<u>FINAL</u> <u>REPORT</u>

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EFFECTS OF ACID MINE WASTEWATER UPON GRAND LAKE, NEOSHO AND SPRING RIVERS OF NORTHEASTERN OKLAHOMA

AND

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

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The investigators on this project wish to dedicate their work to the memory of a friend and coworker, David Ritt.

ABSTACT

This investigation is an attempt to assess the influence of discharging acid mine waters on the surface water quality of Neosho and Spring Rivers, and Grand Lake in northeastern Oklahoma. Concurrently, fracturing effects on bedrock influencing the migration of surface and ground waters was investigated.

Surface water quality was analyzed for calcium, magnesium, iron, zinc, lead, etc., for trend analysis between sites. In addition, alkalinity, pH and specific conductivity were measured and correlations obtained for all parameters. Sediment core analysis was performed for metals loading into the upper end of Grand Lake. Acute toxicity bioassays were performed utilizng the aquatic invertebrates, Daphnia magna and Ceriodaphnia sp. Tar Creek and discharging mine waters were compared to assess changes in physical processes responsible for production of acidity and solublization of large quanities of toxic metals.

The chemical data appeared to correlate with site locale and precipitation events. Changes in water chemistry, while marked in Neosho and Spring Rivers, was less evident in Grand Lake. Grand Lake sediments indicate that deposition of iron and zinc is occuring; reflecting Neosho-Spring River loading. Acute toxicity has not been noted for sediment samples from upper Grand Lake, a result of minimal dissolution of metals at the water-sediment interface. Discharging mine waters are supplying larger quanities of reduced metals into Tar Creek, resulting in even lower surface water pH's.

Orientations of vertical fractures were measured in degrees of azimuth and statistical analyses performed to assess trends. Analyses of orientations indicate major fracturing zones trend northeasterly, with complimentary fracturing occurring northwesterly. Morphology of surface drainage in the area supports the former observations.

PART I:

EFFECTS OF ACID MINE WASTEWATER UPON GRAND LAKE, NEOSHO AND SPRING RIVERS OF NORTHEASTERN OKLAHOMA

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INTRODUCTION

Surfacing mine water from abandoned underground lead and zinc mines, in northern Ottawa County, Oklahoma, has resulted in the areas' placement on the Environmental Protection Agency's list of hazardous sites and available for 'clean-up' with Superfund. The mines are estimated to contain over 76,000 acre-feet of low pH, highly metal-contaminated water (OWRB, 1983). In late 1979, the acidic mine water began surfacing at several points in the Tar Creek drainage basin and in subbasins along Spring River. At the time of this report, Tar Creek is void of life, except for a few aquatic insects and one species of algae capable of tolerating such harsh chemical conditions. Rock Creek, two miles east-southeast of Quapaw is also showing signs of impact from surfacing mine waters.

The overall objective of this investigation was to determine the extent of the impact of acid mine waters upon Neosho and Spring Rivers, and in particular Grand Lake. Grand Lake is a major impoundment, i.e. 1,672,000 acre feet, on the Grand (Neosho) River. The upper-most reach of Grand Lake occurs at the confluence of Neosho and Spring Rivers. The Tar Creek confluence with Neosho River occurs approximately 10 miles upstream. Deterioration of water quality within the Neosho or Spring Rivers could effect Grand Lake resulting in a serious economic impact upon a multimillion dollar recreation and resort industry.

