide general locations for potential mineral deposition.

2.2 BASEMENT FAULTS AND GRAVITY AND MAGNETIC LINEAMENTS IN THE MID-CONTINENT REGION

In addition to surface lineament and fracture studies, various reports and papers have been published on the analysis of lineaments interpreted from gravity and magnetic surveys and of basement structures. Figure 2–16 shows those areas in the Mid-Continent region for which studies of gravity and magnetic lineaments, and/or basement fault systems are available. The individual studies are reviewed in the following paragraphs.

In an effort to decipher the surface manifestations of basement tectonic structures in south-central Kansas, a study was conducted comparing gravity, magnetic, and surface lineament trends (Dwivedi 1983). The linear anomalies interpreted from gravity and aeromagnetic surveys are shown in Figures 2–17 and 2–18, respectively. Dwivedi showed that lineaments interpreted from gravity and aeromagnetic data were mostly caused by anomaly patterns. Slope mapping of gravity and magnetic data can be used to predict the locations of basement controlled faults.

Another study analyzed the gravity and aeromagnetic data in all of Kansas (Johnsgard 1983). The gravity and magnetic lineaments interpreted from the study are displayed in Figures 2–19 and 2–20, respectively.

Figure 2–21 shows the basement fault system in eastern Kansas (Berendsen et al. 1983). The surface lineaments interpreted from surface drainage patterns are given in Figure 2–6. The consistency in orientation between the surface lineaments and basement fault system can be clearly observed. Berendsen et al. observed the alignment of oil and gas reservoirs along major basement fault trends in the area.

The basement fault systems for the more general Nemaha Uplift region is showed in Figure 2–22 (Burchett et al. 1983). The corresponding surface lineaments and fracture traces are

shown in Figure 2–2. The trend of the Nemaha Uplift and the Mid-Continent geophysical anomaly is clearly represented by that of the basement faults in the region.

Figure 2–23 shows the basement fault systems of a much larger region than those in the previously mentioned studies. It was compiled by Sims (1985) in cooperation with the geological surveys of Arkansas, Illinois, Iowa, Kansas, Minnesota, Missouri, Nebraska, Oklahoma, South Dakota, Tennessee, and Wisconsin.

The studies reviewed in this section cover a broad area of the Nemaha Uplift and the Mid-Continent geophysical anomaly. The data collected are of various types including surface lineaments, surface major fracture zones, surface fracture traces, gravity and aeromagnetic lineaments, and basement fault systems. These linear features have been digitized for mathematical analyses.

3.0 AN ORIENTATION ANALYSIS OF LINEAR FEATURES IN THE MID-CONTINENT REGION

Orientation is one of the most revealing characteristics of linear features, such as surface lineaments, surface fracture zones, surface fracture traces, gravity and magnetic lineaments, and basement faults. Rose diagrams provide one of the most informative ways of representing orientation data. Rose diagrams for all the linear features acquired in the Mid-Continent region were generated by the authors of this report.

Figures 3–1 to 3–16 show the rose diagrams of the surface lineaments, major fracture zones, and/or fracture traces in various parts of the Mid-Continent region. They were generated based on length instead of usual frequency. One can see from these rose diagrams that the surface linear features in the Mid-Continent region have four preferred orientations: northeast-southwest, northwest-southeast, north-south, and east-west. A majority of the surface linear features in the region are oriented northeast-southwest and northwest-southeast, which may reflect the regional structural styles of the Mid-Continent region. In contrast, those surface linear features oriented north-south and/or east-west appear to be related to local geological structures. These features are less prevalent than those oriented northeast-southwest and northwest-southeast.

The surface linear features in the areas along the Nemaha Uplift and the Mid-Continent geophysical anomaly appear in three sets: two major sets oriented northeast-southwest and northwest-southeast, and one minor set oriented north-south direction (Figures 3–1, 3–2, 3–3, 3–5, 3–6, 3–7, and 3–9). The minor set may result from the effects of the Nemaha Uplift system and the Mid-Continent geophysical anomaly. The surface linear features in the areas away from the Nemaha Uplift system appear only in two sets oriented northeast-southwest and northwest-southeast (Figures 3–8, 3–10, 3–11, 3–15, 3–16). This pattern, as mentioned earlier, is likely to represent the regional structural norm.

The surface linear features in the northern parts of the study area appear in three sets: two oriented northeast-southwest and northwest-southeast, and one oriented east-west (Figures 3–4, 3–12, and 3–14). The occurrence of the east-west oriented surface linear features may indicate a slight change in structural style in the northern parts of the study area.

The rose diagrams of the gravity and magnetic lineaments acquired in Kansas are given in Figures 3–17, 3–18, 3–19, and 3–20. These gravity and magnetic lineaments appear primarily in three sets: two major sets oriented northeast-southwest and northwest-southeast, and one minor set oriented east-west.

The rose diagrams of the Precambrian basement fault systems in the region are shown in Figures 3–21, 3–22, and 3–23. The Precambrian basement faults are primarily oriented in two directions: northeast-southwest and northwest-southeast.

A comparison of the surface and subsurface linear features indicates that the Precambrian basement faults are consistent in orientation with the gravity and magnetic lineaments, surface lineaments, and fracture traces in the Mid-Continent region. The Precambrian basement fault system, as shown in Figure 2-23, consists of two sets trending northeast-southwest and northwest-southeast. These faults later were reactivated and propagated upward all the way to the surface, as reflected by the geophysical anomalies and the surface lineaments, fracture traces, and fracture zones. During the process of reactivation and propagation, additional sets of faults or fractures were induced due to local structural complications. The propagation of basement fault systems upward to the surface provides a mechanism for hydrocarbon migration and entrapment. The association of surface lineaments, fracture traces, and fracture zones with oil and gas traps in the Mid-Continent region is investigated below.

4.0 SIGNIFICANCE OF SURFACE LINEAMENTS, MAJOR FRACTURE ZONES, AND FRACTURE TRACES FOR OIL AND GAS EXPLORATION IN THE MID-CONTINENT REGION

It has been reported in the literature that at least in some parts of the Mid-Continent region oil and gas traps line up well with the trends of surface lineaments, fracture zones, and/or fracture traces. As a result, surface linear features have been used to search for additional reserves in mature oil and gas fields in the region (Herman et al. 1986; Perry and Lee 1986; Swanson and Shannon 1990; Guo and Carroll 1995).

Figure 4–1 is the overlap of the surface lineaments and the subsurface pre-Permian oil and gas reservoirs in the Hugoton gas field in Oklahoma Panhandle (Swanson and Shannon 1990). One can see from this figure that both the geometry of individual reservoirs and the relative locations of most reservoirs clearly follow the trends of the surface lineaments in

the area. Consequently, the surface lineaments were used as a guide to structural contouring, facies mapping, and delineation of areas of fracture-enhanced permeability. They were used to direct seismic programs and to select deeper exploration candidates in the area.

Figure 4–2 shows the overlap of the surface lineaments and the subsurface oil and gas traps in Osage County, Oklahoma (Guo and Carroll 1995). The subsurface oil and gas traps in the county (represented by rectangles in Figure 4–2) were mapped from the Mississippian Chat Formation. The rose diagram of the strikes of these traps (i.e., the directions of the rectangles' long axes) is given in Figure 4–3. A close resemblance between Figures 3–8 and 4–3 indicates the exceptional consistency in orientation between the surface lineaments and fracture traces, and the subsurface oil and gas traps. The association in position between the surface lineaments and the subsurface traps in this area is readily observed from Figure 4–2. The consistency in orientation and the association in position between the surface linear features and the subsurface oil and gas traps makes it very attractive to use surface lineaments as a guide for delineating new oil and gas traps in the county. In fact, the surface lineaments and fracture traces were analyzed and used in selecting locations for a 3D seismic survey in Osage County (Reeves et al. 1995).

A study in the northern Denver Basin (Perry and Lee 1986) showed that the two sets of surface lineaments (Figures 2–11 and 3–11) parallel to the basement fault systems in the area. The surface lineaments correlate to many hydrocarbon-production trends. Thus, they may be used in extending present oil and gas trends and in prospecting for new reserves in basin.

A similar case was reported in the northern part of the Forest City Basin in southwestern Iowa (Herman et al 1986). Some of the existing oil and gas reservoirs in the southern part of the Forest City Basin apparently are structures oriented in northeast-southwest direction parallel to one of the major sets of the surface lineaments in the area. As a result, the surface lineaments mapped in the northern part of the Forest City Basin were used, after integration with geophysical data, to search for hydrocarbon prospects.

Figure 4–4 shows the distribution of the oil and gas fields in Kansas (Paul and Bahnmaier 1981). Those in the northern two-thirds of the Central Kansas Uplift and northern part of the Anadarko Basin clearly trend northwest-southeast. Many of those in the Sedgwick, Cherokee, and Forest City basins appear to trend northeast-southwest. Many of those in the southern part of the Nemaha Anticline and in the northern part of the Sedgwick Basin appear to trend north. These three major trends (northeast-southwest, northwest-southeast, and north-south) of the oil and gas fields in Kansas are apparently very consistent with the trends of the surface and subsurface linear features in the state (Figures 3–2, 3–5, 3–6, 3–7, 3–16 to 3–21).

Based on the above observations about the significance of using surface lineaments and fracture traces for oil and gas exploration in the Hugoton gas field; Osage County, Oklahoma; northern Denver Basin; and the Forest City Basin, as well as the general consistency in orientation between the oil and gas fields and subsurface and subsurface linear features in Kansas, it is reasonable to conclude that any potential new oil and gas reservoirs in the remaining parts of the Mid-Continent region, if they exist, will be likely associated with the surface lineaments and fracture traces in the region. Therefore, surface lineament and fracture analysis should be employed as a cost effective tool for delineating preliminary locations for more sophisticated and more expensive geophysical and/or geochemical surveys in the Mid-Continent region.

5.0 CONCLUSIONS

This report presents the results of a preliminary analysis of surface and subsurface linear features for hydrocarbon exploration in the Mid-Continent region. A tremendous amount of data was acquired, including data on surface lineaments, surface major fracture zones, surface fracture traces, gravity and magnetic lineaments, and Precambrian basement fault systems. These linear features were digitized and an orientation analysis was performed. The significance of using these surface linear features for inferring potential oil and gas traps in the Mid-Continent region was assessed. The following conclusions were obtained.

- The surface linear features in the Mid-Continent region consist of two major sets trending northeast-southwest and northwest-southeast, and one minor set trending north-south or east-west. The north-south–trending minor set of surface linear features tends to appear in the areas along the Nemaha Uplift system; the east-west–trending minor set tends to show up in the northern parts of the study area.
- The lineaments interpreted from gravity and magnetic data in Kansas are predominantly northeast-southwest and northwest-southeast with a minor set trending east-west.
- The Precambrian basement faults in the Mid-Continent region consist of two systems trending northeast-southwest and northwest-southeast. The general consistency in orientation among the Precambrian basement faults, the lineaments interpreted from gravity and magnetic data, and the surface linear features indicates that the systematic fault systems at basement in the Mid-Continent region probably have been reactivated many times and have propagated upward all the way to the surface. Therefore, they may have acted as the loci for the development of other geological structures in the study area.
- The association both in orientation and position between surface linear features and subsurface oil and gas traps was observed in northeastern Oklahoma, the Oklahoma Panhandle, the northern Denver Basin, and the Forest City Basin. It is

hypothesized that this relationship also exists in other parts of the Mid-Continent region. Therefore, surface lineament and fracture analysis should be employed as a cost effective tool for hydrocarbon exploration in the Mid-Continent region.

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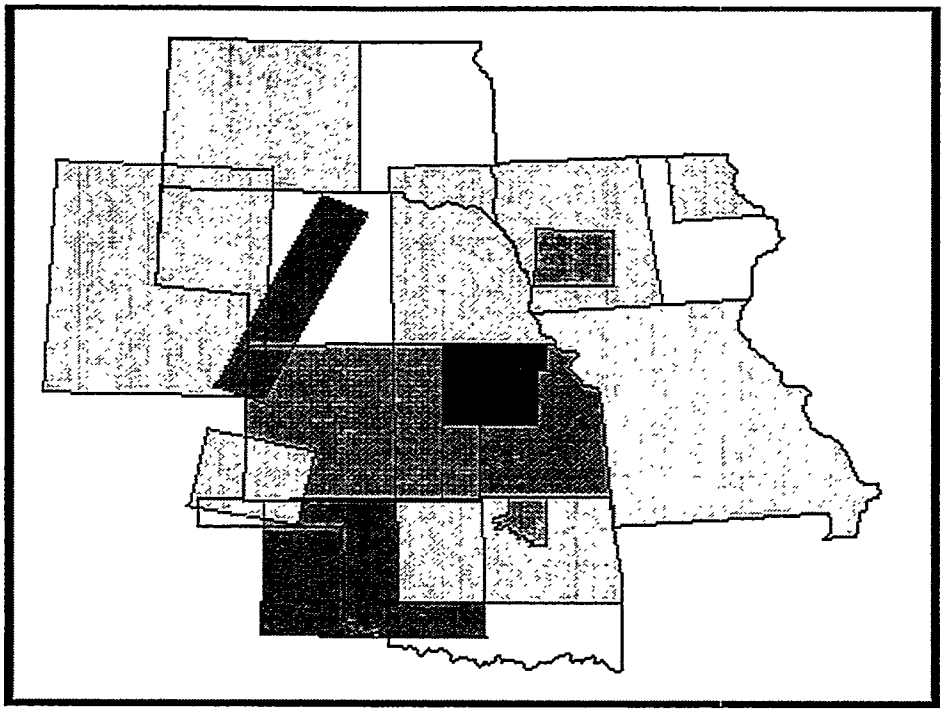

Figure 2–1 Areas (Shaded) Where Surface Lineament and Fracture Data were Collected and Digitized

