PART II:

EFFECTS OF GEOLOGICAL FRACTURES AND LINEAMENTS UPON HYDROLOGIC FLOW OF ACID MINE WASTEWATER

BY

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Introduction

An investigation into the nature and extent of fracturing in the brittle carbonate and chert of the Boone Formation was begun in August of 1983. The study area centers around the Picher mining field in northeastern Oklahoma and is bounded by the Neosho River on the west, and the Spring River on the east. The headwaters of Grand Lake of the Cherokees occur at the confluence of the two rivers. Waters from the Tar Creek drainage basin enter the Neosho River just southeast of Miami, Oklahoma. The specific objective was collection of fracture orientation data from throughout the area, providing insight as to the local geology and role of fracturing in migration of surface and ground waters.

GEOLOGY AND FRACTURE ANALYSIS

General Geologic Considerations

Although much has been written concerning Boone Formation stratigraphy and petrology, no attempt has been made at mapping comprehensively the individual members of the Boone Formation. It is felt that such completeness of mapping would contribute to the understanding of such parameters as origin, quality, and significance of discharged waters, as well as their relationship with fractures, among the various members. Such mapping is under consideration as a task for the approaching cooler months, when vegetative cover is less inhibitive, and water levels are lower. To date, from information currently available to this study, two Boone Formation members have been differentiated in mapping. The St. Joe Limestone member was mapped and published in a U.S. Geological Survey Professional Paper by Mcknight and Fischer (1970), and the Short Creek Oolite member was mapped and published in the Oklahoma Geological Survey Bulletin 72 (Reed, et.al., 1955).

Serious attempts at stratigraphic correlations between various field sites, well logs, and core logs are upcoming as more and more information is made available for use. Intricacies in lateral facies relationships, as well as limited exposures in many cases, make detailed geologic observations critical for every location. Variations in the nature, degree, and continuity of fracturing among the various members have been noted in the field. Joints and joint sets or systems present in one member may be less well developed or absent in another; these conditions are occassionally repeated at other sites among members thought to be stratigraphic equivilents of the former.

Fracture Analysis

Assuming that the above observations correctly represent a significant characteristic of regional structural deformation, the task of conducting fracture studies for each member of the Boone Formation seems a logical undertaking. Although an ominous task under ordinary conditions, it is further complicated by the fact that Boone stratigraphy is not known or mapped in such detail at present. It may be, however, the most effective method available for determining the interrelationships of fractures from various members and, thus, fracture continuity throughout the system.

The in-field recording of fracture orientations has resulted in the collection of rose-diagrams collectively labled Figure 1. Sites designated J1-J4 represent the sites which provided the largest and, perhaps, the most significant data pools. Sites designated Jm1-Jm3 represent sites having fewer numbers of measurable fractures due to limits of exposure or relative lack of deformation (or lost to the effects of recrystallization and secondary deposition). These locations are included because it was felt that the fractures recorded were either prominent, or showed signs of solution activity, or both. Figure 2 is a map showing the locations of sites from both classes, and Figure 3 is a map of the mean fracture orientations recorded from each site. Table 1 provides a description of these sites, and Table 2, the pertinent statistics.

As a matter of observation, it is noted that short segments along the Spring River trend with nearly the same orientation as the predominant fractures measured in the area (40°-50° azimuth). Though speculative in nature, it should be noted that flow rates and, especially, discharge rates of the Spring River are significantly less than those of the Neosho River during the same time period. Adherence of surface flow to fracturing trends in the area may be more readily discernable given such conditions. Note also that small streams tributary to the Spring River from the east exhibit similar flow directions. For the sake of completeness, the author wishes to report estimated fracture trends in quadrant 2 (330°-345° azimuth) which were observed along the Spring River north of Devil's Promenade. After more complete sampling, these fractures may be established as complimentary to those of quadrant 1.

By the same argument, the flow direction of the Neosho River, roughly southeast, may be related to an important set of fractures whose trend averages approximately 330° azimuth recorded at site J2. The relatively greater flow rate, and greater average pool elevations of the Neosho River may tend to obscure such indicative linear segments as those observed along the more ephemeral Spring River. Again, for the sake of completeness, note that the limbs of many meander bends along the Neosho River trend roughly northeast; this would coincide with the most prevalent orientations recorded at sites J2, J3, and J4.

In the future, more fracture sampling sites are to be located. These will be north of present sites on the Neosho River, and both north and south of sites on the Spring River. It may be more difficult to locate such exposures along the Neosho River, in particular, north of Miami, because of the characteristically flat topography associated with the Pennsylvanian shales in the area.

Fracture studies in the Boone Formation of the mining area are limited to data collected during exploration and mining. The availability of such data depends on the cooperation of local mining concerns. In addition, ground truthing and interpretation of data produced from small-scale remote sensing techniques, such as LANDSAT should result in the discovery of large-scale fracture zones.

Interestingly, springs and seeps investigated along the river systems, whether flowing or only evidenced, show a marked preference for issuing from horizonal bedding plane fractures rather than from the near vertical fractures recorded in this report. These horizonal fractures may provide avenues for the passage of ground waters between zones of discontinuous vertical fractures or, perhaps, vice-versa. In either event, the need for continued investigations into the interrelationships of vertical and horizonal fractures and their impact on the movement and quality of waters through the system is well established.

Conclusions

This research has established the need for a more complete understanding of Boone Formation stratigraphy; subsequent correlation between field sites, well logs, and core logs will provide much of the needed information. More extensive investigation, such as the mapping of formation members, is planned for the fall of this year. At the same time, new sites for measuring fracture orientations will be added. Increasing the number of sites and/or the number of readings per site will increase the probability that the population of fracture orientations is well represented. Of particular importance is the further investigation of the relationships between surface water flow directions, and the trend of the near-vertical fractures measured in the area. Segments along both the Spring and Neosho Rivers have been identified as trending in the same directions as the most prevalent fracture orientations so far measured. Additionally, the relationships between horzonal bedding plane fractures and the nearly vertical fractures will be explored. These studies will be of great importance in the determination of ground water flow directions and rates.

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Table 1

Site Descriptions

J1 (NE1/4,SW1/4,Sec.5,T28N,R24E);

Just north of bridge on west bank of the Spring River at Devil's Promenade. Highly brecciated Moccasin Bend (?) Member.

J2 (NE1/4,NE1/4,Sec.27,T27N,R23E);

Approximately 400 yards north of Connor's Bridge on the south bank of the Neosho River, at Mudeater Bend. Unsure of member involved. 11 fractures taken to be of more than average importance (8 in quad.1, 3 in quad.2).

J3 (NW1/4,SW1/4,Sec.30,T27N,R24E);

South bank of the Neosho River approximately 3 miles downstream of Mudeater Bend apex. Joplin (?) Member. 3 fractures taken to be of more than average importance.