The specific objective of this study, therefore, was to determine the capacity of Grand Lake to neutralize or dilute the acid mine waters without irrevocable damage to the ecology of the impoundment. Previous studies by Governor's Task Force on Tar Creek had determined that Neosho River had sufficient buffer capacity, i.e. alkalinity, to neutralize the acidic Tar Creek waters. Estimates of combined daily lead and zinc loading into upper end of Grand Lake prior to surfacing of mine waters was reported at 359.2 and 6.020 pounds, respectively. The daily loading of lead, zinc and cadmium by Tar Creek into Neosho River is calculated at (lbs/day based on average flow of 8 mgd, 1984) .4, 3227 and 2.7 lbs, respectively. Investigations of heavy metal chemistry and transport in surface waters indicated limited transport of dissolved species in neutral or slightly alkaline water (Stumm and Morgan, 1970, Florence, 1982). This was confirmed for upper end of Grand Lake by Tar Creek Task Force Reports which found relatively low levels of lead and zinc in the water column of upper Grand Lake but much higher levels in sediments. Therefore, a major focus of this study was to determine the critical levels of buffering agent to prevent redissolution of the high levels of lead and zinc from Grand Lake sediments. Normally buffer systems can neutralize acids generated by biological processes; however, anthropogenic activities may increase acidic substances to a level exceeding the buffer capacity of the system. If this occurs, the pH may decline to levels lethal for most biological organisms, i.e. <5 for many species. Thus, the buffer capacity of upper Grand Lake is extremely important for maintaining acceptable water quality to support aquatic life and for recreational activities. The buffer system must not only neutralize acid mine wastes, but also other inputs such as acid rainfall.

A major emphasis of this study thus focuses on the buffer capacity, i.e. acid-base equilibria, of upper Grand Lake to determine if this system has enough "reserve" capcity to neutralize additional pertubations such as acid rain.

METHODS

Surface water samples were collected from various sites during the course of the study. A 3.2 liter VanDorn water sampler was used for the collection of water samples. All samples for heavy metal analyses were collected midway between sediments and the water surface in polypropylene bottles and acidified to a pH<2. Concurrently, samples were collected and analyzed for pH, alkalinity, specific conductivity, dissolved oxygen, etc., to aid in assessment of the general water quality. All measurements were made directly in the water sampler to minimize changes in water chemistry. Alkalinity samples were collected in polypropylene bottles, filled to overflow to eliminate air spaces, refrigerated, and alkalinity determined electrometrically within six hours. This procedure was compared with phenolphthalein-methylorange and on-site electrometric titrations with no differences noted. In fact, samples containing reduced metals required oxidation with hydrogen peroxide, prohibiting field analysis (ASTM, 1978). Duplicates were compared and all analysis performed according to standardized methods (EPA, 1979).

Sediment cores, 5 cm. X 70 cm., were collected from the upper end of Grand Lake and mouth of Tar Creek with a core sampler with removable PVC tubes. The sampler was a ballcheck single tube core sampler, with PVC core tubes and core catchers to prevent mixing of sediments when the core was withdrawn. The core tubes were packed in ice and frozen until analyzed. Sediment grab samples were also collected from the upper end of Grand Lake, to be used in bioassays with *Daphnia magna*, *Ceriodaphnia* sp., and *Selenastrum capricornutum*, two aquatic invertebrates and a green alga, respectively. Sediments were collected from the upper 6 inches using an standard Ekman dredge. Upon storing in plastic bags, the samples were packed in ice and frozen until analysis was performed.

All sediment sampling was made from a 20 foot barge type boat supplied by the Department of Zoology, Oklahoma State University. The boat is equipped with a 105 horsepower Chrysler engine and a depth chart recorder to permit precise location of sampling sites.

Acute bioassays were performed utilizing _Daphnia_ _magna_ and _Ceriodaphnia_ sp. Both have been cultured in reconstituted water and maintained on _Selenastrum_ _capricornutum_ and yeast, respectively (EPA, 1978 and Mount and Norberg, personal communication). For the _Daphnia_ bioassays test solutions contained .1 liter of the reconstituted water, ten replicates of treatments. Grand Lake sediment samples were dried under vacuum and passed through a number 30 sieve. Five grams of sediment was placed in each jar, thoroughly mixed with reconstituted water, and allowed to equilibrate for two days. Ten control solutions were put through the same regime, without Grand Lake sediments. All tests were conducted at 25°C, with a 16:8 hour light:dark cycle. Five neonates, <24 hours old, were placed in each of 10 control and treatment flasks. Additionally, in five treatment and control containers, chironomid larvae were introduced for more effective water-sediment mixing. Any mortality was recorded at 24 hour intervals, for a period of 6 days. _Ceriodaphnia_ sp. bioassays were performed as above, without the introduction of chironomid larvae.