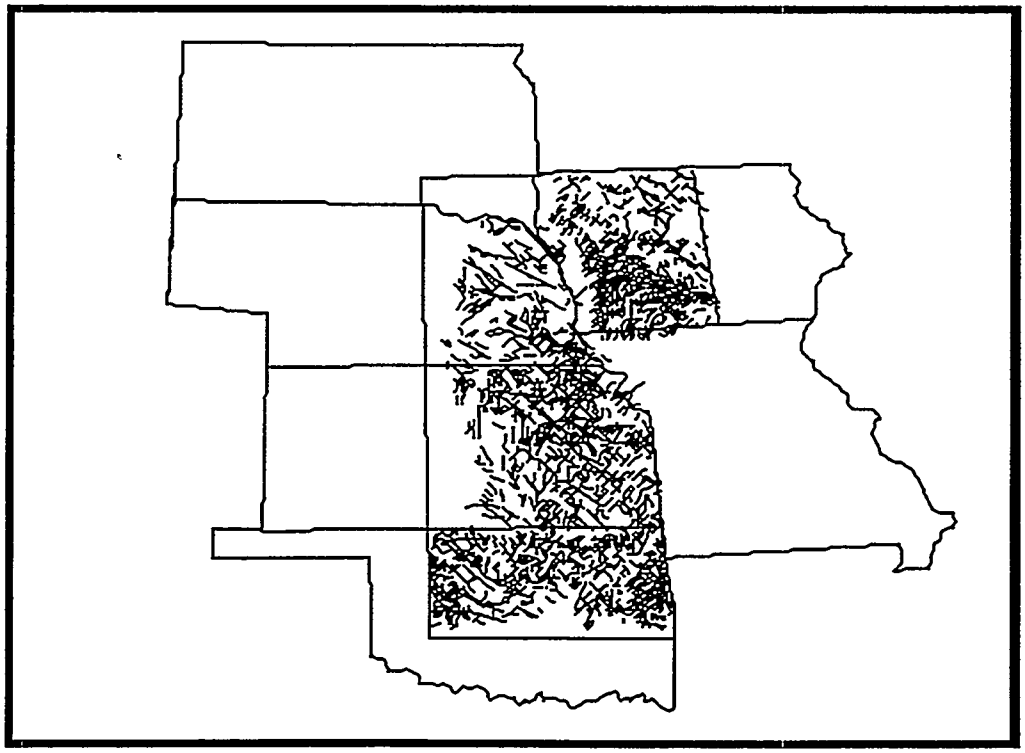

Figure 2–2 Surface Lineaments in the Nemaha Uplift Region

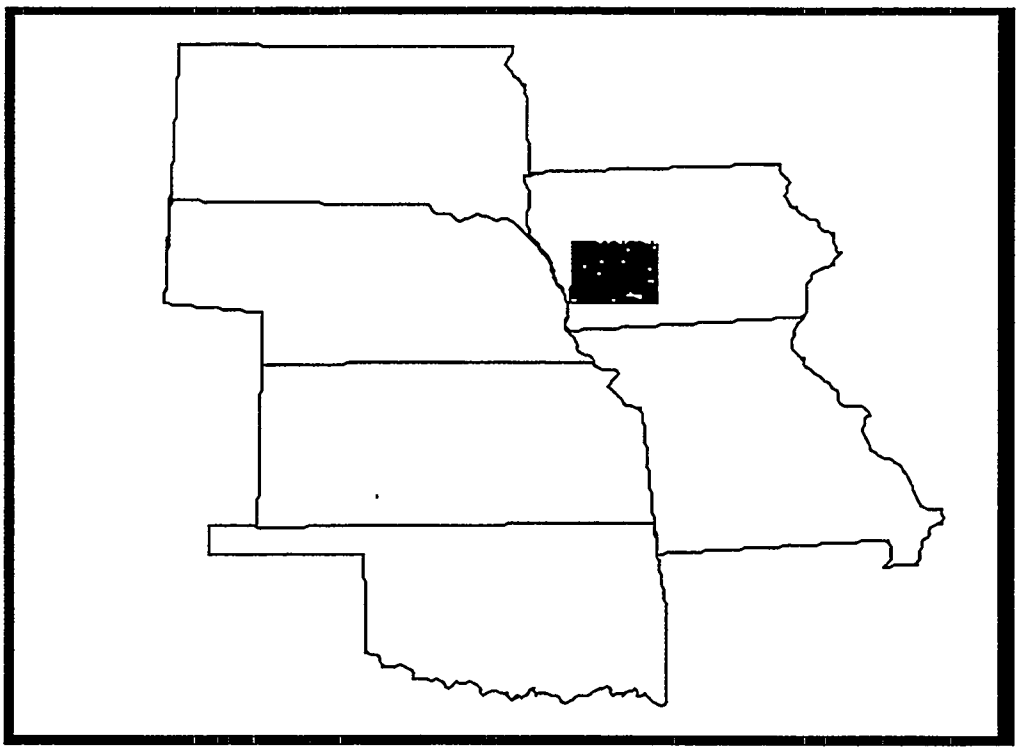

Figure 2–3 Surface Lineaments and Fracture Traces in Southwestern Iowa

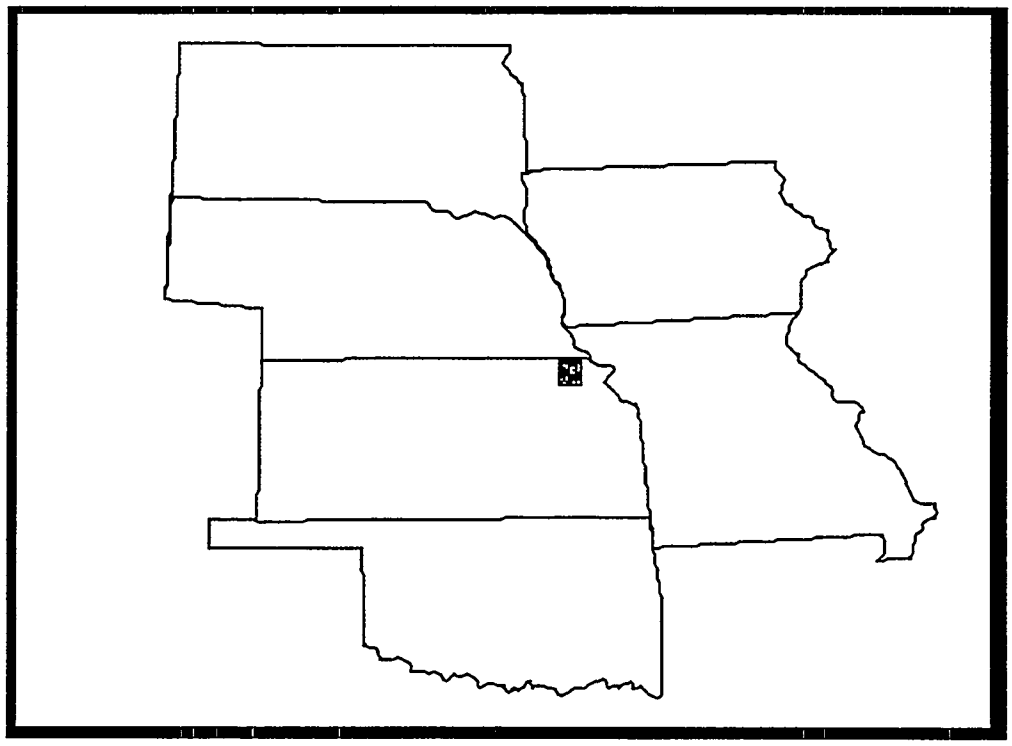

Figure 2–4 Surface Lineaments and Fracture Traces in Nemaha County, Kansas

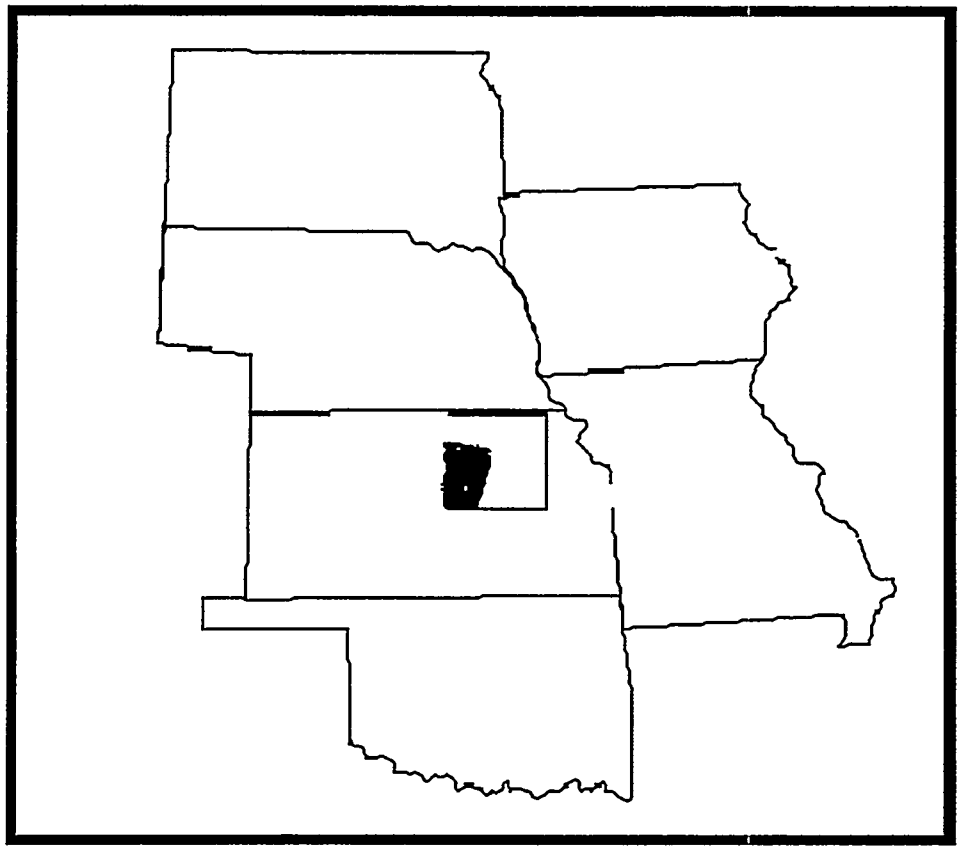

Figure 2–5 Surface Fracture Traces in North-Central Kansas

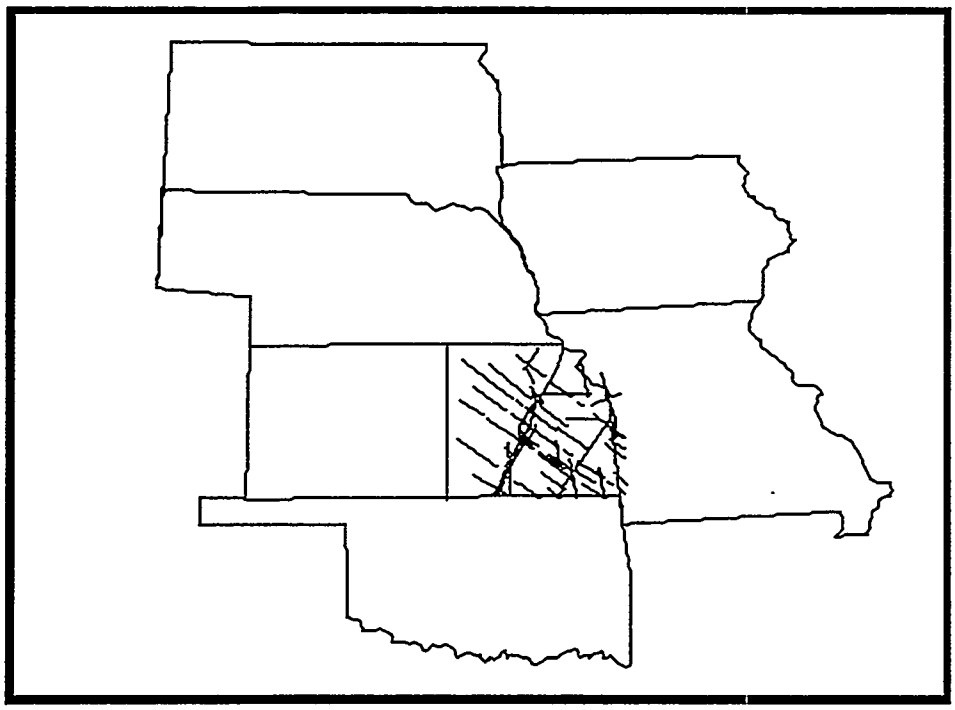

Figure 2–6 Surface Lineaments and Fracture Traces in Eastern Kansas

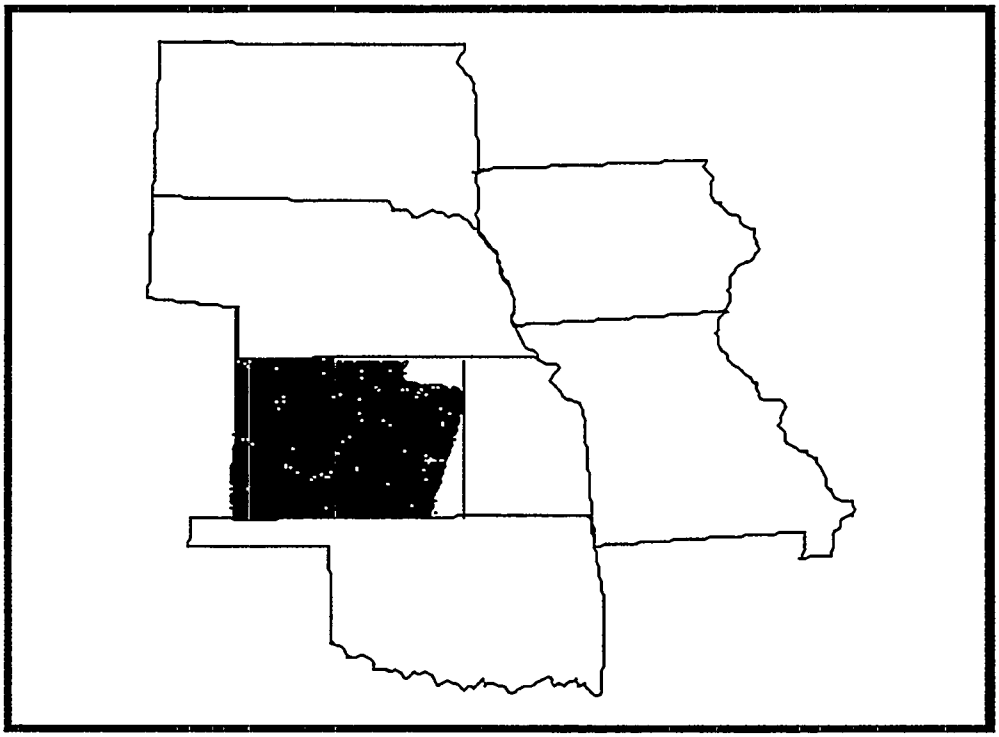

Figure 2–7 Surface Lineaments and Fracture Traces in Western Kansas

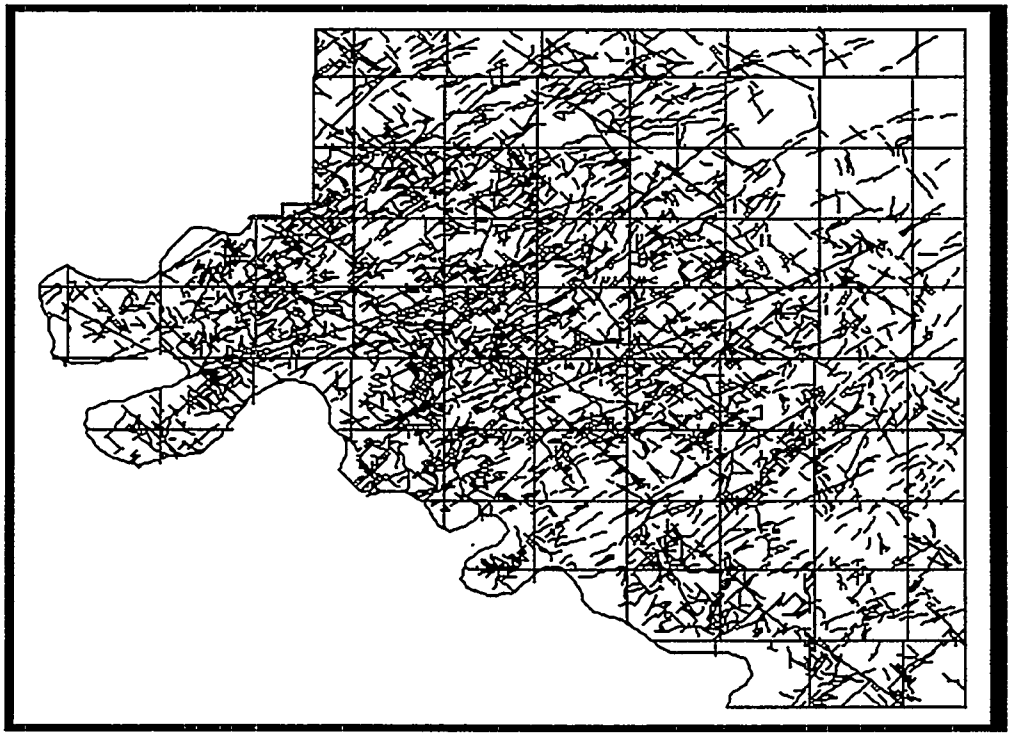

Figure 2–8 Surface Lineaments and Fracture Traces in Osage County, Oklahoma

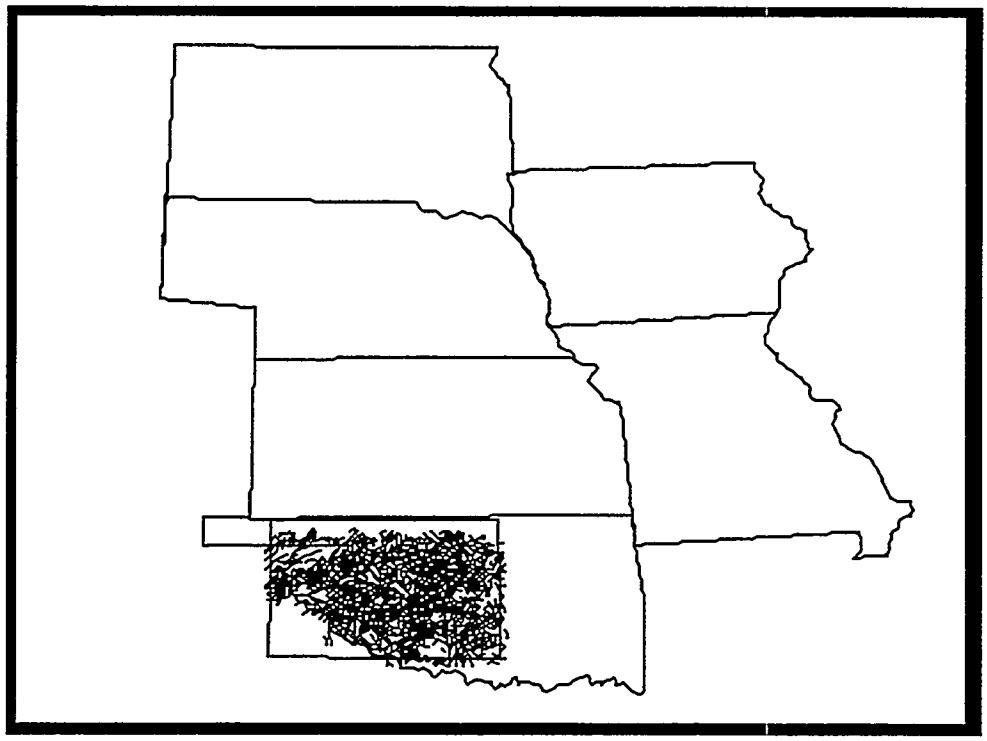

Figure 2–9 Surface Lineaments and Fracture Traces in the Anadarko Basin in Western Oklahoma