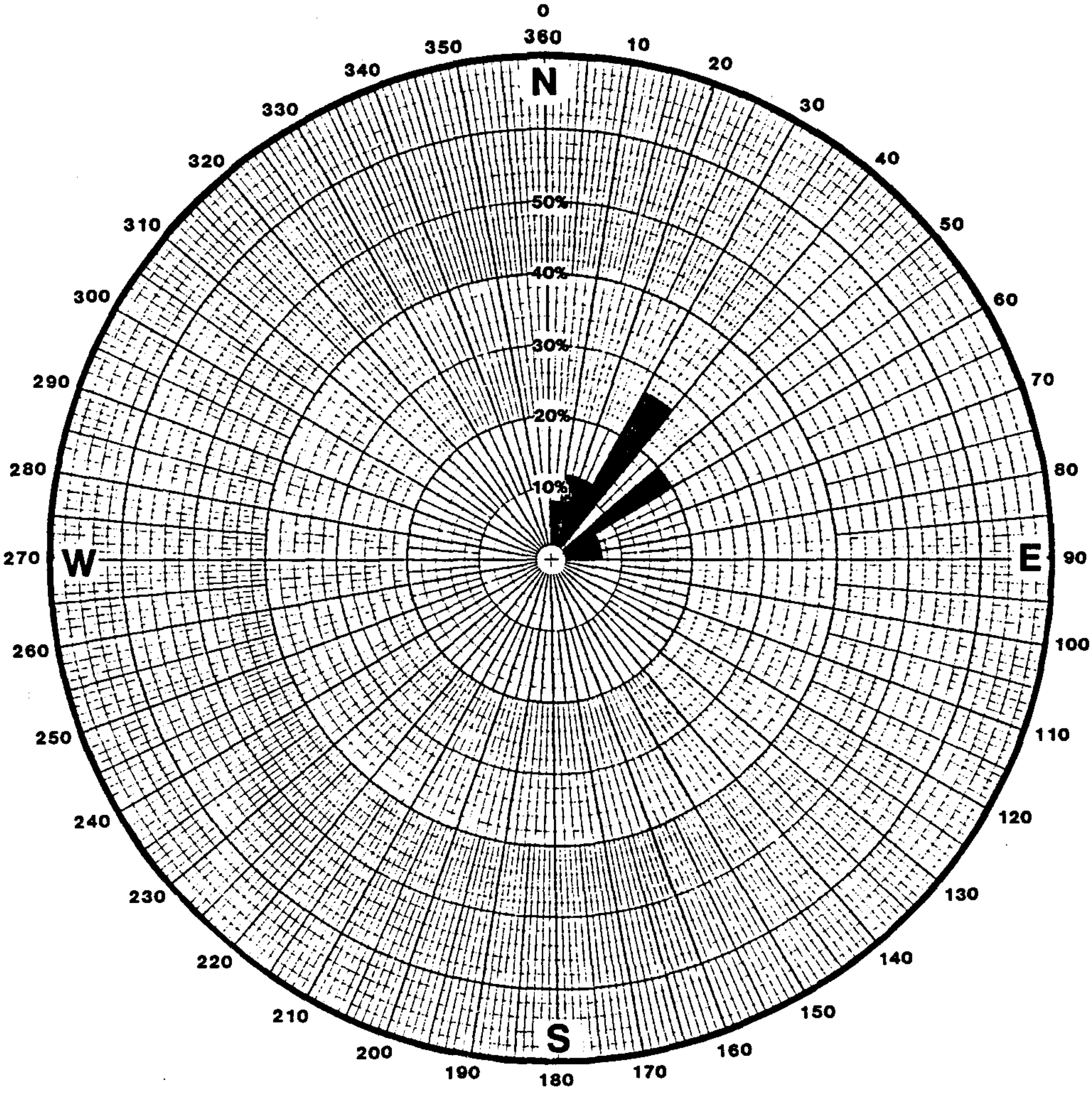
J4 (NE1/4,SW1/4,Sec.19,T27N,R24E);

North bank of Neosho River, approximately 0.5 miles upstream of the confluence with the Spring River. Joplin Member and Short Creek Oolite.

Table 2

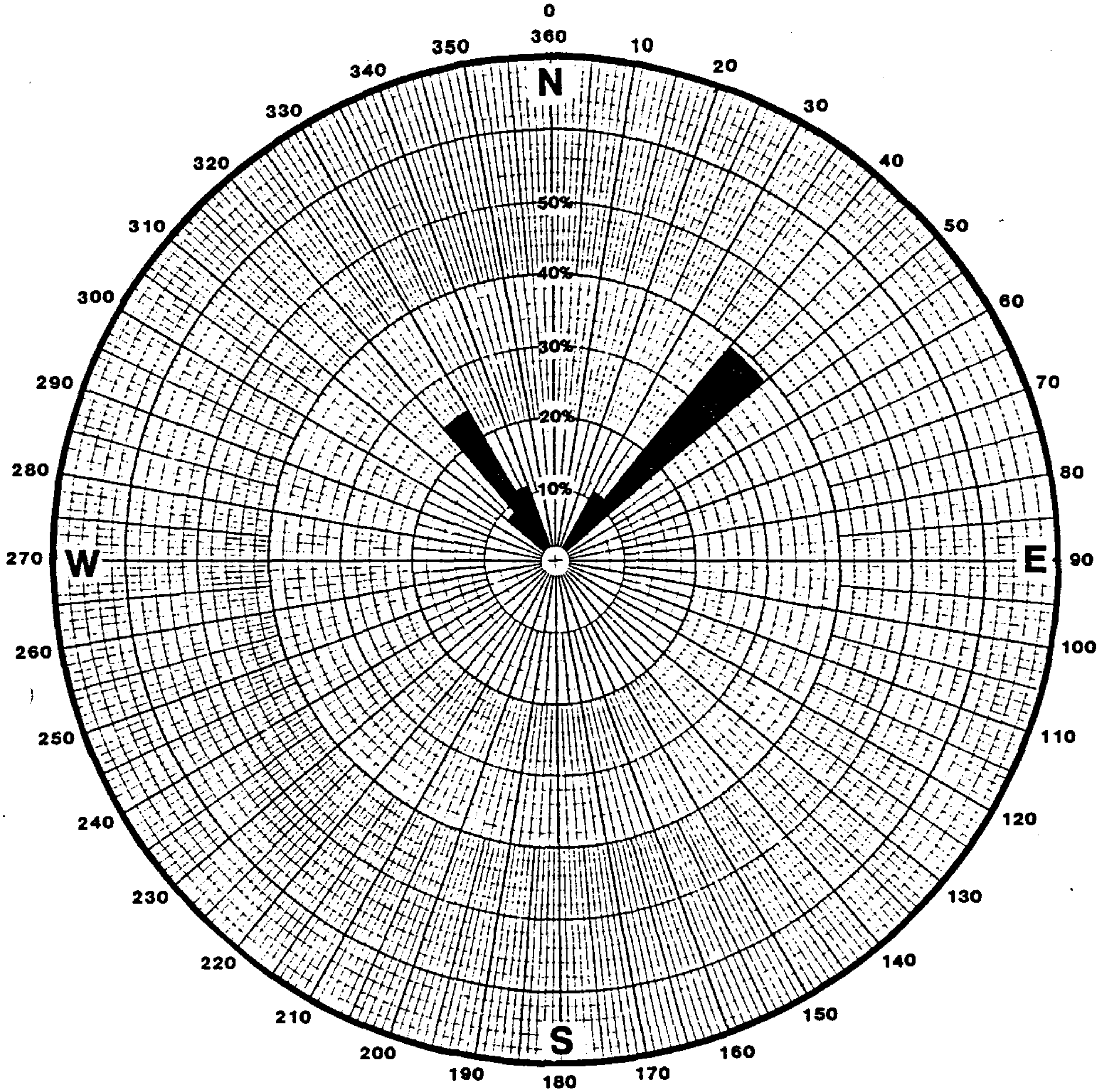
Fracture Statistics

Site	Sample Size (n)	Sample Mean Azimuth (bearing)	Sample Standard Deviation
J1	15	42.1° (N42°E)	23.7
J2	24	45.7° (N46°E) (Quad1)	4.4
	22	329.8° (N30°W) (Quad2)	7.7
J3	19	72.3° (N72°E)	18.4
J4	10	50.1° (N50°E)	5.3