Bioassays designed to examine impact on reproduction are in progress. The treatment preparation is as above, with one _Daphnia_ _magna_ per container. The young produced are counted and gestation times compared with controls.

RESULTS AND DISCUSSION

Samples were collected from selected locations on Tar Creek, Neosho River, Spring River and Grand Lake with the corresponding Water Resource Board sites in parentheses (Table 1, Figure 1). The concentration of toxic metals at all sites, excluding Tar Creek sites, fell within the EPA's maximum allowable concentration (MAC) except: For zinc and chromium, sites 10 and 19 (Neosho River), exceeded EPA's MAC, while sites 5 and 13 (Grand Lake) exceeded MAC limits for zinc and chromium, respectively (see Tables 2 and 3).

An intensive effort was made in July, 1983, to collect an extensive set of samples from Grand Lake and the Neosho and Spring Rivers to reflect conditions during low flow, summer conditions (Table 4). All parameters, on the Neosho River, were within acceptable ranges and reflect the minimum of discharge occuring from Tar Creek. All Grand Lake values were within the normal range for surface waters in this area. The clarity of water was strikingly different when comparing site 5 with site 7 on Grand Lake. Large amounts of sediments were transported into Grand Lake (site 5) primarily as a result of the Neosho and Spring Rivers. Elk River was very clear with a slightly lower specific conductance. The zone of mixing of Elk River Arm and Neosho-Spring River Arm of Grand Lake was clearly delimited, sediments settling out quickly once they reached the Elk River confluence.

The analysis performed on August 11, 1983, showed no significant differences other than zinc was slightly elevated below the confluence for Spring and Neosho Rivers. The means for all sites within Grand Lake, Neosho River, and Spring River were calculated and plotted to illustrate general trends (Figure 2-10). Tar Creek sites were excluded because of the high levels of metals. Grand Lake showed slight variation in alkalinity, whereas a high degree of variability was found in Neosho and Spring Rivers (Figure 2). The later may be due to several facts: 1. The inputs of acid mine waste periodically decrease the buffer capacity of the rivers, via the entry of extremely concentrated acidity and reduced metals, which, upon oxidation, produce even more acidity. 2. Low bicarbonate runoff waters mix with the buffered waters of the rivers, resulting in a dilution of the waters and buffers. 3. The rainfall is acid enough during rainfall events as to significantly decrease the normally high alkalinity of the rivers. The USGS monitoring records of flow in the Neosho and Spring Rivers and Tar Creek indicate that large volumes of low pH water may reach the rivers. Rainwater typically has a low alkalinity and a pH of approximately 5.6. The rainfall was measured in July, 1983, and March, 1984, at Twin Bridges State Park, and found to have a pH of 3.60 and 4.05, respectively. This is considered to be acidic and could also decrease the buffering capacity.

It is likely that all three events are occuring, but because this area has large exposed surfaces of carbonates, acidification of river waters is unlikely. Carbonate rocks tend to reduce acidity and buffer the water, i.e. increase alkalinity (Drever, 1982, Krauskopt, 1979). Though Grand Lake is a sink for contaminants transported by the acidified waters, no direct threat of acidification exists, under present conditions, though subtle changes in water chemisty are possible.

There was a positive correlation between rainfall and the pH values for all three groups of sites (Figure 3). The range of pH observed in both rivers is greater than observed for Grand Lake. The low pH values for October and March for the river samples corresponds to a decrease in alkalinity values, whereas the slight fluctuations in pH in Grand Lake indicates adequate buffering capacity for the current inputs of acidic water. Correlation coefficients for several parameters and the relationship between alkalinity and pH are reported (Table 5 and Figure 4).

The observed ranges of calcium and magnesium concentrations in the river systems was much larger then observed at the Grand Lake Stations (Figures 5 and 6). Calcium concentrations correlated very well with alkalinity values suggesting that changes in alkalinity were linked with changes in calcium carbonate dissolution (Table 5).