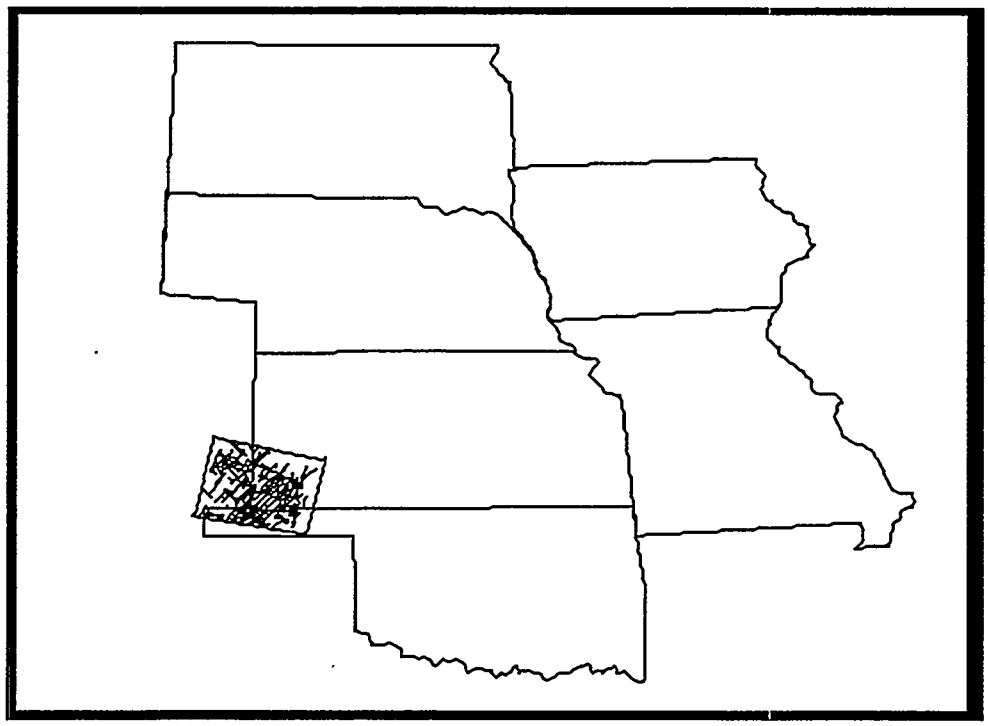

Figure 2–10 Surface Lineaments and Fracture Traces in the Western Hugoton gas Field in Southwestern Kansas and the Oklahoma Panhandle

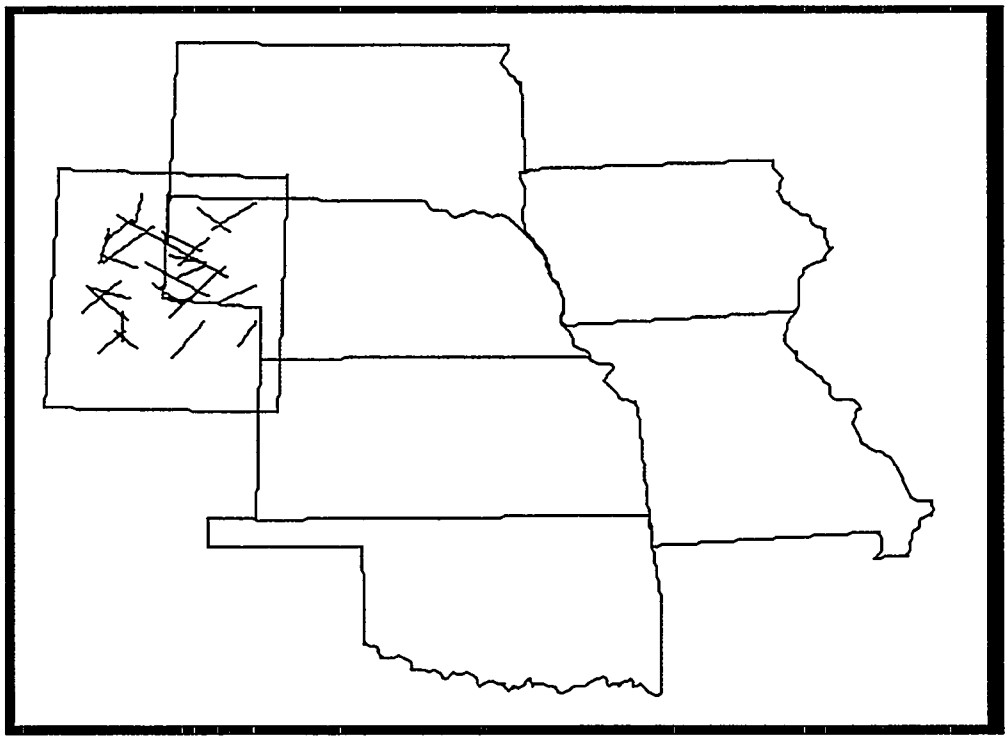

Figure 2–11 Surface Lineaments in the Northern Denver Basin

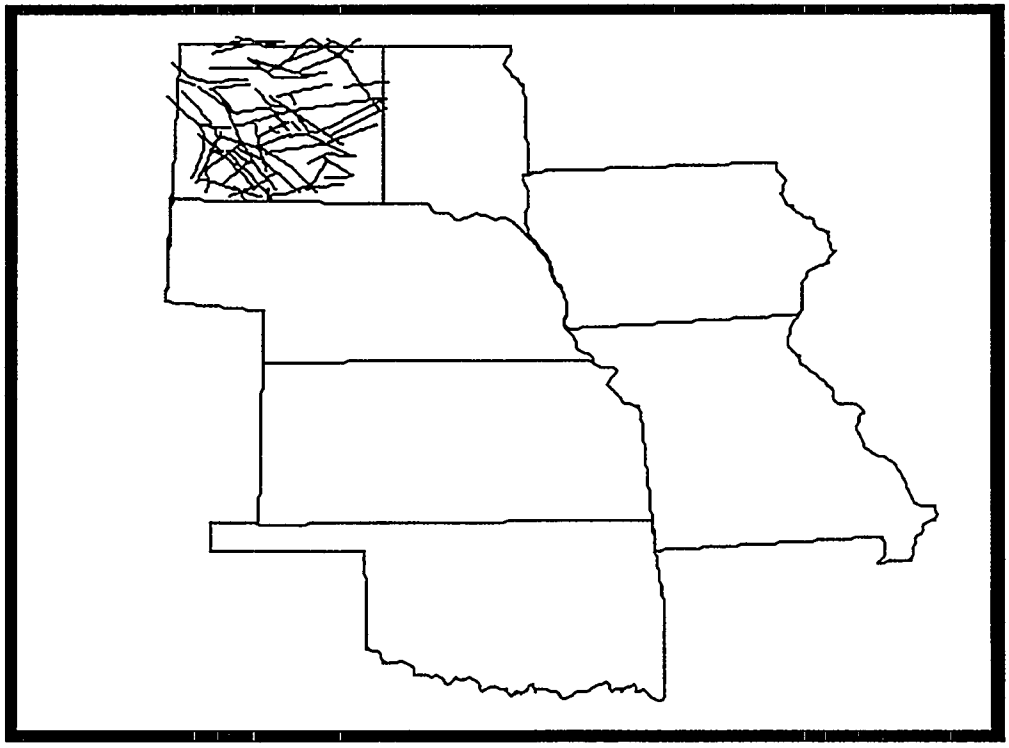

Figure 2–12 Surface Lineaments in Western South Dakota

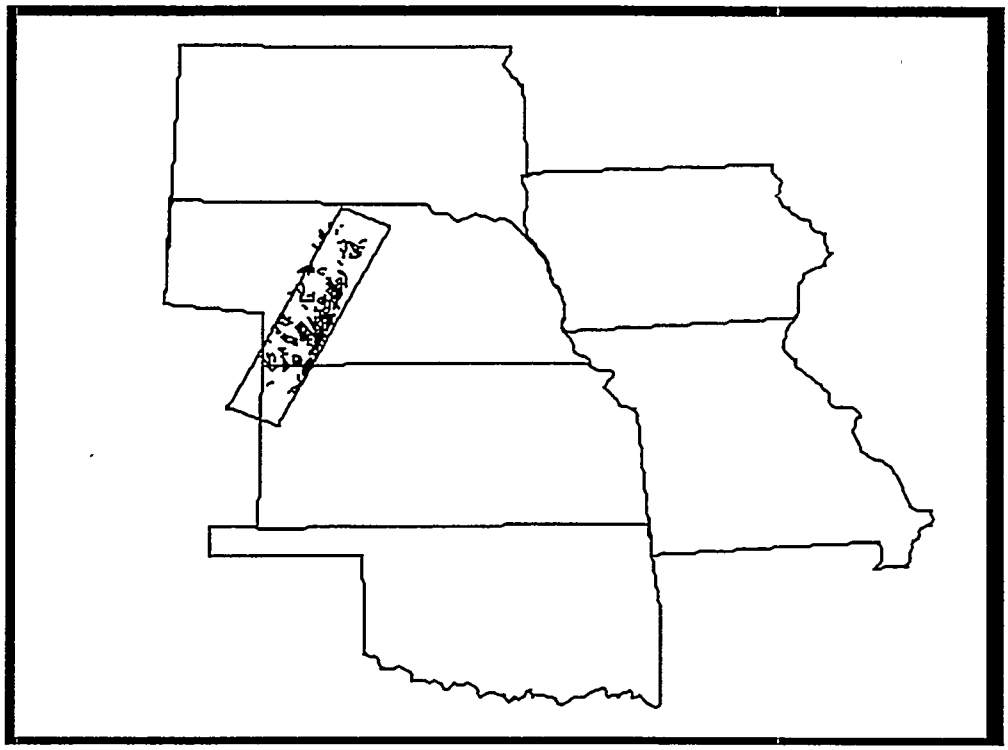

Figure 2–13 Surface Lineaments in Western Nebraska

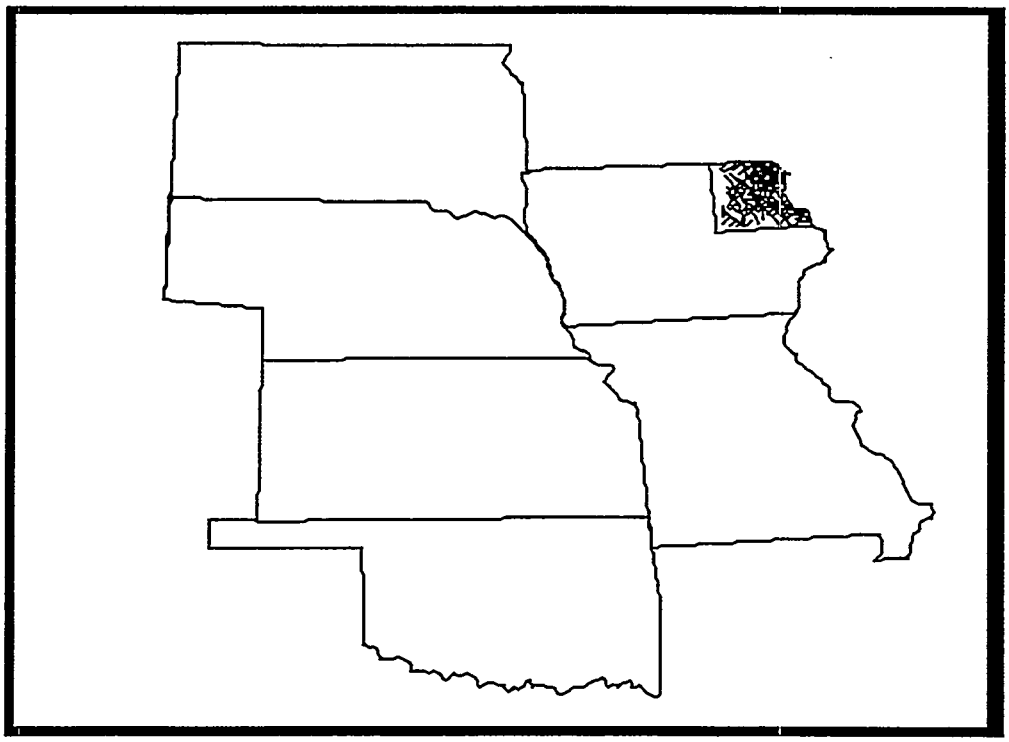

Figure 2–14 Surface Lineaments and Fracture Traces in Northeastern Iowa

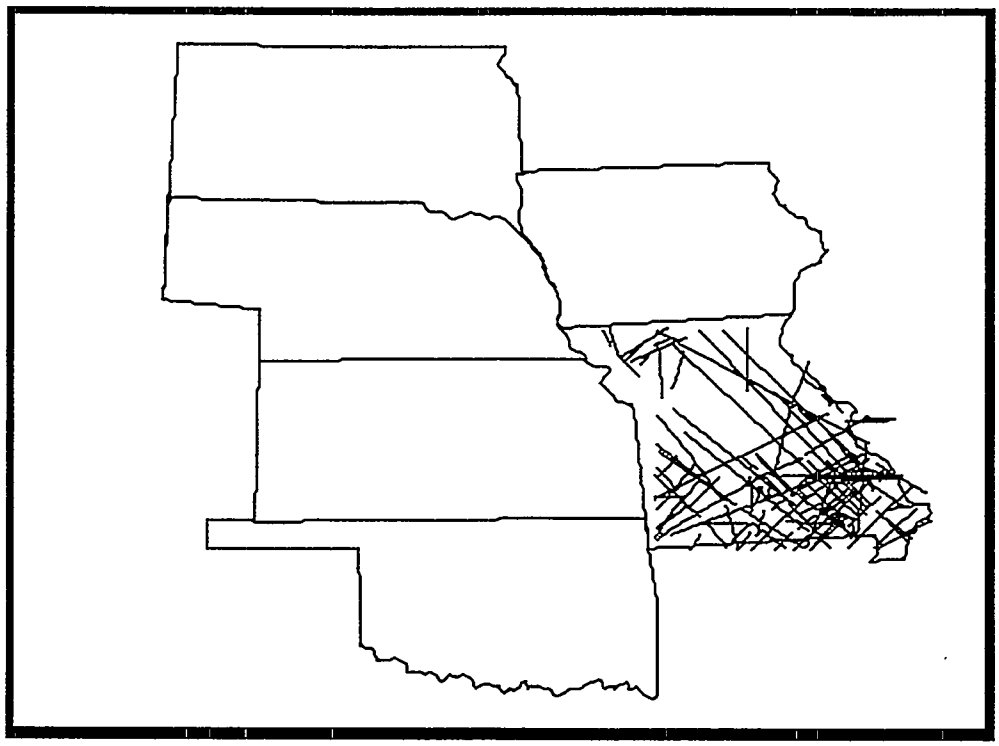

Figure 2–15 Surface Lineaments and Major Fracture Zones in Missouri

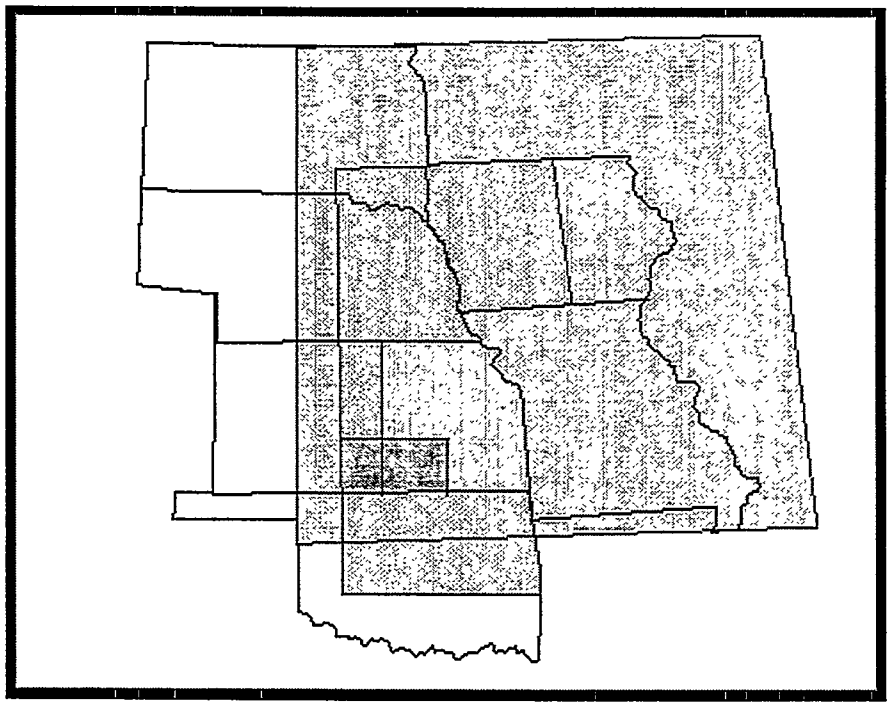

Figure 2–16 Areas Where Information on Gravity and Magnetic Lineaments and Basement Fault Systems Have Been Collected and Digitized