SITE J1

FIGURE 1.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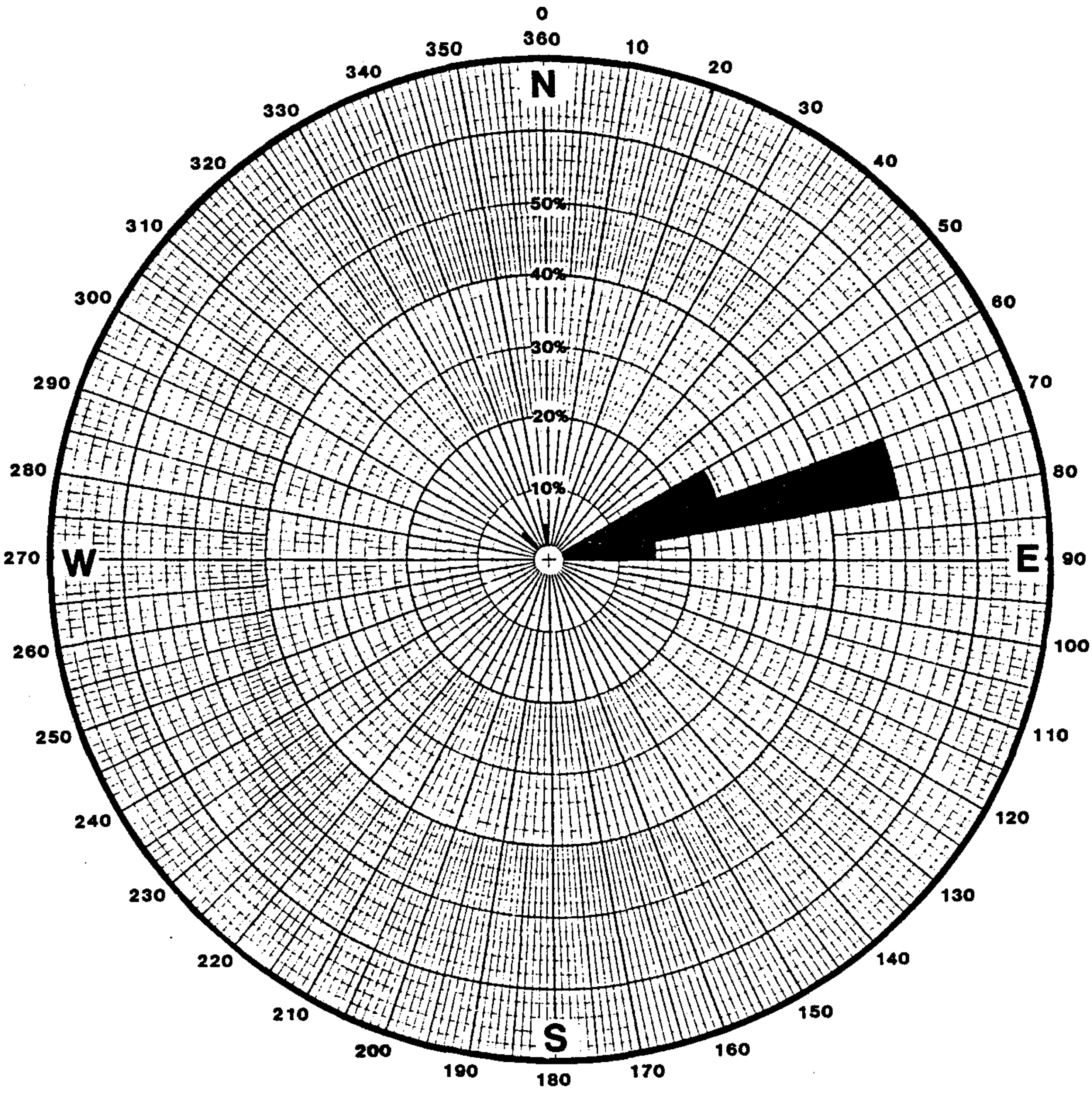