The loading of iron into the Neosho and Spring Rivers indicate a positive correlation with rainfall events (Figure 7). Large volumes of runoff entering these rivers tend to scour the bottoms of the tributaries and transport the precipitated iron compounds deposited upon oxidation of the acid mine water. Iron, as with lead and zinc, negatively correlates with pH, indicating that higher pH's result in lower soluble iron concentrations (Table 5). The concentration of iron in Grand Lake was not significantly higher than normal, probably due to the transported iron settling out, when contacting these higher pH waters.

The concentration of manganese in Grand Lake was low and fairly constant, whereas the range in concentration within Neosho and Spring rivers was greater (Figure 8). Acid mine drainage has a characteristically higher concentration of manganese then the 'normal' levels found in rivers in this area.

Zinc concentrations ranged more widely in the rivers then did lead concentrations (Figures 9 and 10). The elevated zinc concentrations in mine waters would make suspect, the origin of the zinc in the river waters. Grand Lake mean lead values suggested other sources for the lead in the surface waters. Only one date for Spring river suggested any lead being transported in the water column. Lead's extremely low solubility even in slightly acid waters, indicates it's transport is with particulates. Any lead concentrations detected below Elk River are unlikely to have acid mine water origins. Deposition of iron, lead and zinc into Grand Lake is most likely by sedimentation rather then precipitation. In fact, the Oklahoma Water Resource Board has reported the metals from sediments in the Neosho and Spring Rivers (OWRB, 1983). Tar Creek is contributing to the overall metals loading in the Neosho River while Spring River contributions reflect it's pathway through the many mining fields in the tri-state area. An alarming statistic is from the same OWRB report dealing with plankton metals concentration. Enrichment of metals in plankton as compared to the water concentrations indicate that cadmium, lead and zinc can concentrate in lower food chain organisms (Table 6). The effect of such bioconcentrating of metals is not clearly defined. Whether the filter feeding fish, or the plankton, both or neither, are being stessed is not known. The danger of high levels of metals in the sediments is to benthic organisms and the potential of becoming redissolved into the water column if a pH decrease should occur. A purely physical effect occurs, as seen in Tar Creek, where the benthic organisms are literally buried beneath precipitating metals and sedimenting particulates.

Daphnia magna and Ceriodaphnia sp. acute toxicity bioassays were performed on Grand Lake sediments. No mortality was noted during the course of the experiment, indicating that the sediments were not acutely lethal for either species.

Sediment cores were analyzed from the upper end of Grand Lake (site 5) and the resulting metals concentrations are reported (Figure 11). The total iron concentrations showed no trend whereas zinc tended to decrease with depth. Data on other elements, e.g. lead, cadmium, etc., were unavailable at the time of this report. Analysis on cores from the mouth of Tar Creek are forthcoming.

TAR CREEK

Tar Creek's surface water quality is dominated by the discharge of acid mine water and runoff from tailings left by the mining operations. The extremely high concentrations of toxic metals is due to the oxidation and dissolution of sulfide compounds, e.g. pyrite, galena,sphalerite, etc. Iron and zinc sulfides are the primary compounds that produce the acidity and resulting metals load in the surfacing mine water. The oxidation pathway for iron sulfide (pyrite) is typical of sulfide oxidations that result in the release of protons (acidity) and dissolved metals (Figure 12). This is primarily for iron and zinc sulfides, lead produces little if any net acidity. Once the pathway of oxidation is initiated, acidity increases along with a corresponding increase in soluble metals. Even in the absence of oxygen a 'backtrigger' reaction may occur in which $Fe_2(SO)_4$ can oxidize the sulfide, and itself be reduced, releasing more ferrous iron to become oxidized, producing acidity, even in the absence of oxygen. Sulfide orebodies several hundred feet deep undergo oxidation, oxygen concentrations being extremely low (Hawley and Shikaze, 1971). In fact, 10^{-60} atmospheres oxygen or more are sufficient for pyrite oxidation (Barnes and Romberger, 1968).