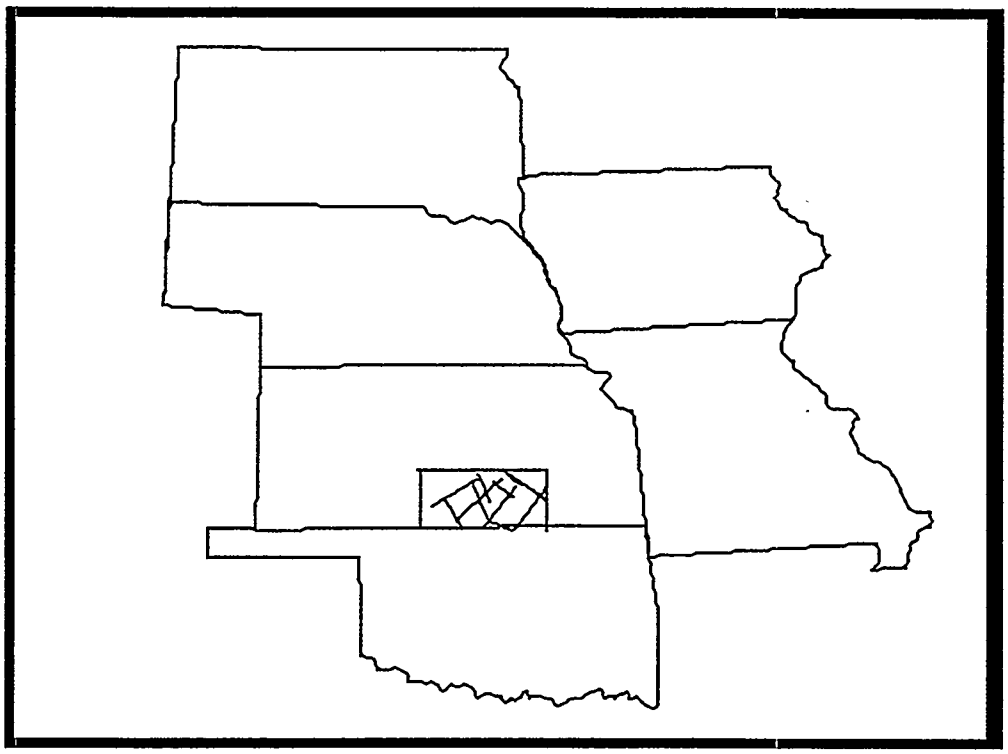

Figure 2–17 Lineaments Interpreted from a Gravity Survey in South-Central Kansas

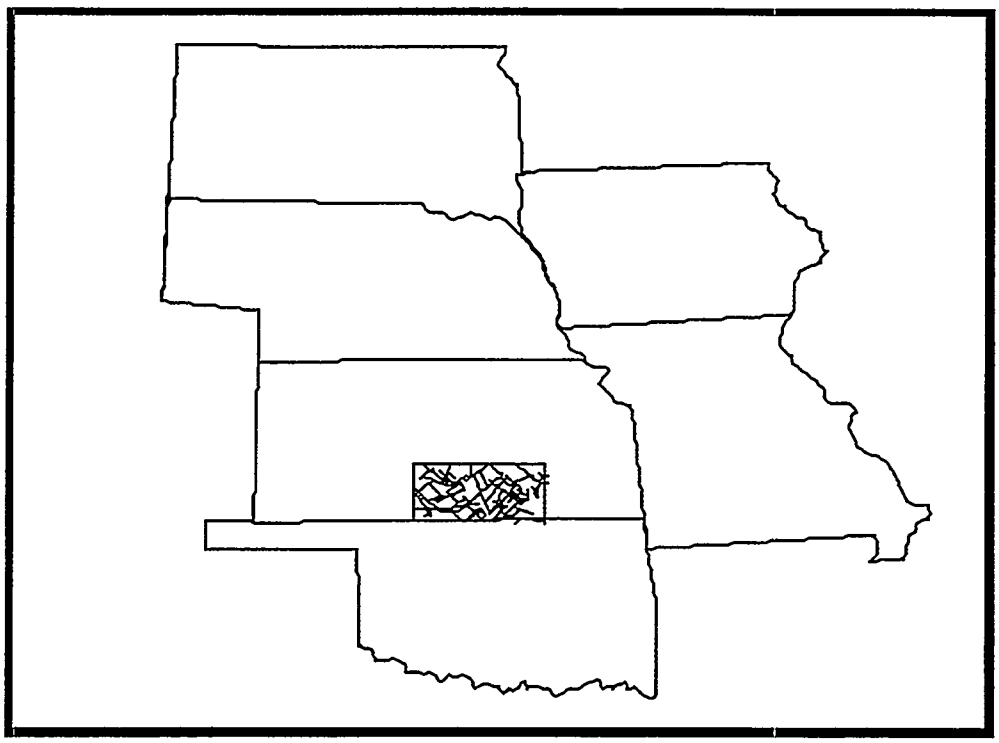

Figure 2–18 Lineaments Interpreted from a Aeromagnetic Survey in South-Central Kansas

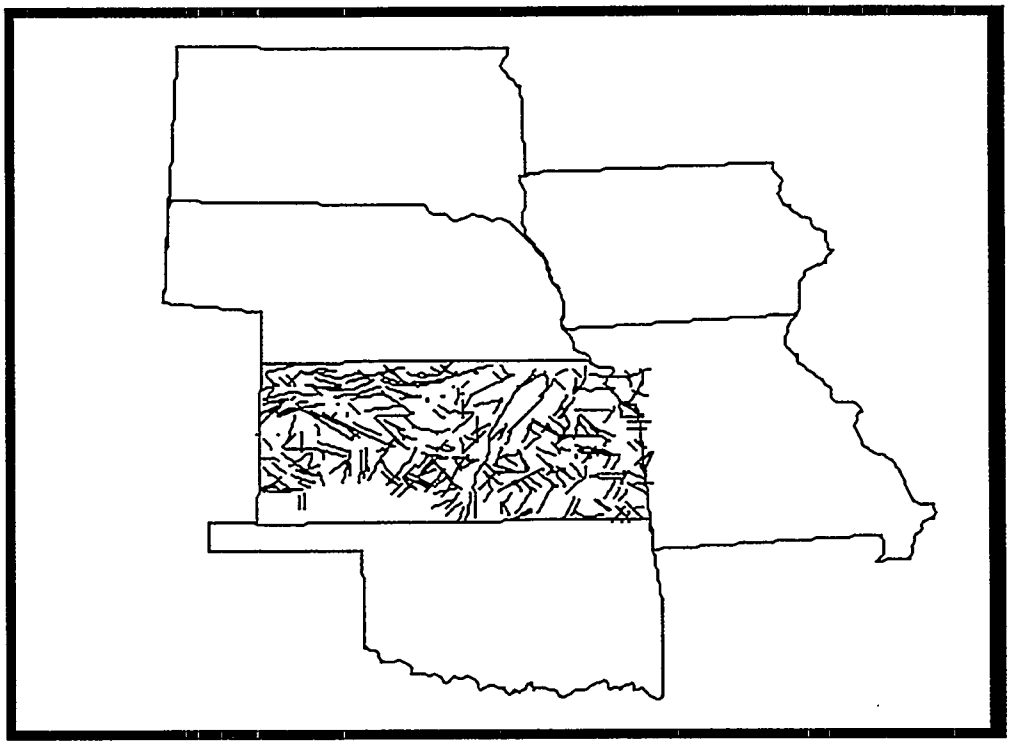

Figure 2–19 Lineaments Interpreted from a Gravity Survey in Kansas

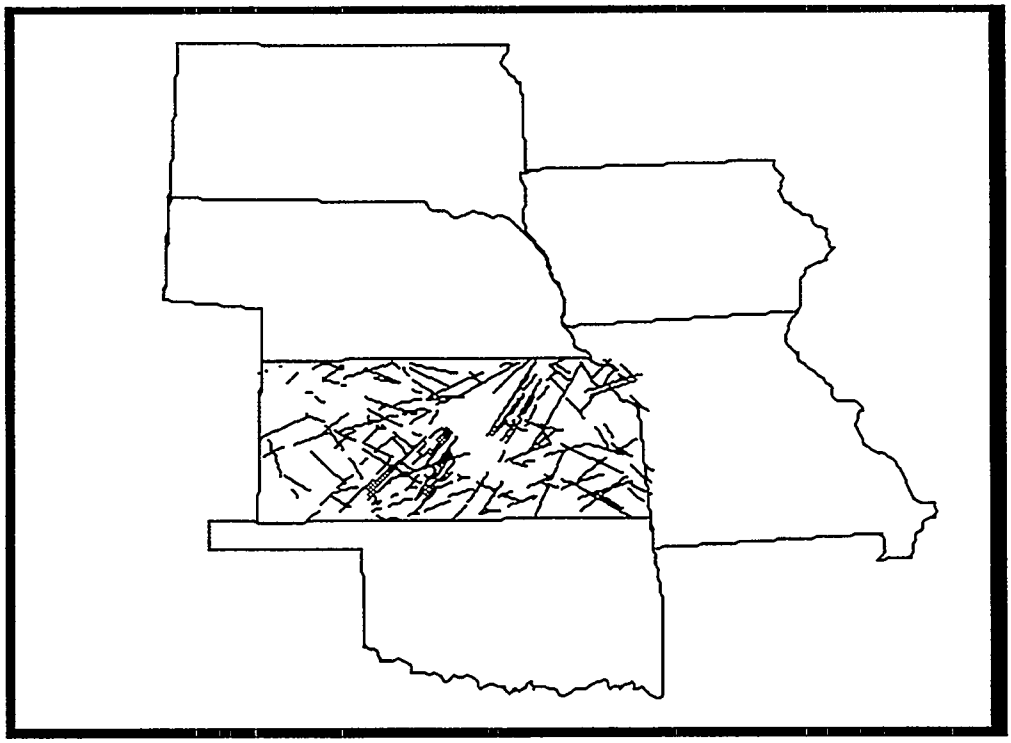

Figure 2–20 Lineaments Interpreted from a Aeromagnetic Survey in Kansas

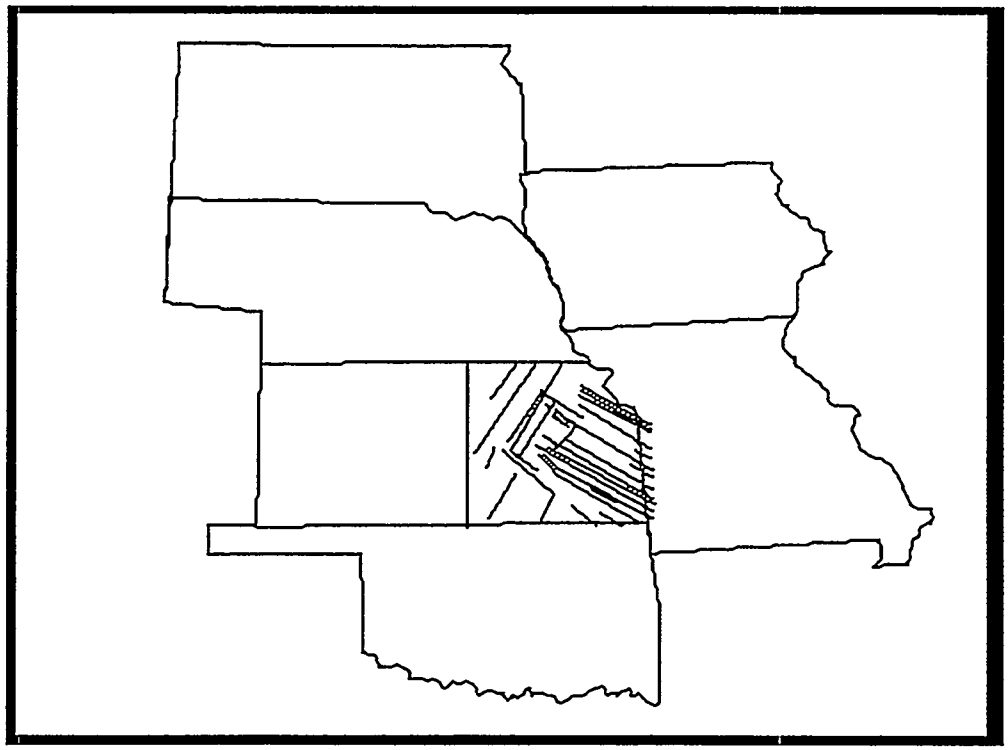

Figure 2–21 Basement Fault System in Eastern Kansas

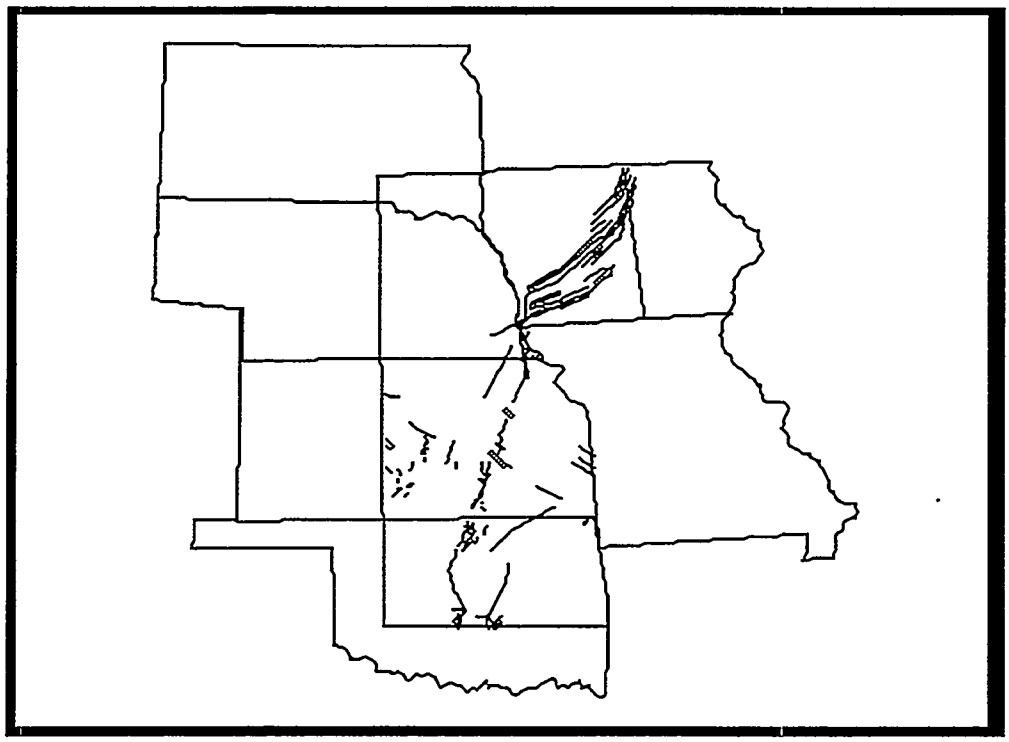

Figure 2–22 Basement Fault System in the Nemaha Uplift Area

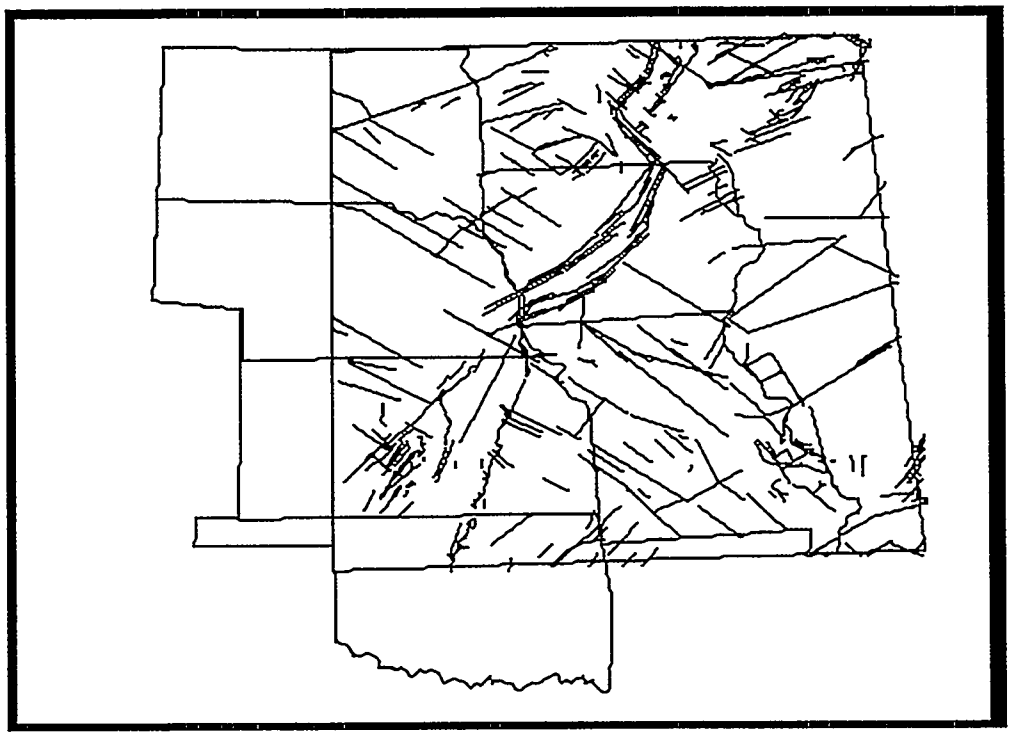

Figure 2–23 Basement Fault Systems in the Northern Mid-Continent

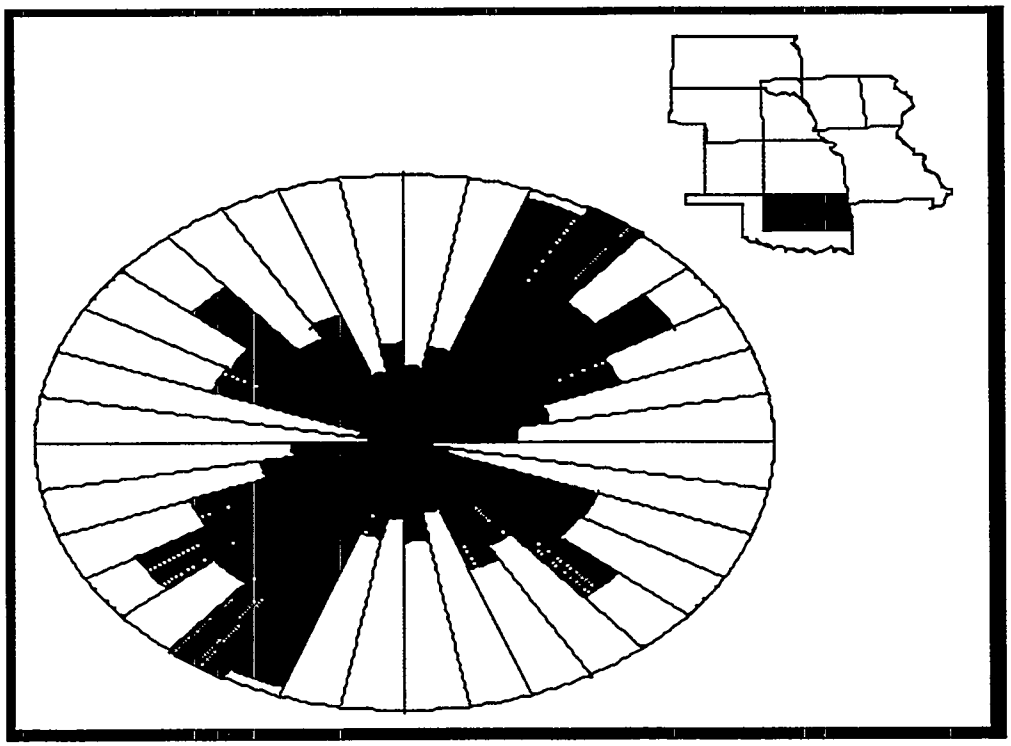

Figure 3–1 A Rose Diagram of the Surface Lineaments in North-Central and Northeastern Oklahoma