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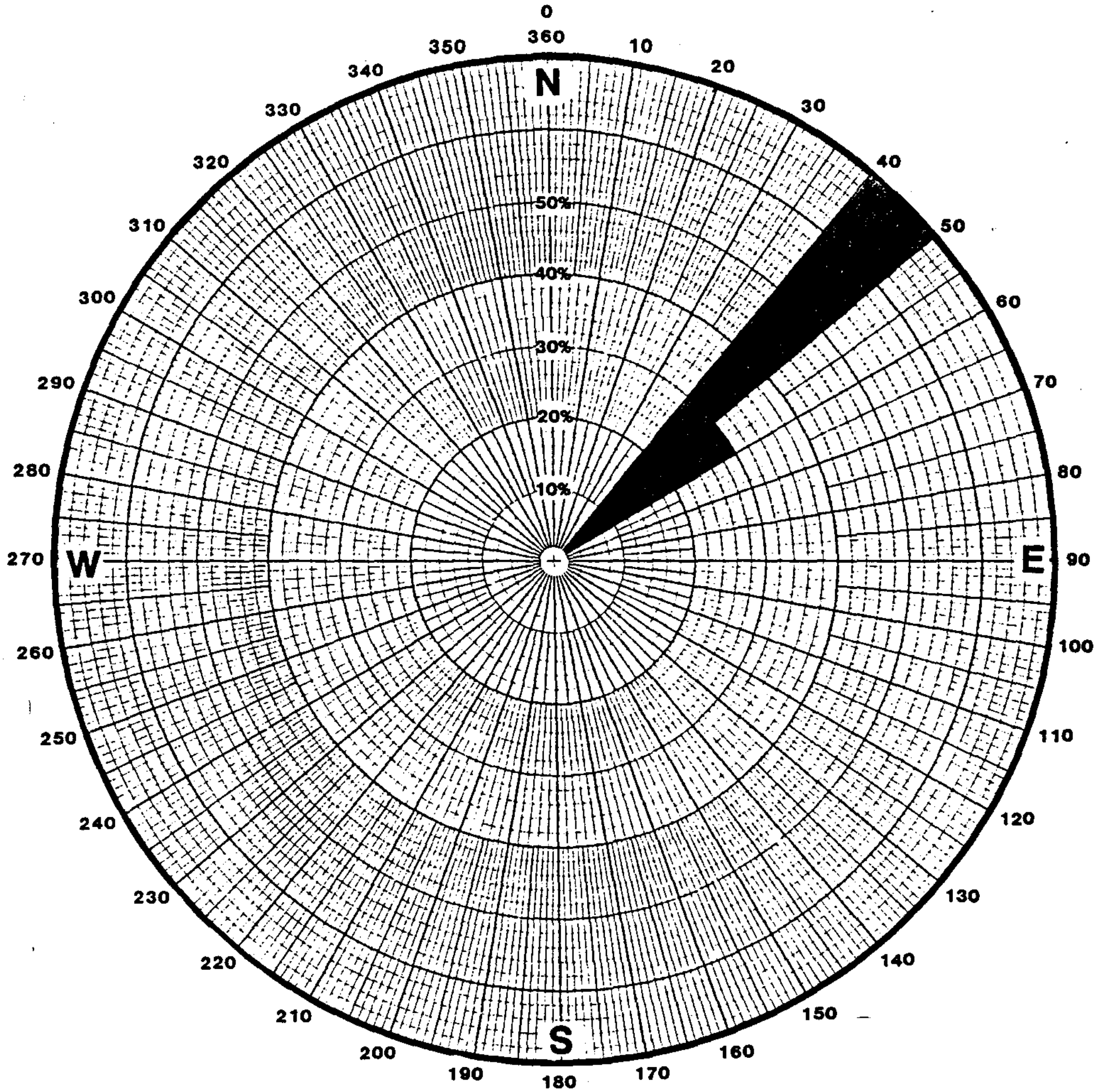
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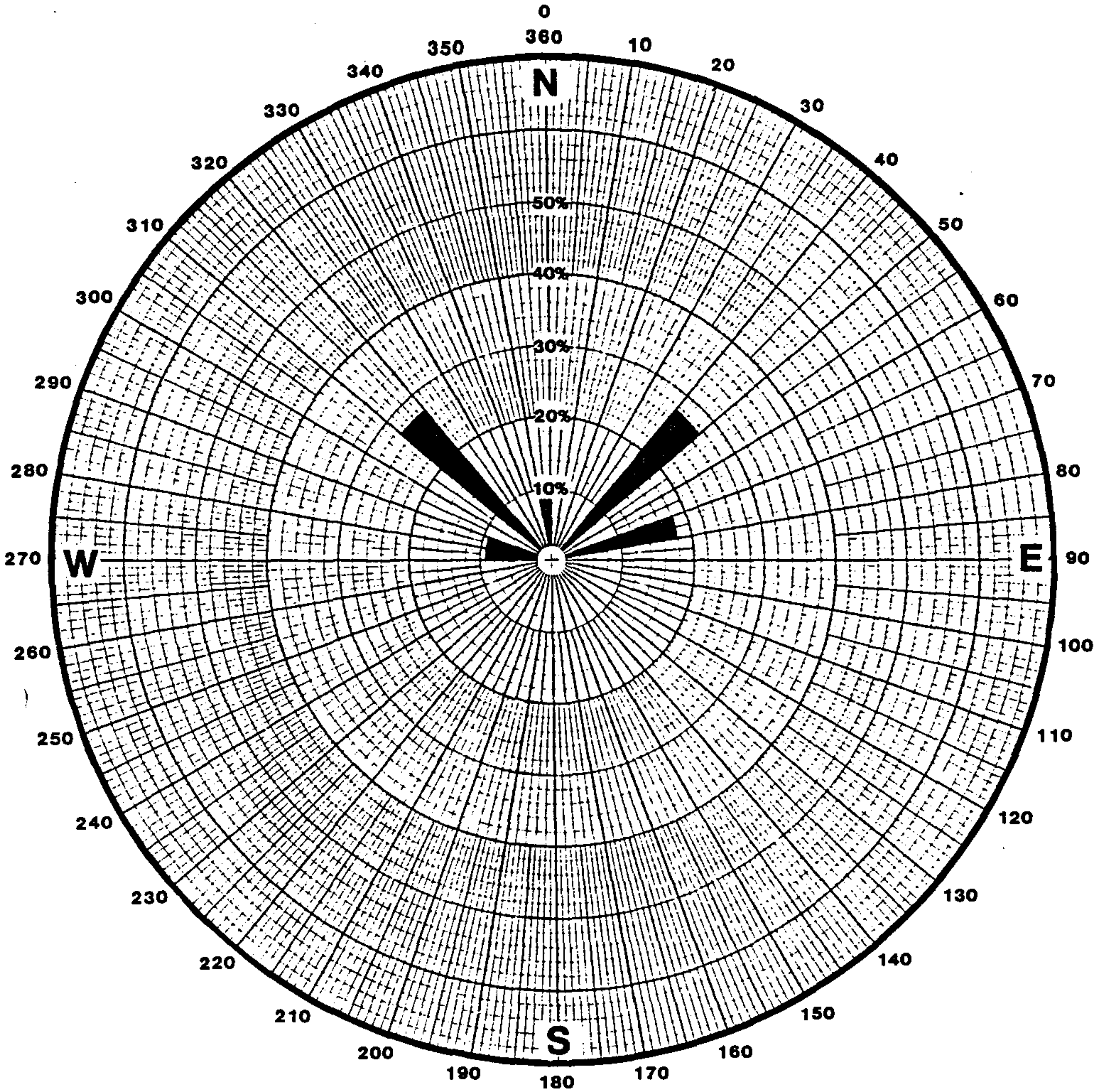
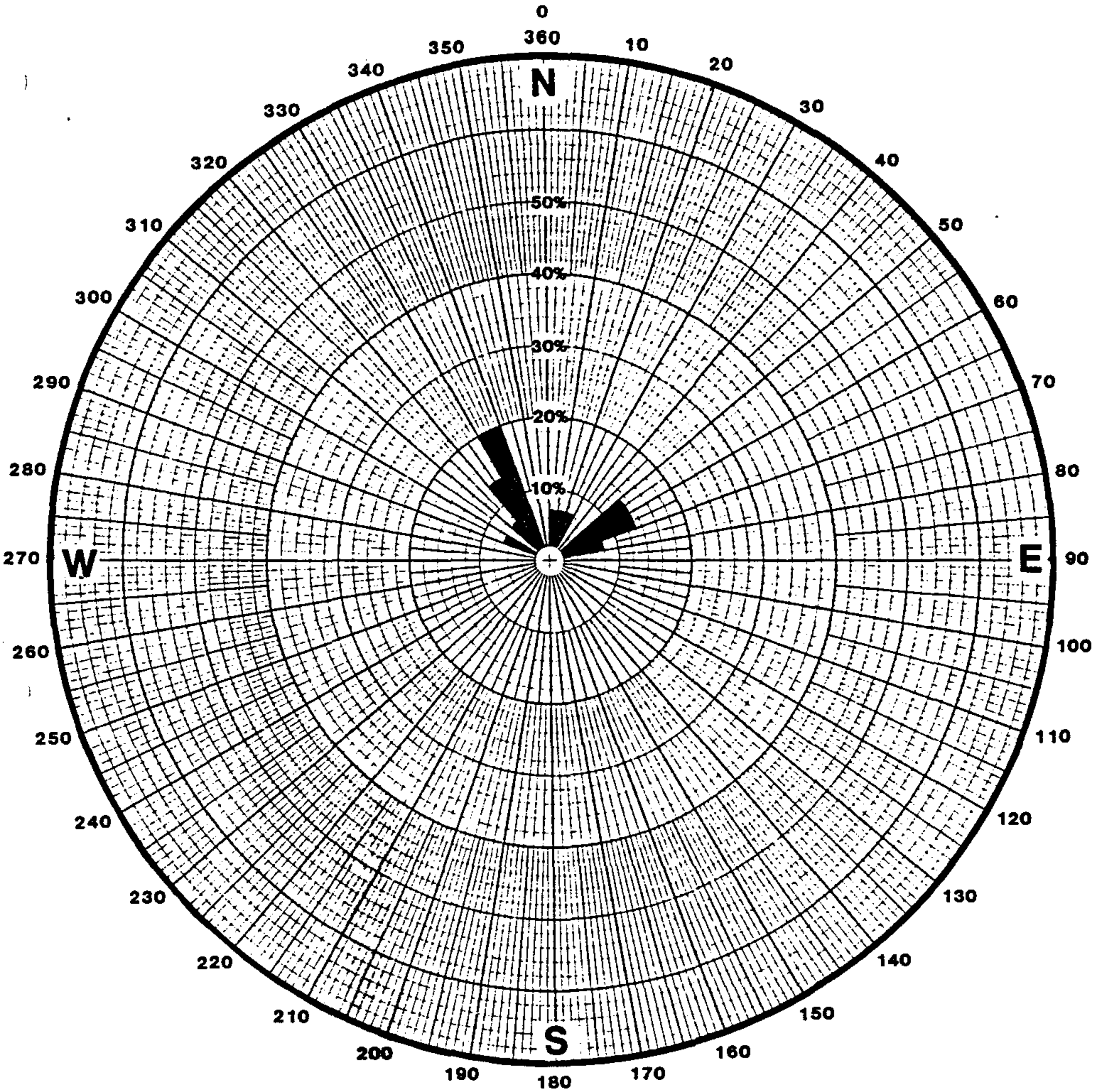