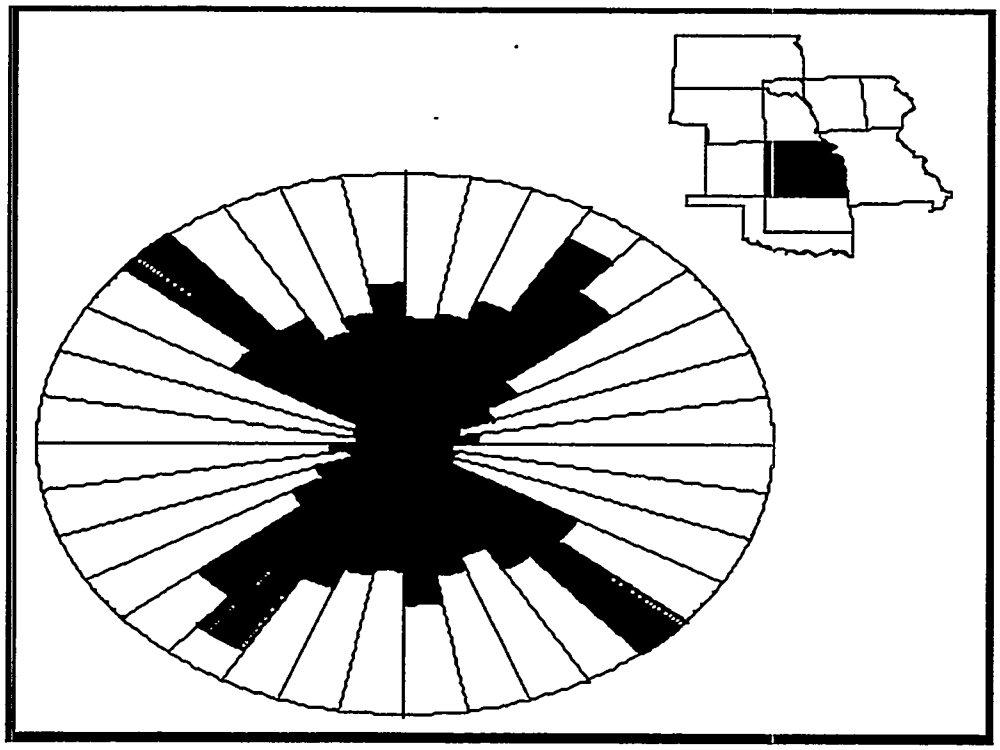

Figure 3–2 A Rose Diagram of the Surface Lineaments in Eastern Kansas

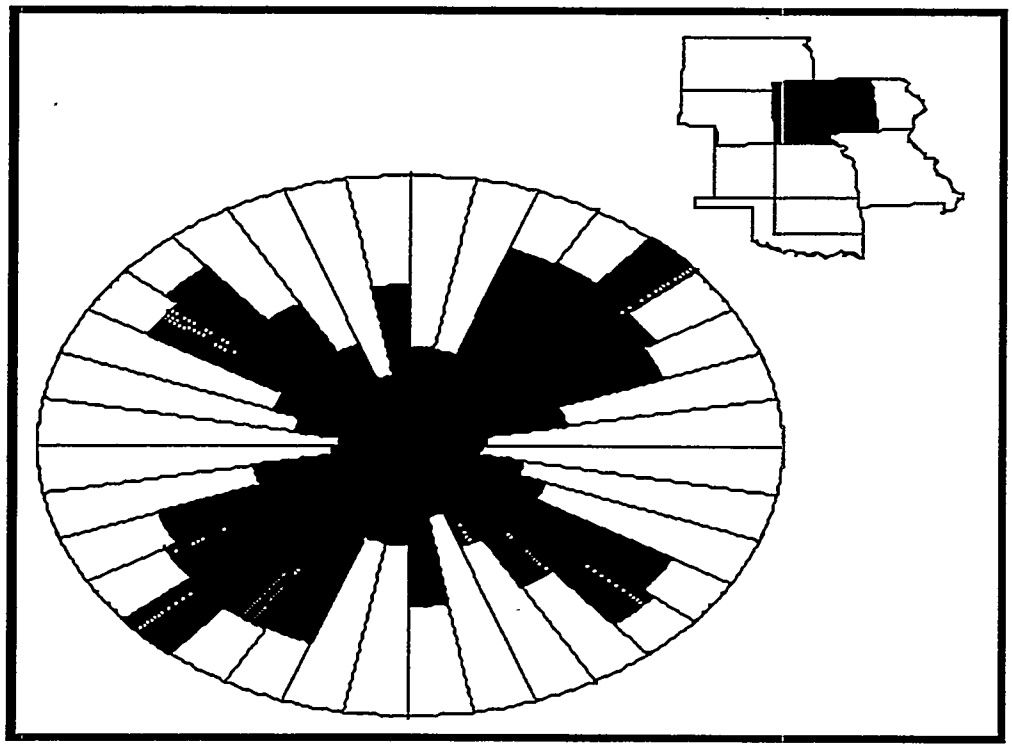

Figure 3–3 A Rose Diagram of the Surface Lineaments in Eastern Nebraska and Western Iowa

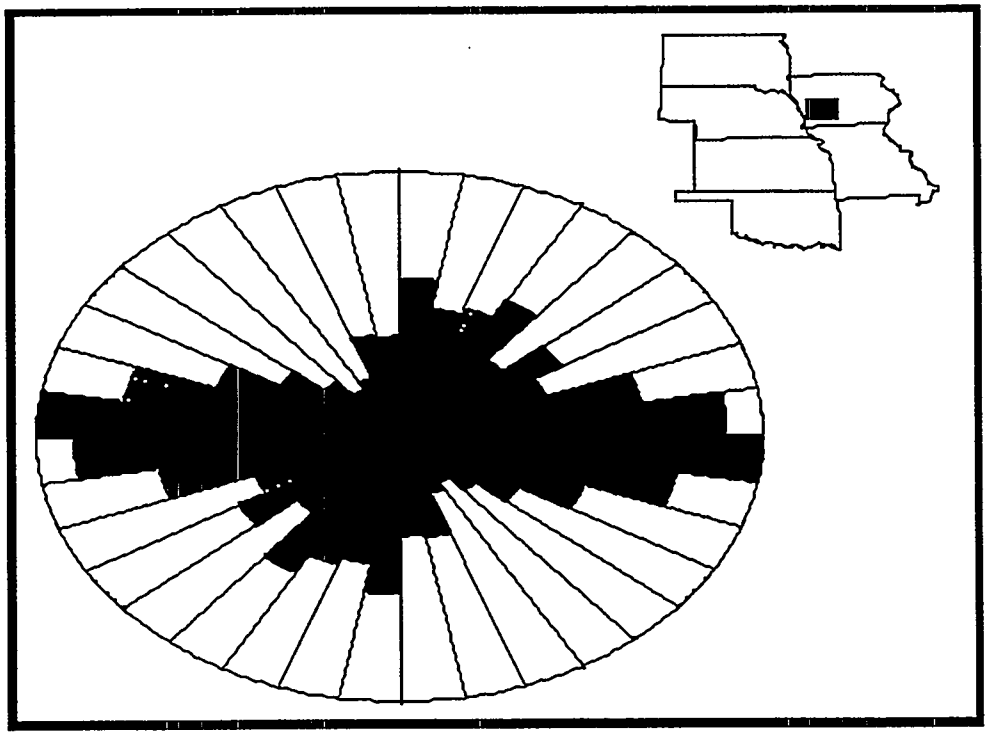

Figure 3–4 A Rose Diagram of the Surface Lineaments and Fracture Traces in Southwestern Iowa

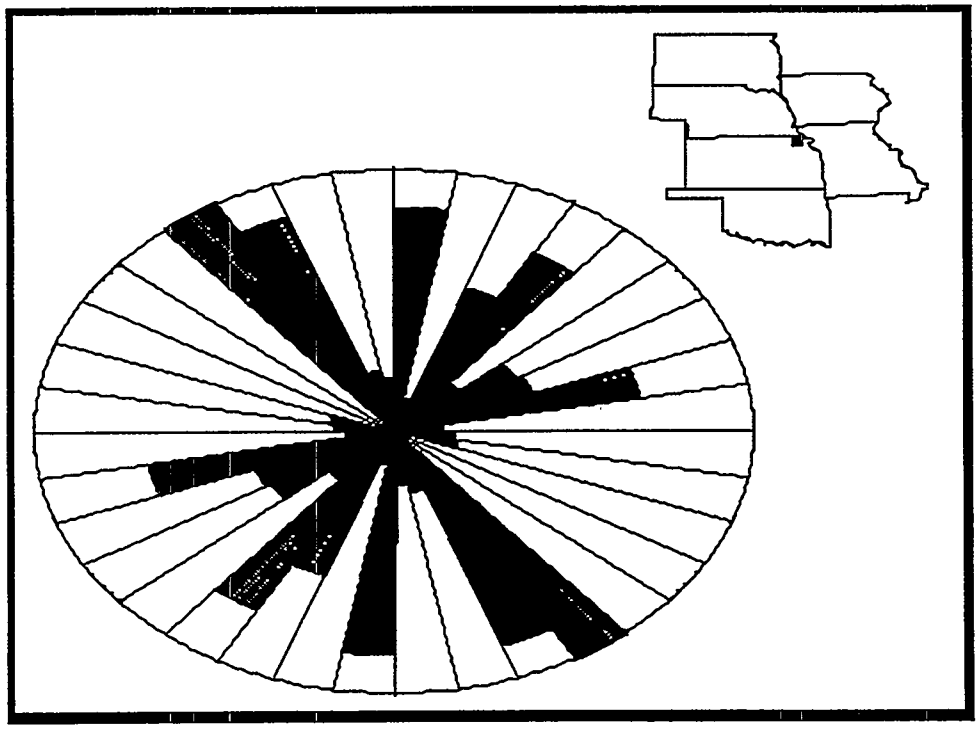

Figure 3–5 A Rose Diagram of the Surface Lineaments and Fracture Traces in Nemaha County, Kansas

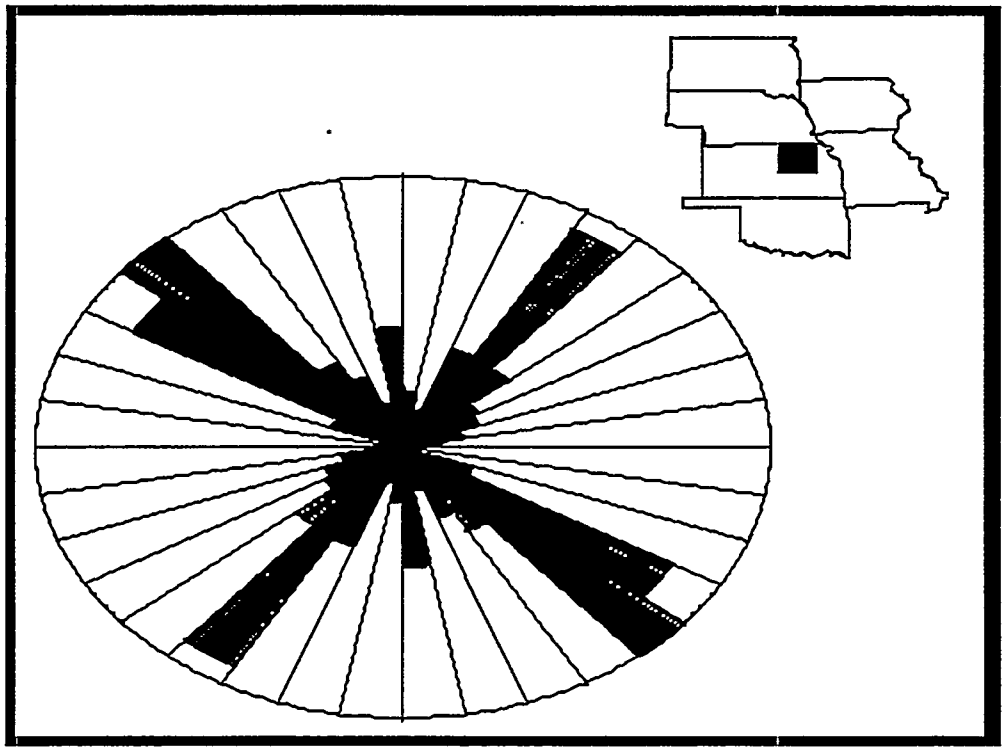

Figure 3–6 A Rose Diagram of the Surface Fracture Traces in North-Central Kansas

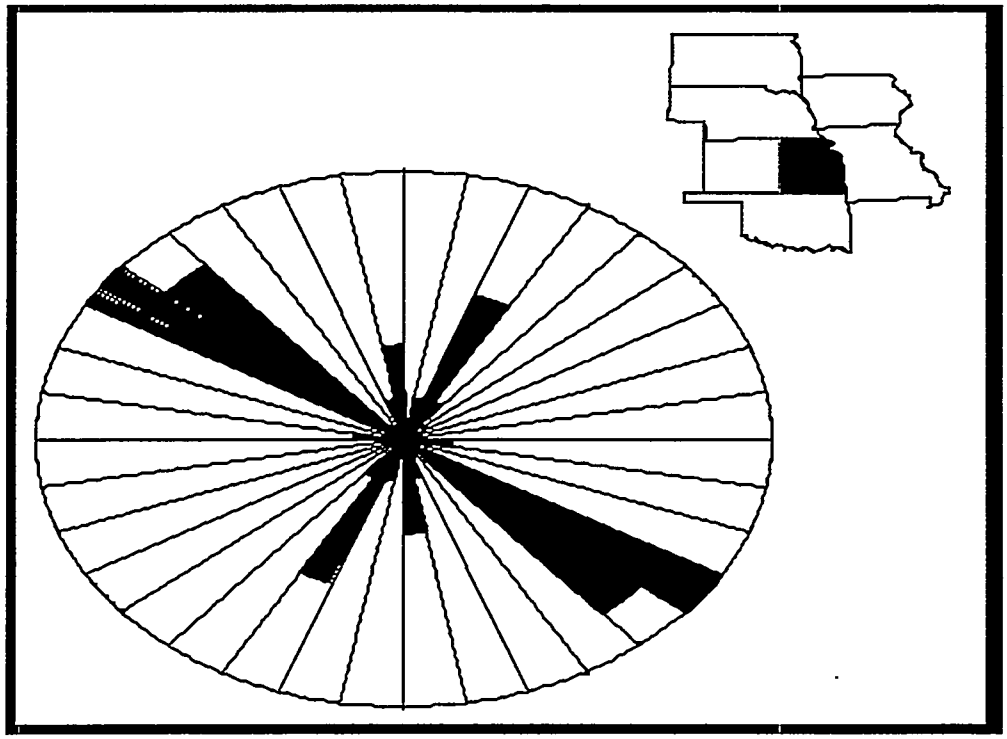

Figure 3–7 A Rose Diagram of the Surface Lineaments and Fracture Traces in Eastern Kansas

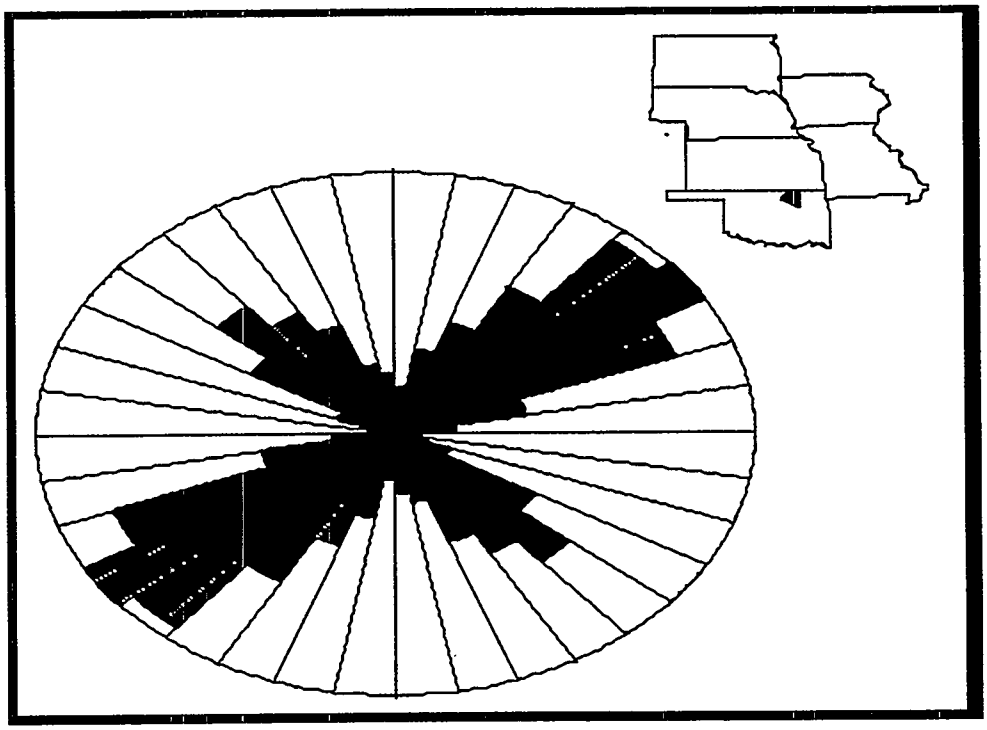

Figure 3–8 A Rose Diagram of the Surface Lineaments and Fracture Traces in Osage County, Oklahoma

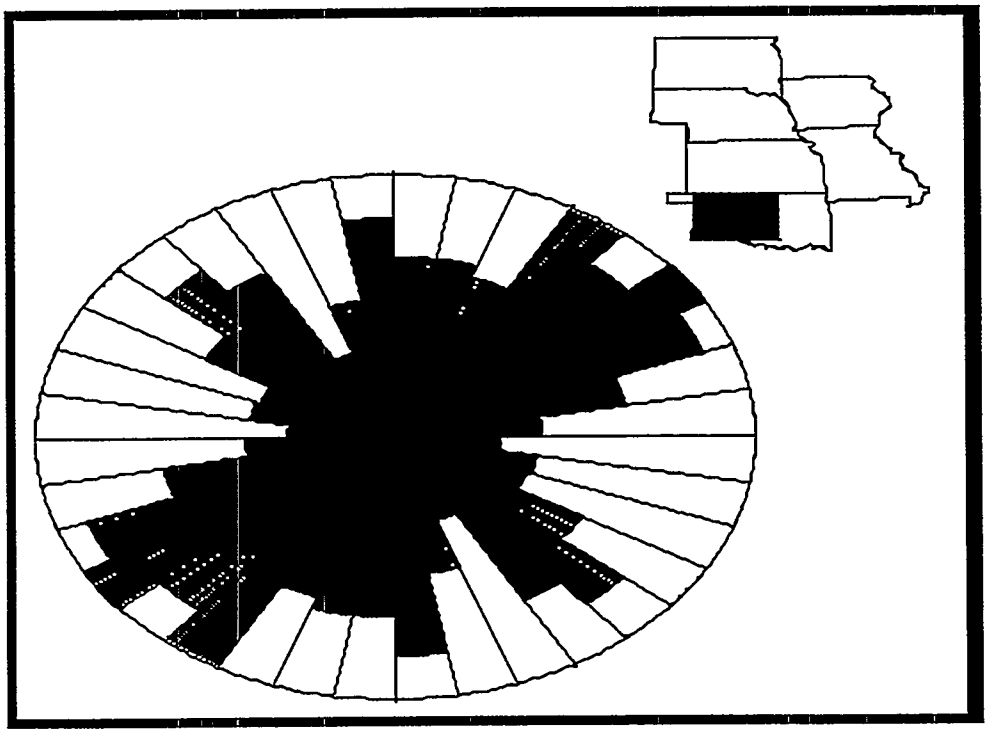

Figure 3–9 A Rose Diagram of the Surface Lineaments and Fracture Traces in the Anadarko Basin in Western Oklahoma

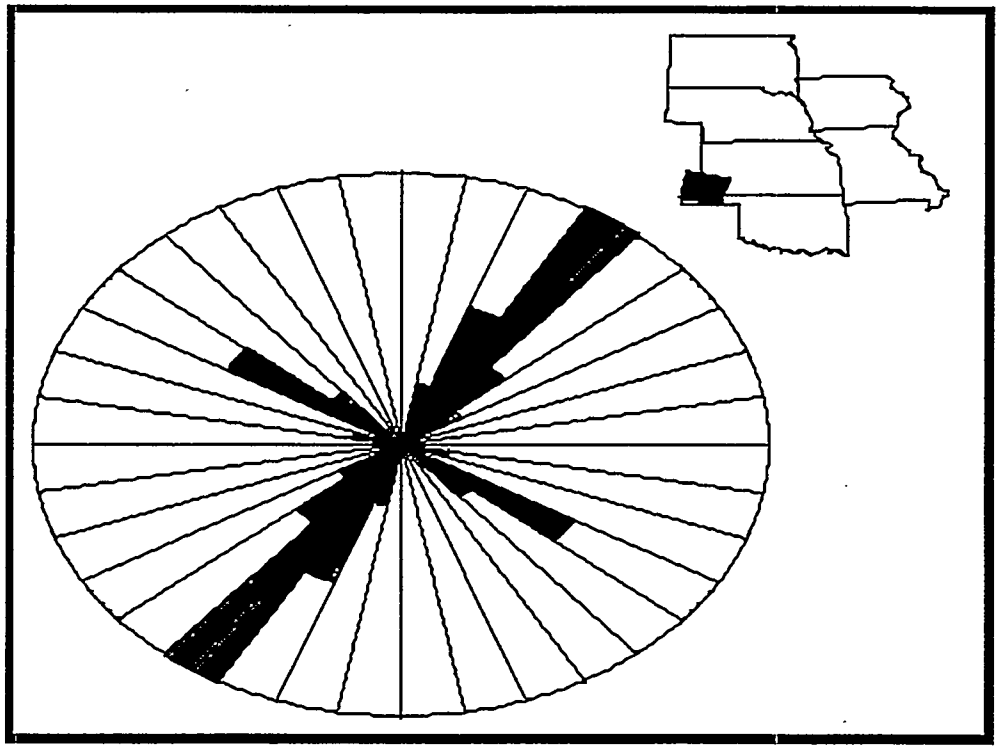

Figure 3–10 A Rose Diagram of the Surface Lineaments and Fracture Traces in the Western Hugoton Gas Field

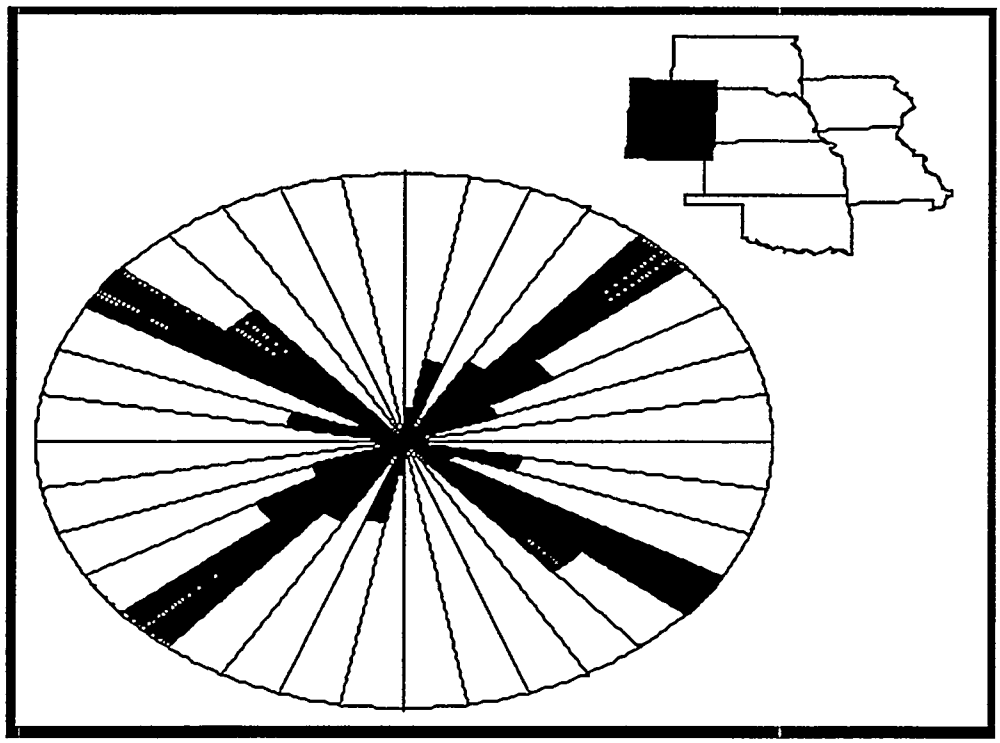

Figure 3–11 A Rose Diagram of the Surface Lineaments in the Northern Denver Basin

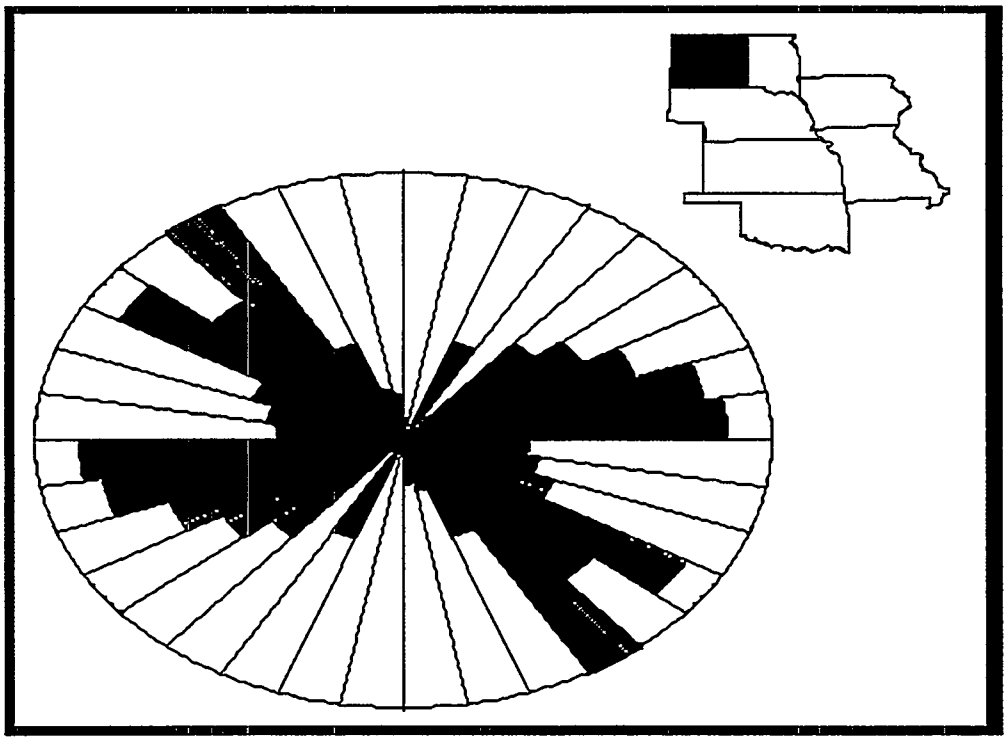

Figure 3–12 A Rose Diagram of the Surface Lineaments in Western South Dakota

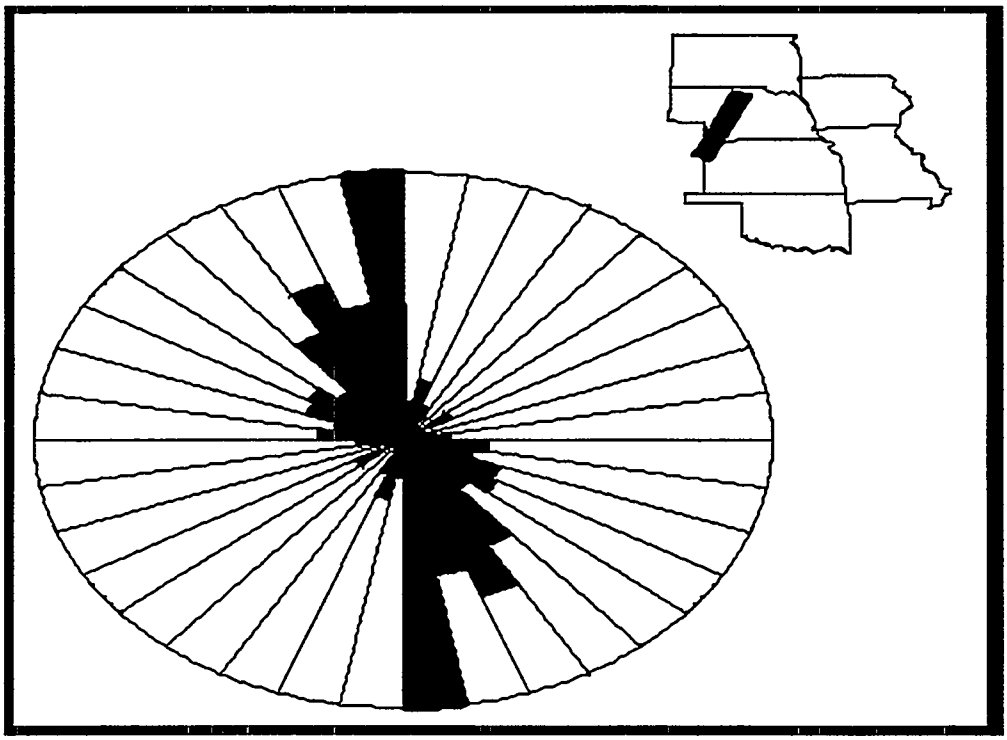

Figure 3–13 A Rose Diagram of the Surface Lineaments in Western Nebraska

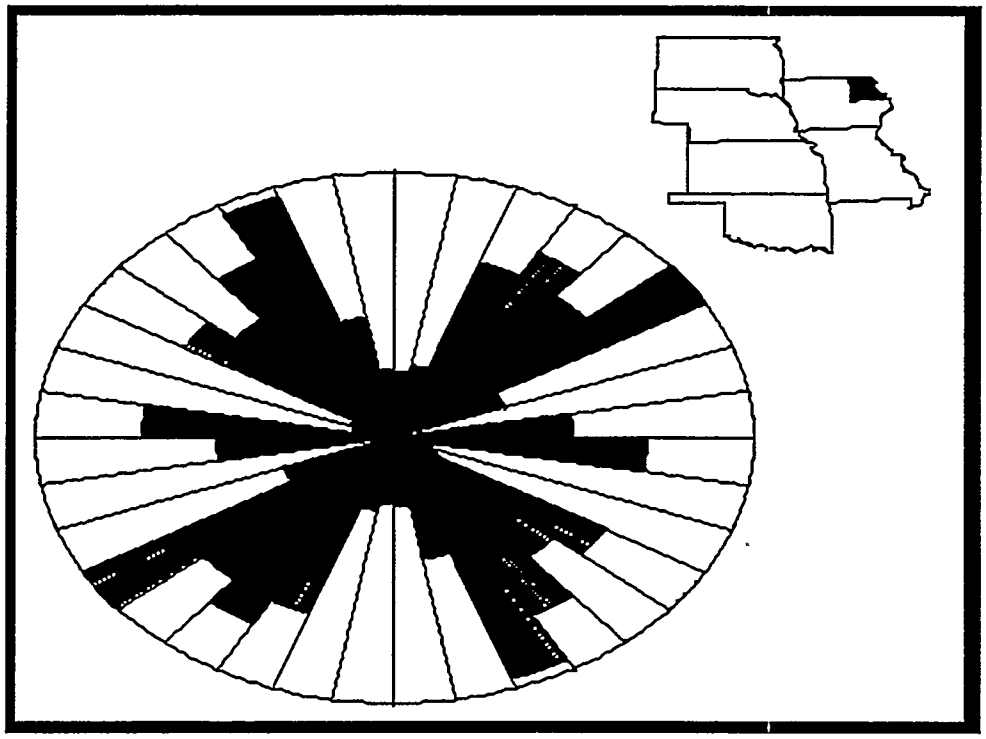

Figure 3–14 A Rose Diagram of the Surface Lineaments and Fracture Traces in Northeastern Iowa