NEOSHO TRENDS



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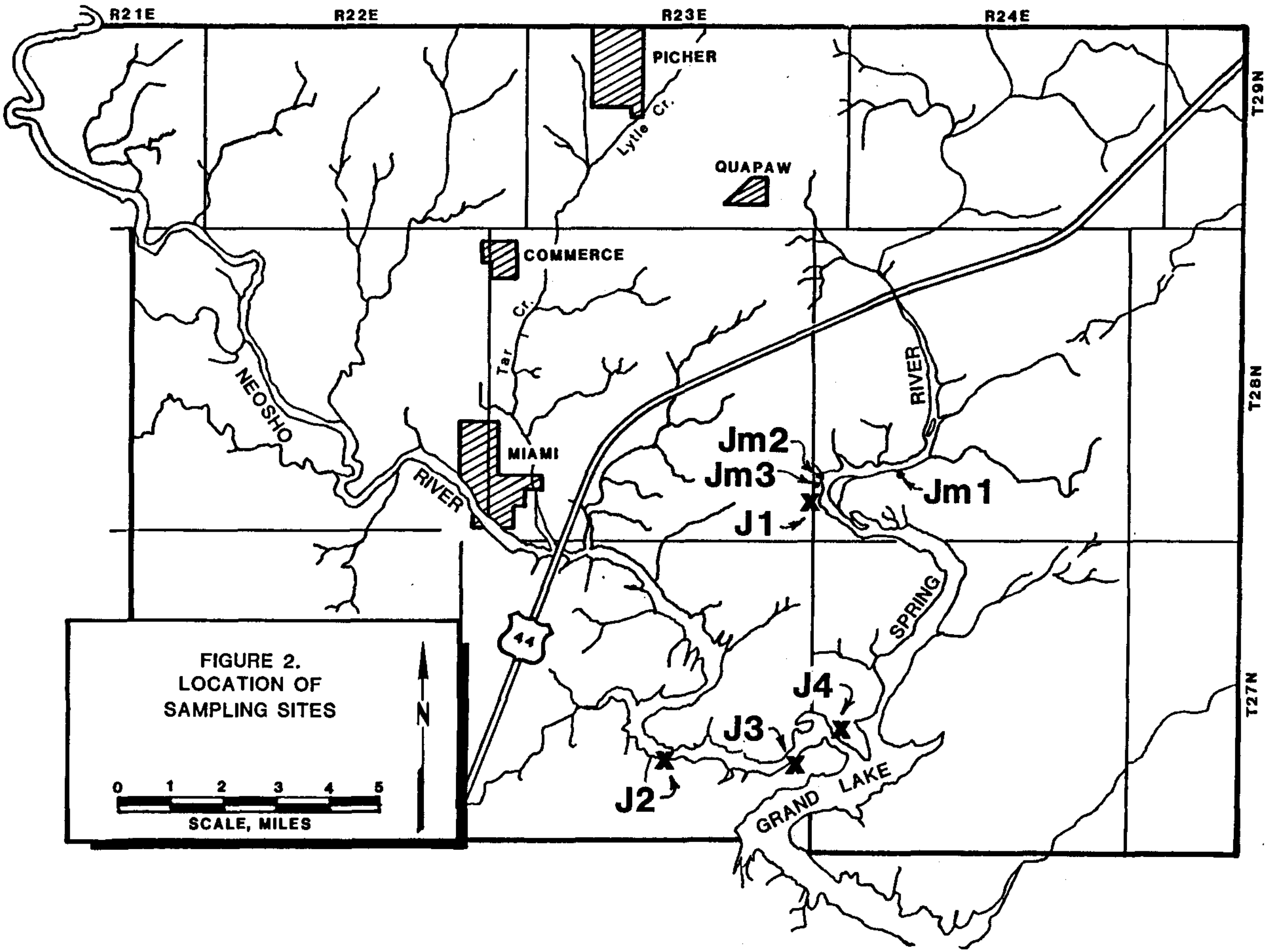

FIGURE 2.
LOCATION OF
SAMPLING SITES

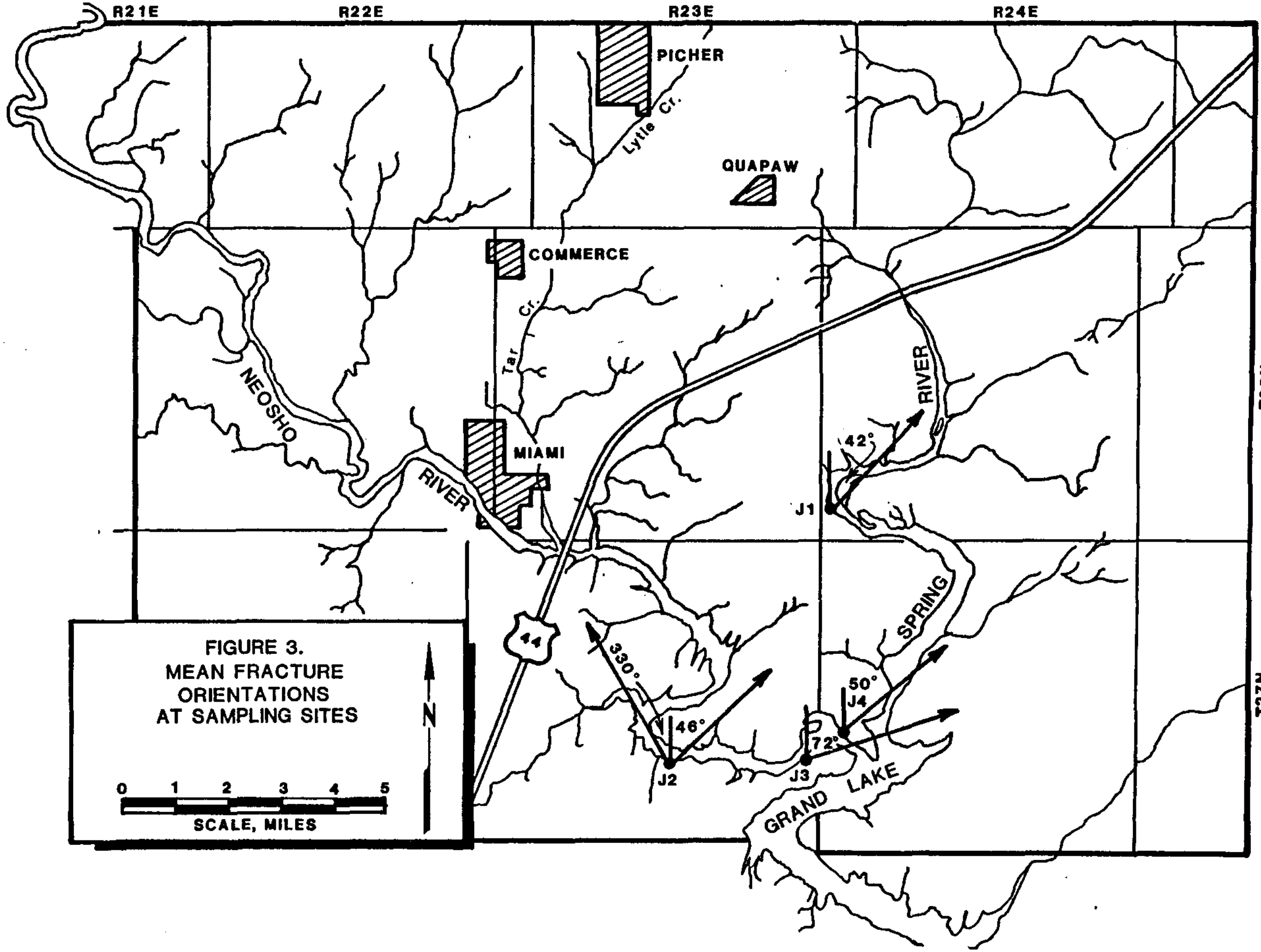

FIGURE 3.
MEAN FRACTURE ORIENTATIONS AT SAMPLING SITES

PART III.

Lineaments in Northeastern Oklahoma: A Preliminary Assessment

by

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Summary:

The geologic structure of northeastern Oklahoma is known relative to the former lead and zinc mining but is relatively unknown with regard to the interaction of the structure with the movement of water, surface and subsurface. In an effort to assess the gross geologic structure, Landsat digital data were analyzed in the CARS facility. Various enhancement techniques, including band averaging, band ratioing, and principal component analysis, were employed to enhance the data in a search for lineaments. After the data were enhanced, most of lineaments were detected on the principal component enhancement. In all, 32 lineaments were detected in the study area that were not related to human activity. The directional trend of the lineaments, can be summarized as a primary trend (60–70° East of North) and a secondary trend (120–130° East of North). The directional trend of lineaments is similar to the orientation of the fracture pattern detected by Vaden and Kent. This correlation suggests that the geologic structure can be interpreted with remote sensing techniques and field analysis. Additional field work is necessary to confirm this correlation and to study how the movement of water is related to this structure.

Introduction:

The development of remote sensing over the last decade has provided earth scientists with another tool with which to view the earth and assess inter-relationships among various phenomena. Since the time of the first photograph taken from a balloon, scientists have sought methods to capture the image of the earth for study at more controlled locations, such as in the laboratory. After World War II, airphoto interpretation served as the primary method of analyzing the surface. From standard black and white images to color and infrared images, the science of aerial photograph enhanced the analysis and interpretation of the earth surface. As with many techniques, however, some problems such as image size and scale were difficult to overcome. Some solutions required space-age technology.

Satellites and manned-space craft have provided a new look at the earth. From high observation points, the surface was more generalized, a process which enhanced the interpretation of some phenomena. Advances in technology changed the nature in which data were collected (i.e. scanned vs photographed) and the method of analysis (i.e. digital vs. visual). Moreover, the data collected extended beyond visible light, thereby providing different observations of our sometimes too familiar planet. In the mid-1970's, digital images were readily available for the purpose of analyzing the surface. Data collected by a satellite, however, have poor resolution because 1 sampling unit on LANDSAT is approximately 1 acre in size. An image, therefore, covered a large surface area. The resulting small-scale images often revealed linear features that often were not visible on aerial photographs. When the linear features could not be related surface phenomena, analysis showed relationships to subsurface or geologic phenomena. The term "Lineament" has subsequently been defined as "linear surface trends or alignments of regional morphological features, such as streams, mountain ranges, and escarpments, and tonal features that may be the surface expressions of fracture or fault zones (Walsh & Vitek, 1981). Numerous researchers have positively identified lineaments as faults and fracture zones, phenomena which may not be easily detected during field analysis.

Within northeastern Oklahoma, decades of mining and processing lead and zinc have greatly disrupted the surface. Upon chosing the mines, pumps to keep out water were stopped. Since the 1950's, the mines slowly filled with ground water and surface water. Changes in the acidity of the water in response to the chemical interactions between the water and minerals in the rock have created a potentially hazardous situation for residents of the area. Hydrostatic pressure from water flowing into the mines forces very acidic water to the surface. Potential for acidic water to contaminate the source of residential water is also a major threat. Studies by the Oklahoma Water Resources Board, Oklahoma Geological Survey, U.S. Geological Survey, and agencies have focused on immediate solutions to the problem. Plugging wells and diverting the flow of surface water from the mines are two solutions being implemented.

The purpose of this portion of the paper was to identify any major geologic lineaments using Landsat digital data. Such lineaments, if major faults or fracture zones, could enhance the movement of surface water to the mines in southeastern Oklahoma. The Center for Application of Remote Sensing (CARS), on the Oklahoma State University campus, maintains state-of-the-art hardware and software for the analysis of digital Landsat data. Computer equipment plus digital display capabilities permit data manipulation and enhancement in an effort to find geologic lineaments. As a preliminary effort, this paper reports upon the procedures employed to identify lineaments.

Insufficient funds were available to perform field checks on the map of lineaments. Additional research is necessary to go beyond the identification stage reported in this portion of the paper. If plugging wells and diverting surface flow do not have significant impacts on the mine water, additional analysis of lineaments may be necessary in an effort to further assess the relationship of the movement of surface water relative to the network of mines and the gross geologic structures in the region.

The Study Area:

The mining district for lead and zinc in northeastern Oklahoma actually extends into southeastern Kansas and western Missouri. Although the major acid mine water problem has been identified and limited to the Tar Creek drainage basin, the analysis of lineaments was extended to a much larger area (see Figure 1). Given the small scale at which the digital data used in this analysis was collected, extending the area beyond the Tar Creek basin did not significantly increase the analysis phase of the project. Actually, the identification of reflectance values improves as the number of samples increases and the size of the sampling increases. The area included in the sample, approximately 1,240 square miles, represents only 9.4 percent of a frame of data and is a very manageable amount of information.

Limited financial resources prevented acquisition of recently sensed data tapes. Presently, a data tape costs $650. A group of Universities, however, have entered into a data sharing agreement. Through this group we acquired two tapes for the cost of blank tapes. The data, acquired scene ID 8279016005500 from March 22, 1977 and scene ID 83164116205 from October 09, 1982, although not ideal for lineament assessment, provided cloud-free data. The availability of two data sets also provided the capability of checking the accuracy of the lineaments detected.