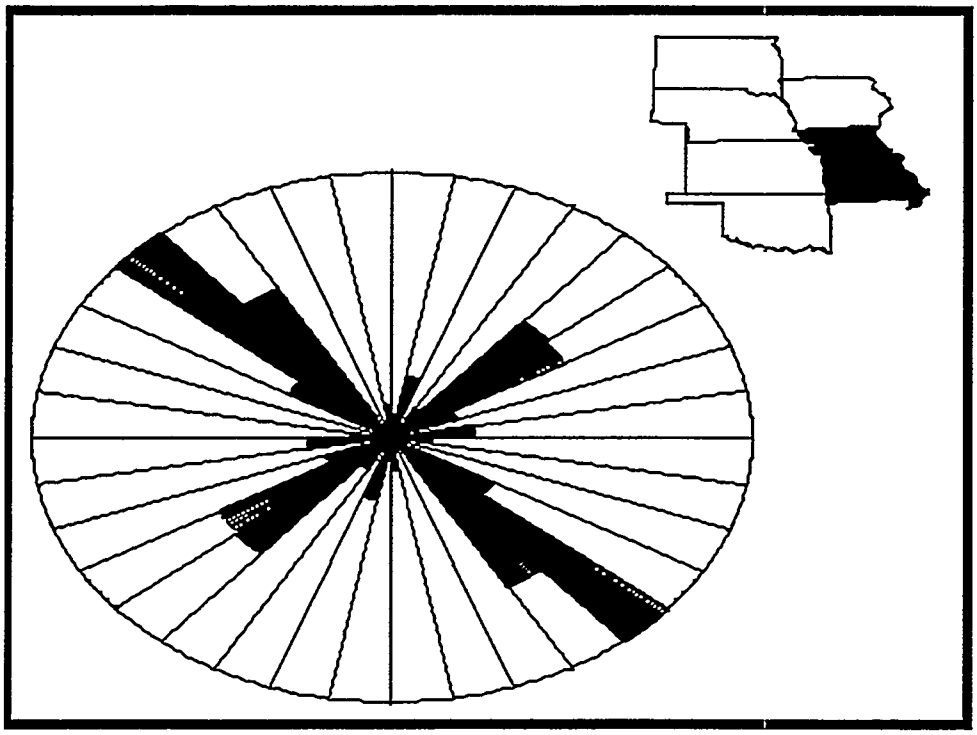

Figure 3–15 A Rose Diagram of the Surface Lineaments and Major Fracture Zones in Missouri

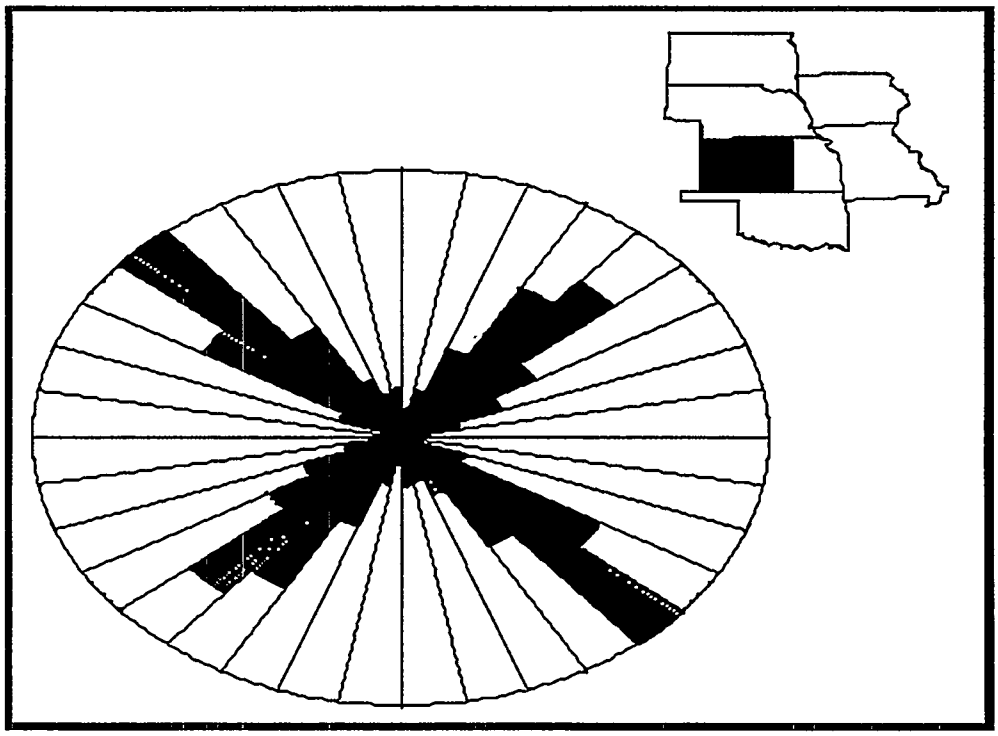

Figure 3–16 A Rose Diagram of the Surface Lineaments and Fracture Traces in Western Kansas