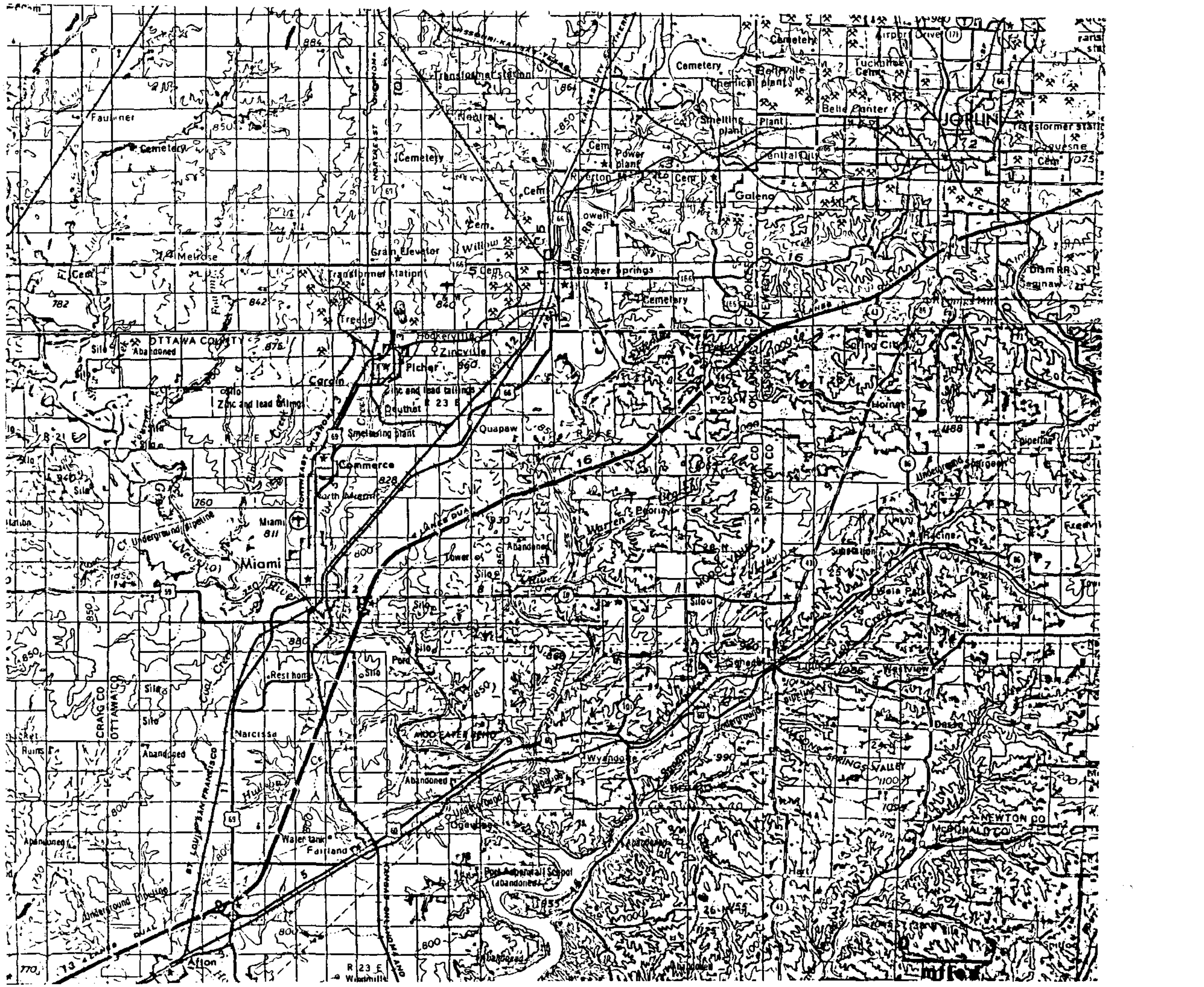

FIGURE 1. The location of the study area in Oklahoma, Kansas and Missouri

Landsat Data: Processing for Lineament Assessment

As the list of selected references demonstrates, earth scientists have devoted considerable effort to the analysis of digital Landsat data for the purpose of detecting and explaining lineaments. Raw data are subjected to a variety of statistical procedures in preparation for lineament enhancement and detection. The details of these procedures are not essential to this paper as they are standard techniques that all data must undergo before being utilized for analysis. Analysis begins with enhancement. or the manipulation of digital imagery which may provide the viewer additional information or insight into the preenhanced image. The goal of enhancement is the improvement in image quality. Many tecniques have been developed and tested in an effort to produce the "best quality" image (Mynar, 1982). Given the present capability of the microcomputing facilities at CARS, enhancement procedures were performed with ELAS software from NASA with minimal effort. A change in microcomputers and operating systems, however, did not proceed smoothly resulting in a delay in evaluating the enhanced images.

This research relied on optical enhancements, a process whereby the results of manipulating the data are displayed on a COMTAL image processing system. The four bands of original Landsat data can be displayed individually, collectively, or in manipulated form on the COMTAL. The simplest enhancement is the "mean value" of all bands. Statistical manipulation of the data for each band is performed by a module in the ELAS software. A second procedure, principal components analysis, attempts to correct for a poor visual display of the original data. The first principal component is the most important in that it contains the most variability of all four original bands. Band ratioing, the third procedure employed, is created by dividing the reflectance value in one band by the reflectance value in another band. The technique, however, highlights the noise in the system and makes the interpretation of lineaments difficult. In our procedures, band 4 was divided by band 5 and band 5 was divided by band 7. Other enhancements were possible but the validity of the techniques were questionable given the dates of our data. Ideally, all lineament analysis is done with data recorded during December, the season with the lowest sun angle in the northern hemisphere. For this reason we relied on the October data, the date closest to the time of the lowest angle.

Results: Lineaments Detected

Lineaments were detected on every enhancement. The greatest number of the lineaments shown on Figure 2 were detected on the first principal component enhancement. Care was taken to eliminate linear phenomena created by cultural features such as highways, railroad right-of-ways, crop patterns, and other forms of land use. The lineaments detected, therefore, are assumed to be associated with geologic phenomena. Spring River appears to be controlled by geologic structure given the pattern or directional tendencies it takes east of the Picher mining district. As shown on figure 2, lineaments are absent in the Picher area. Disruption of the surface during decades of mining have produced a reflectance pattern that detracts from linear tendencies. Lineaments in the surrounding area can be compared to the linear tendencies and joint characteristics identified by Vaden and Kent.

Results of the various enhancement techniques were examined on the COMTAL image processing unit. Of the 32 distinct linear trends detected, 19 were found on the image enhancement produced by principal component analysis. Lineaments were detected by changing the image intensity while viewing the COMTAL. Given the system problems at CARS, the enhanced images of the study area were photographed but lineaments could not be added to the