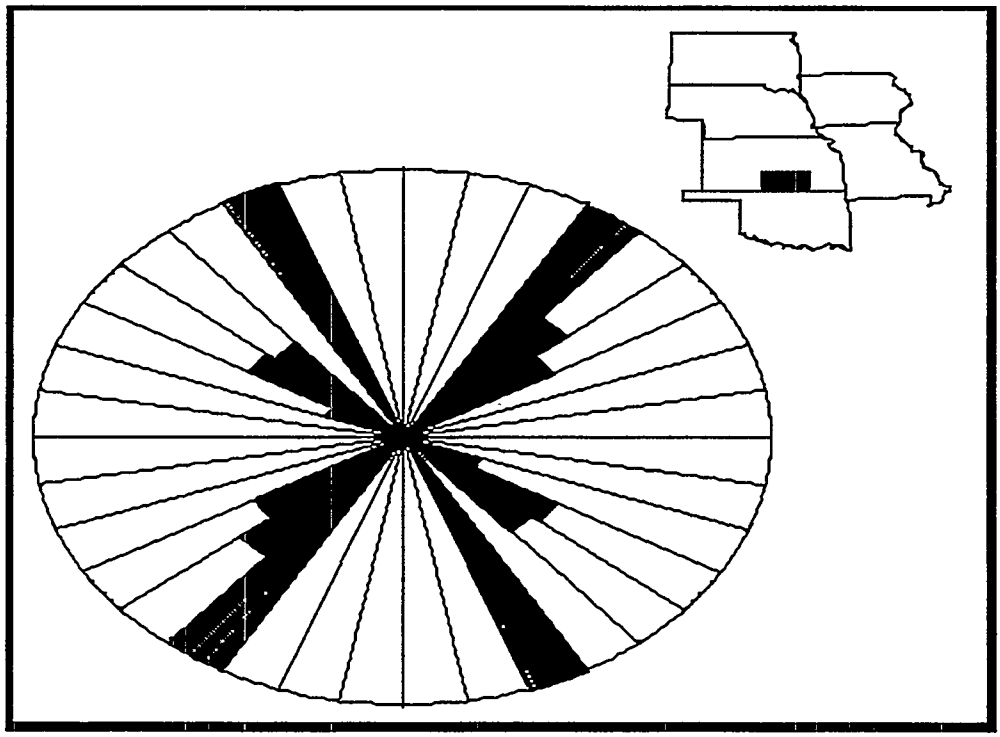

Figure 3–17 A Rose Diagram of the Gravity Lineaments in South-Central Kansas

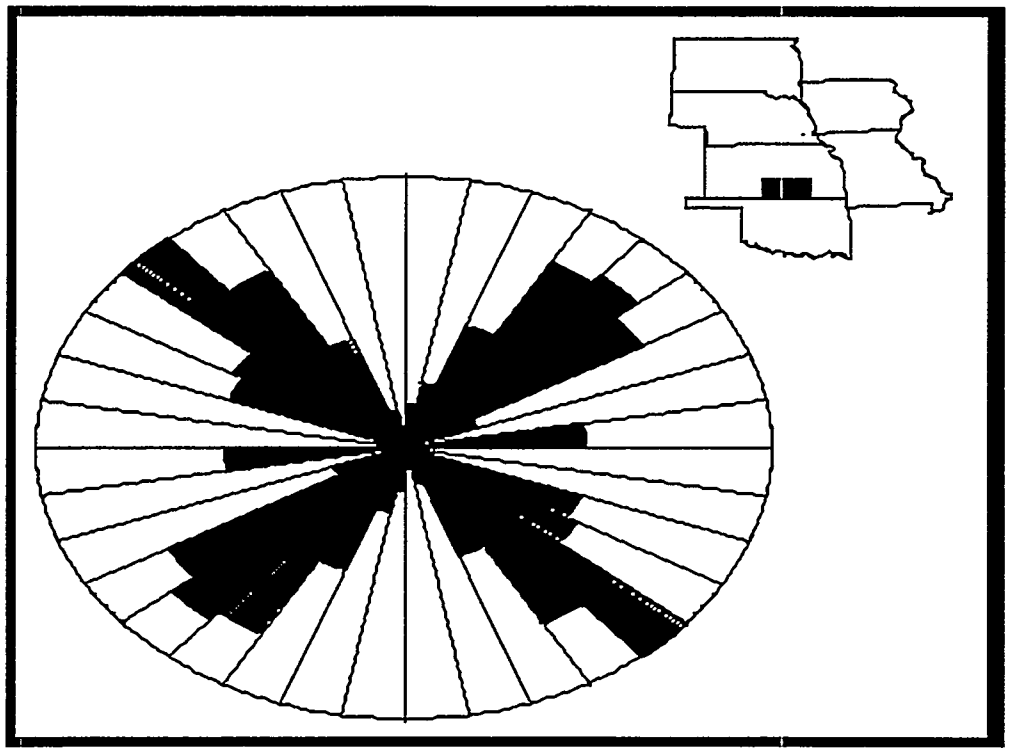

Figure 3–18 A Rose Diagram of the Magnetic Lineaments in South-Central Kansas

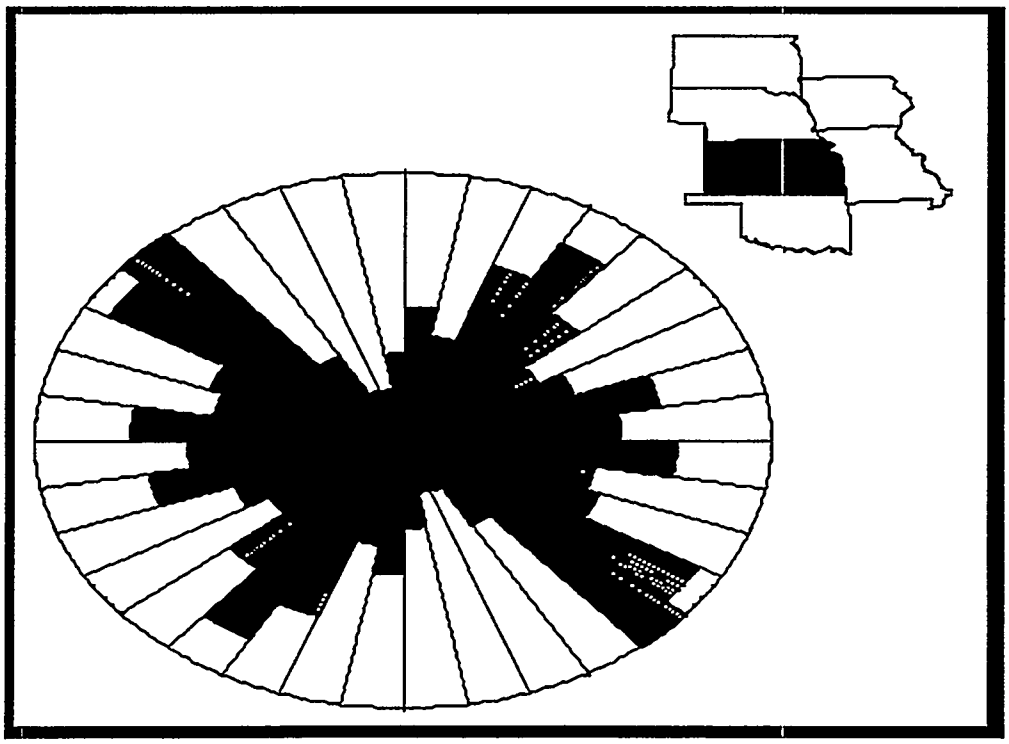

Figure 3–19 A Rose Diagram of the Gravity Lineaments in Kansas

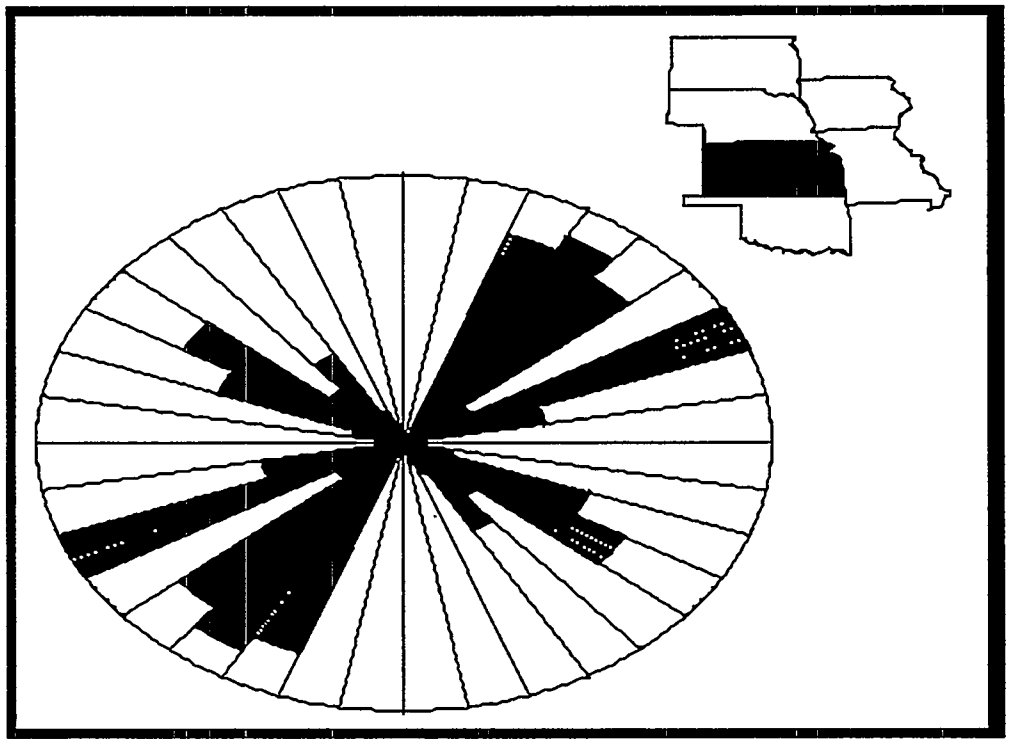

Figure 3–20 A Rose Diagram of the Magnetic Lineaments in Kansas

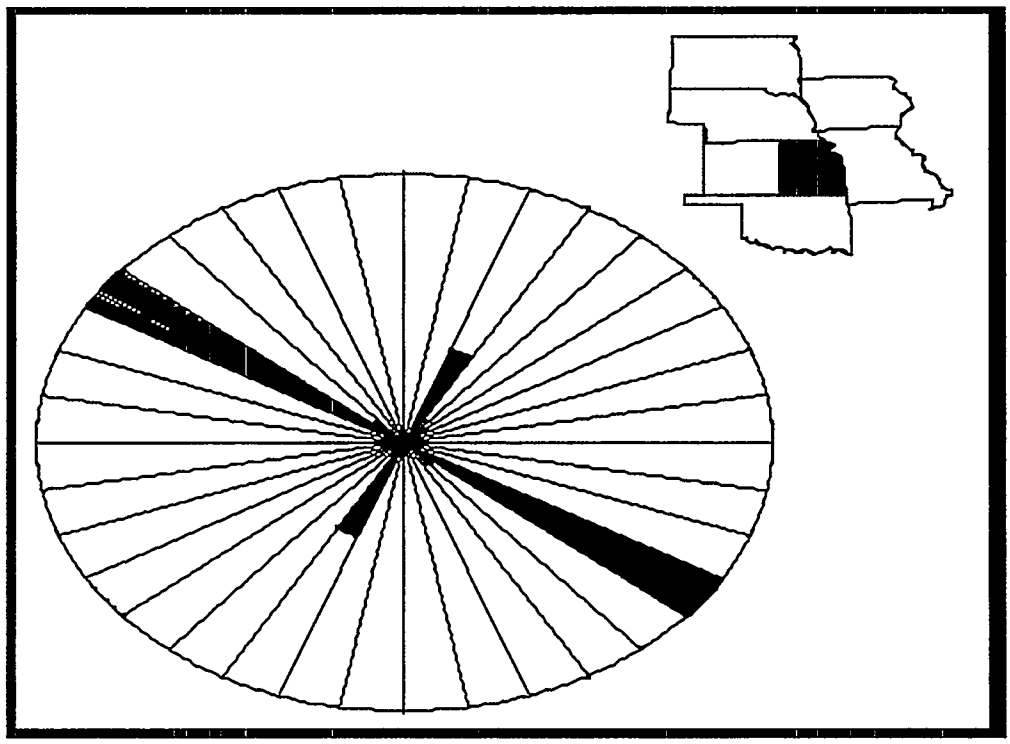

Figure 3–21 A Rose Diagram of the Basement Faults in Eastern Kansas

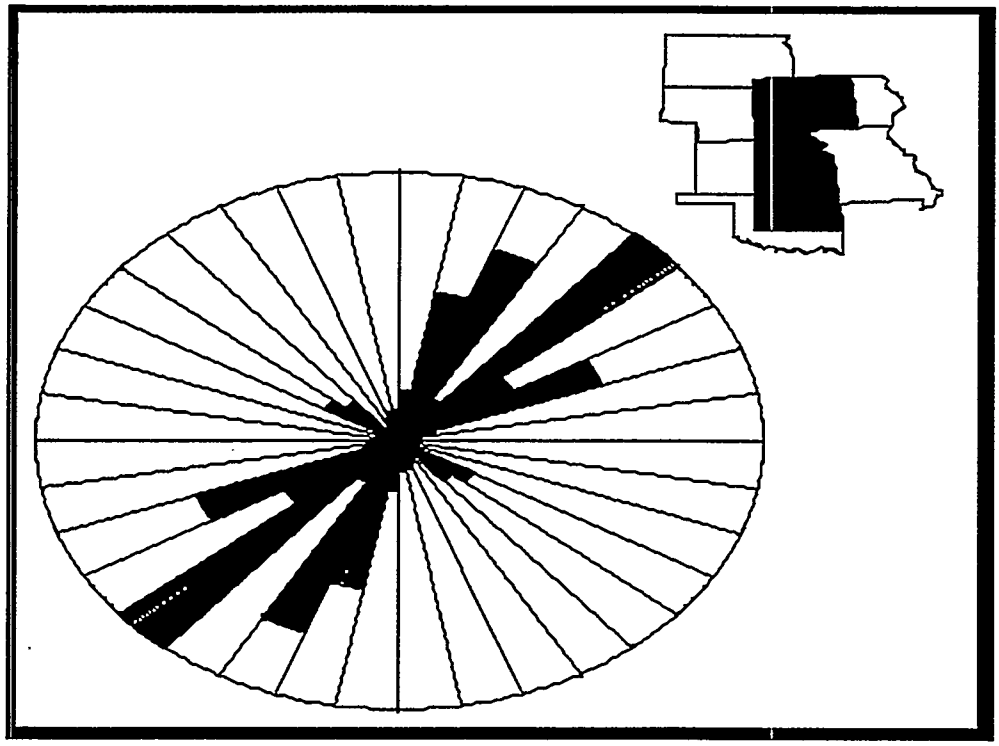

Figure 3–22 A Rose Diagram of the Basement Faults in the Nemaha Uplift Area

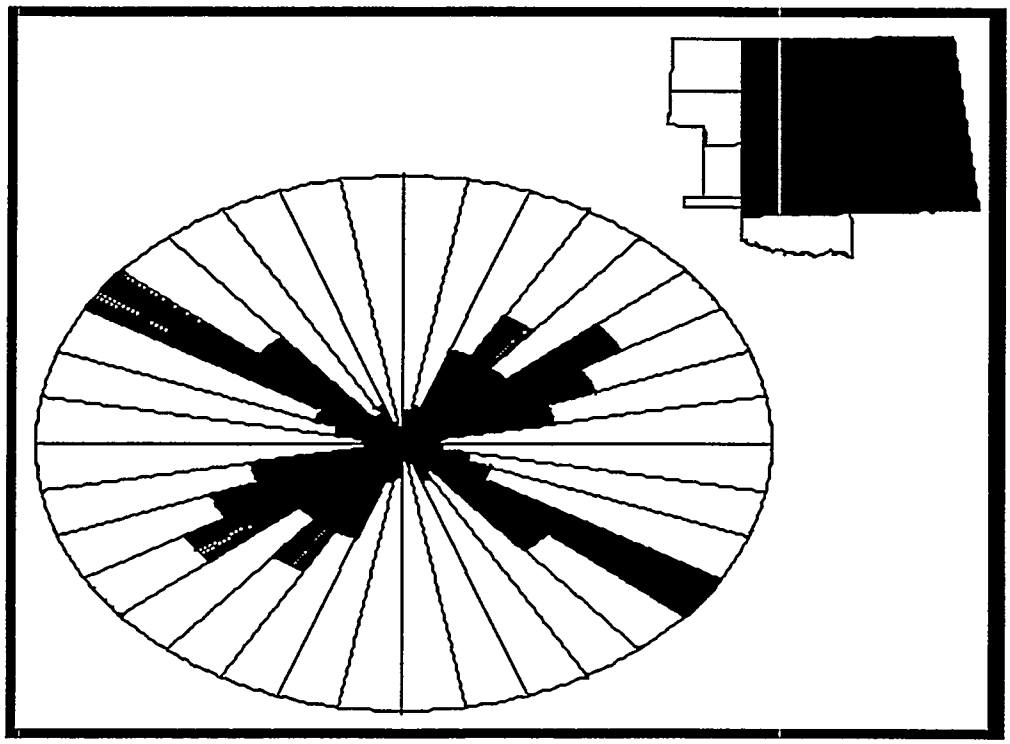

Figure 3–23 A Rose Diagram of the Basement Faults in the Northern Mid-Continent

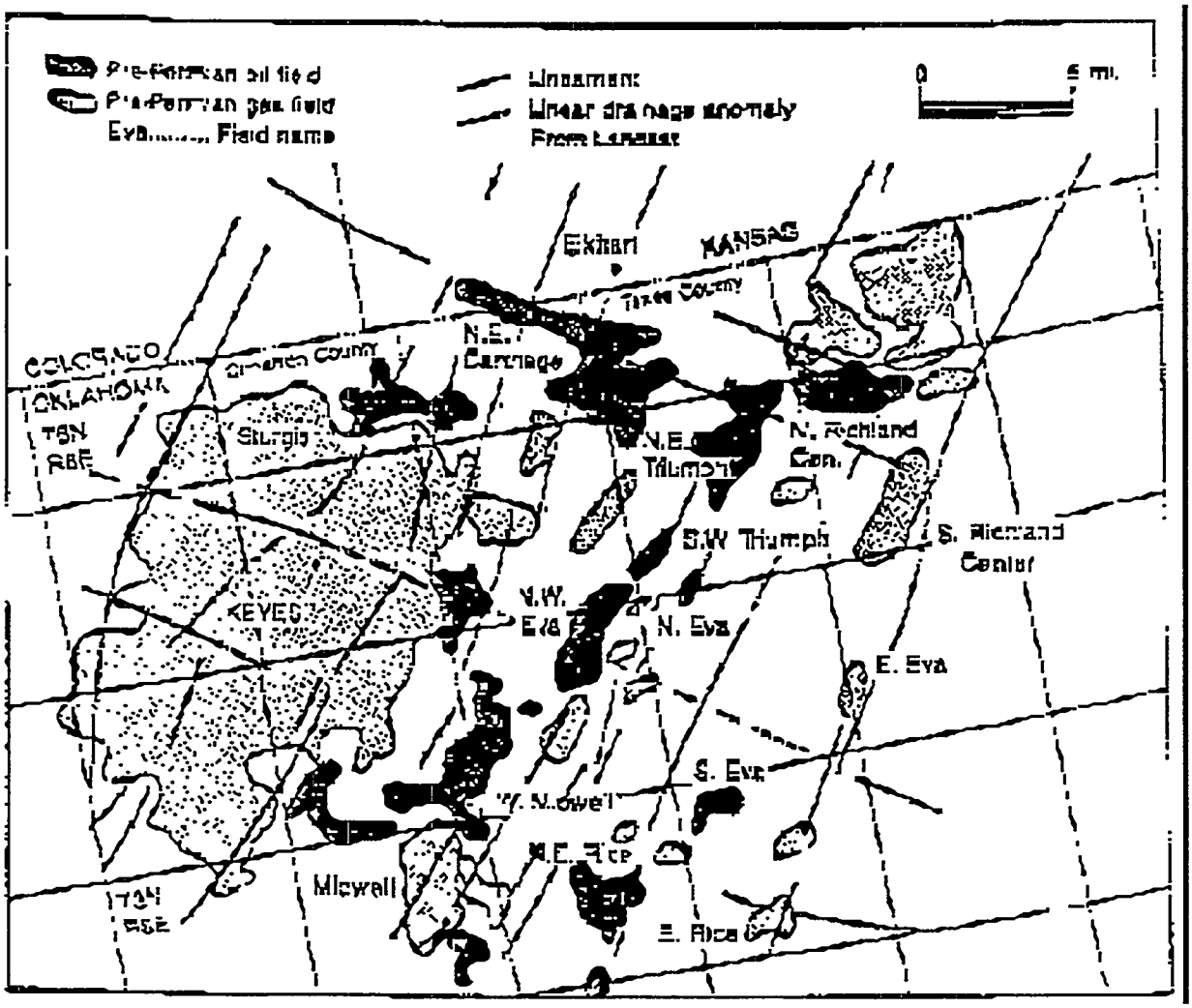

Figure 4–1 Association of Surface Lineaments with Subsurface Oil and Gas Reservoirs in the Hugoton Gas Field in the Oklahoma Panhandle

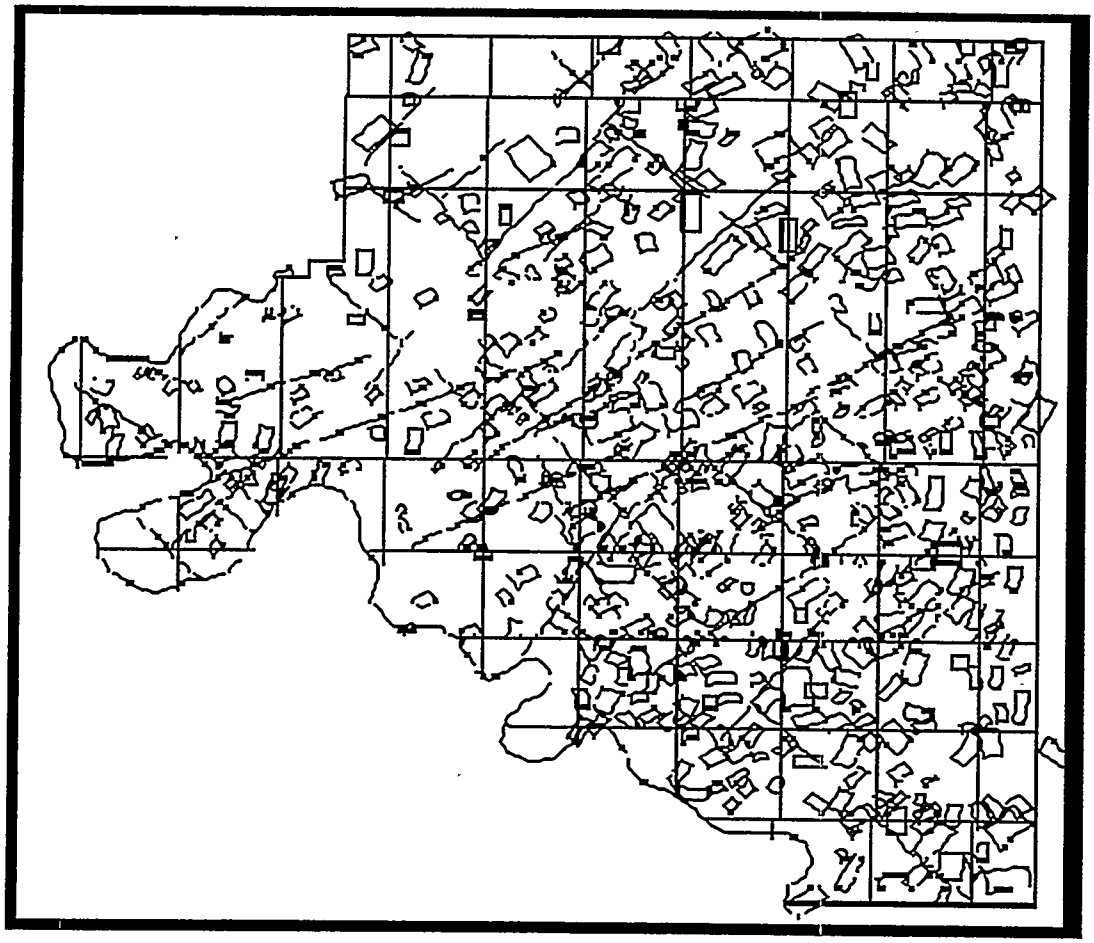

Figure 4–2 Overlap of Surface Lineaments (Lines) and Subsurface Structures (Rectangles) in Osage County, Oklahoma

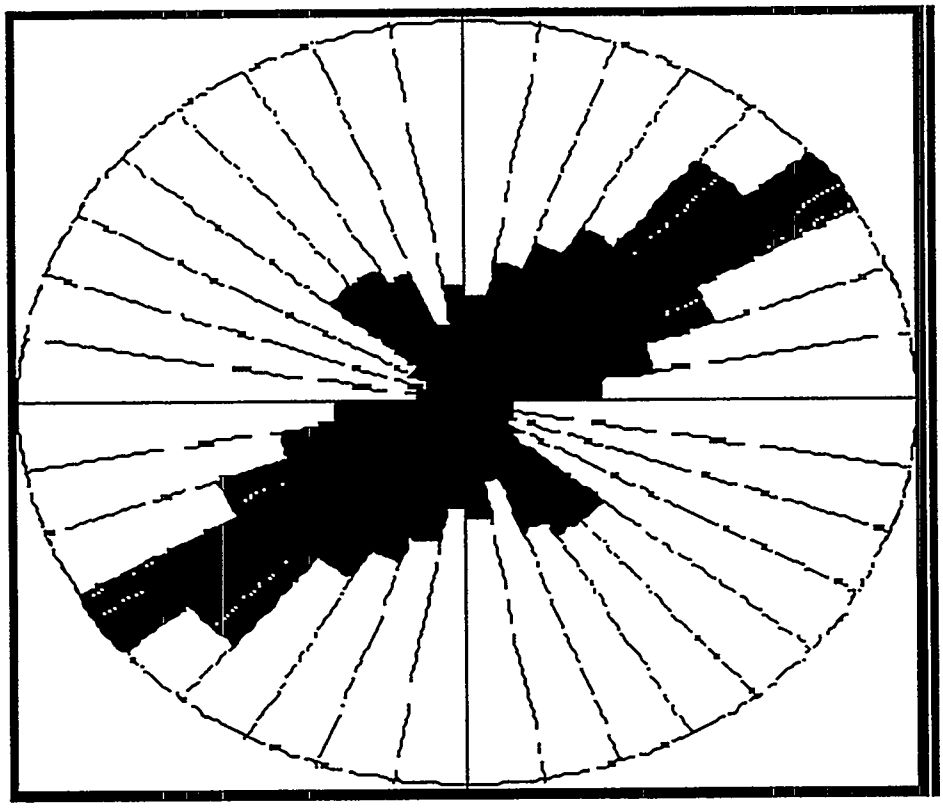

Figure 4–3 A Rose Diagram of the Subsurface Structures in Osage County, Oklahoma

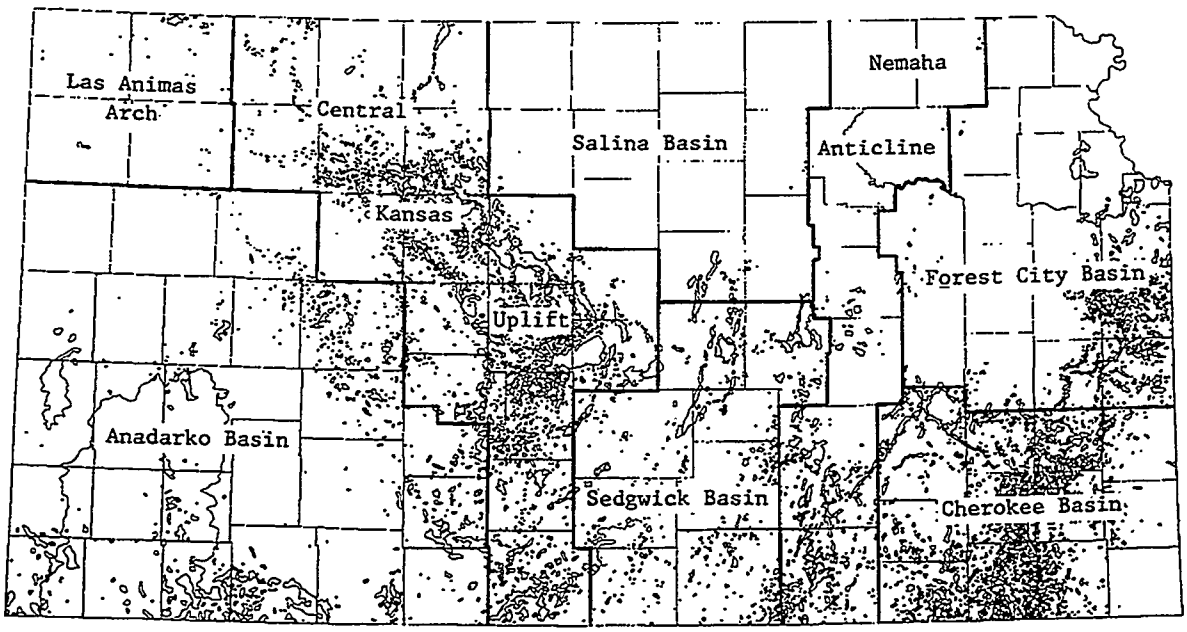

Figure 4–4 Distribution of Oil and Gas Fields in Kansas