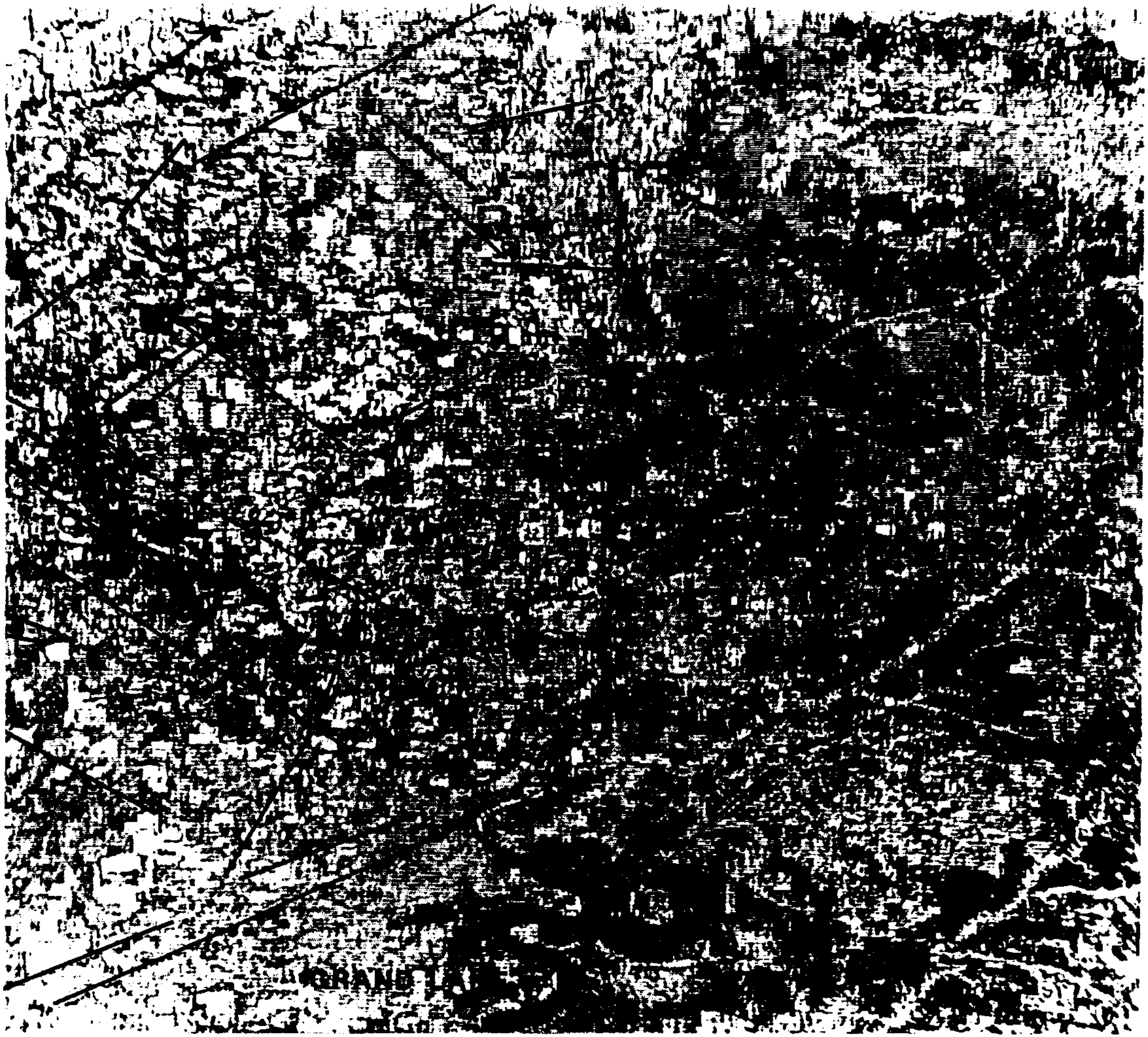

FIGURE 2. Lineaments, heavy black lines, as detected by various enhancement techniques. The base image is the principal component enhancement. Lineaments attributable to cultural phenomena are not shown.

image. Figure 2, a xerox reproduction of the photograph of the principal component enhancement, has been employed as the base map for the lineaments. The dominant trend of the lineaments is NE/SW, although a small cluster trends SE/NW (see Figure 3).

The identification of linear trends in the Landsat data does not prove that geologic lineaments exist. Extensive field work, additional air photo interpretation, and lab analyses are necessary to prove the presence of geologic structure. Extensive research, however, has shown that reflectance not related to land-use is related to subsurface characteristics. Field work by D. Vaden and C. McCormick on the directional characteristics of the fractures in the bedrock show remarkable alignment with the lineaments. Observations from sites J1-J4, available for observation in part II of this report, show a major trend into the first quadrant, the same tendency of the lineaments. Fractures in the bedrock represent small-scale conditions whereas lineaments would be the large-scale components of the characteristics of local geologic structure.

Conclusion:

Enhancement techniques applied to the four bands of Landsat digital data were instrumental in the recognition of lineaments in the study area. Although each procedure produced lineaments, the principal components procedure contributed to the detection of the most lineaments. The inability to detect lineaments in the Tar Creek drainage basin may be a function of the tremendous amount of disruption in the region related to mining, such as chat piles, collapse depressions, and abandoned mine facilities. The lack of lineaments on Landsat data does not prove the absence of these large scale structures. The impact of lineaments on the addition of surface water to the mines, however, can only be examined in other mining areas. Such an examination

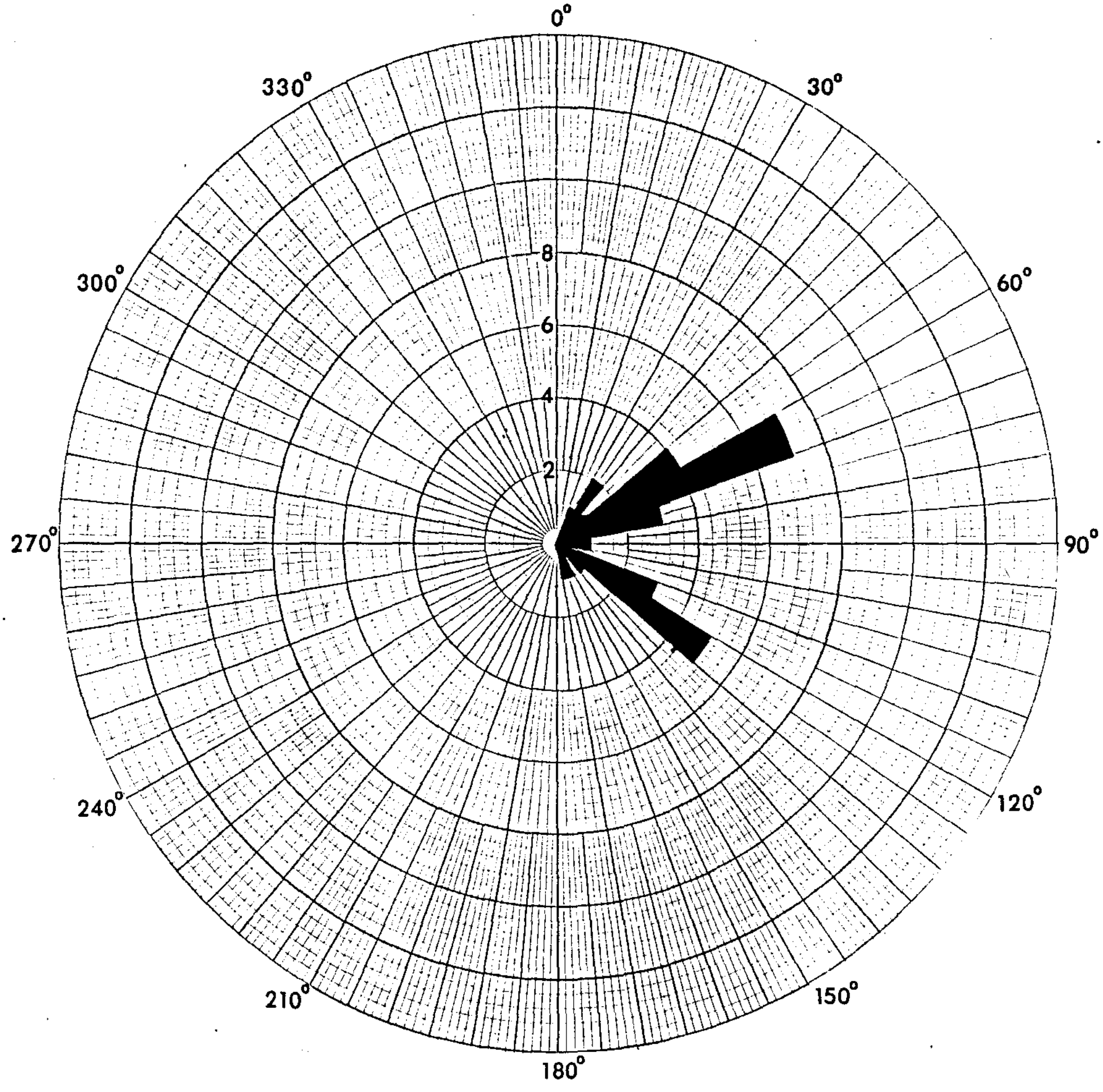

FIGURE 3. Directional tendency of the lineaments portrayed on Figure 2. The values on the graph represent the number of lineaments observed in each 10 degree interval.

was beyond the scope of this paper.

This preliminary assessment of lineaments in northeastern Oklahoma and surrounding states has shown the value of satellite imagery in problems associated with geologic structure. Studies of fracture patterns and lineaments, done independently have derived similar trends for large- and small-scale manifestations of the geologic structure. Additional effort is necessary of future projects in which lineaments detected by various enhancement techniques can be located in the field. Methods of detecting large-scale geologic phenomena can contribute to a better understanding of surficial characteristics.

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