The oxidation state of the iron, +2 or +3, controls the change, in part, of the pH from the original value once the water surfaces. If much of the iron is in the reduced (+2) state, contact with surface oxygenated water, results in oxidation of the iron and the pH of the water decreases even furthur. The relationship of pH over time provides just such an example (Figure 13). Surfacing mine water at site 28 generally had a depressed pH as compared to site 26 (Tar Creek). During low flow conditions the pH of Tar Creek water is decreased due to a higher percentage of the flow deriving from acid mine seeps. In fact the pH of Tar Creek water may be lower than the mine seeps due to oxidation of reduced metals. The large amounts of calcium and magnesium in the surfacing mine water (sites 28 and 29, Table 3) suggests that the mine water is reacting with the carbonate bedrock. A water chemistry model is being developed and preliminary results would suggest that large quantities of precipitating metals are not reaching the surface (Curt McCormick, personal communication). This is supported by alternative methods of calculation and chemical analysis' (Table 3 and Figures 14 -16). Calcium and magnesium concentrations reflect the acidity of the environment they are subjected to, and they, like the sulfates, in such acid environments, remain primarily in the aqueous state. A minimum of analysis should be required to estimate the concentation of sulfates, and in turn the amount of iron (and zinc sulfides) oxidized.

Models aid in prediction of chemical patterns from a minimal of chemical data and its application to delineating whether surfacing mine waters might have common origins is being investigated. The formation of acid mine waters in the tri-state area, especially northeastern Oklahoma and southeastern Kansas, must be understood prior to initiating expensive and often ineffective abatement stratagies.

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TABLE 1

SITE DESCRIPTION

Site 1 - R23E T24N S5. Located 1/3 mile west (upstream) from the Will Rogers Turnpike bridge on the Neosho River. Above Tar Creek.

Site 2 - R23E T28N S5. Downstream from the Tar Creek confluence on Neosho River. Site is 1/10 mile west (upstream) from the Will Rogers Turnpike bridge.

Site 4 - R24E T28N S30. Located 1/3 mile north (upstream) of Highway 10 bridge on Spring River.

Site 5 - R24E T27N S30. Situated 1/2 mile south of Burlington Northern railroad bridge. This is the upper end of Grand Lake approximately 3/4 mile downstream of the Neosho and Spring River confluence.

Site 6 - R24E T25N S15. Located 1/2 west of Cowskin Bridge (Highway 10) on Elk River (Grand Lake).

Site 7 - R24E T25N S12. Situated at the confluence of Elk River and Grand Lake. Note that this is on Grand Lake and disregards the Grand Lake Water that is backed-up into the Elk River basin.

Site 10 - R24E T27N S30. Under Highway 60 bridge on the Neosho River.

Site 12 - R24E T25N S14. Located 1.1 miles upstream from Cowskin Bridge (Highway 10) on Elk River.

Site 13 - R22E T25N S26. On Highway 85A Horse Creek Bridge.

Site 14 - R24E T25N S15. Located on Cowskin Bridge (Highway 10).

Site 15 - Grand Lake Dam. Samples collected from east end.

Site 16 - R24E T24N S17. Located on Honey Creek Bridge (Highway 10).

Site 17 - R23E T28N S31. Located approximately 1/6 mile downstream from highway 125 bridge.

Site 18 - R23E T28N S31. Highway 125 bridge over Neosho in Miami, Ok.

Site 19 - R23E T27N S26. Mudeater Bend Bridge over Neosho River.

TABLE 1, cont.

Site 20 - R24E T27N S19. Highway 60 Bridge and Spring River.

Site 22 - R24E T28N S5. Devil's Promenado Bridge over Spring River.

Site 26 - R23E T28N S30. N.E.O.S.U. and Tar Creek Bridge. (OWRB #20).

Site 27 - R23E T29N S18. Tar Creek and Treece, Ok. (OWRB #7).

Site 28 - R23E T28N S7. Farmers Horse Pasture, Commerce, Ok. (OWRB #14)

Site 29 - R23E T29N S29. OWRB Site #4.

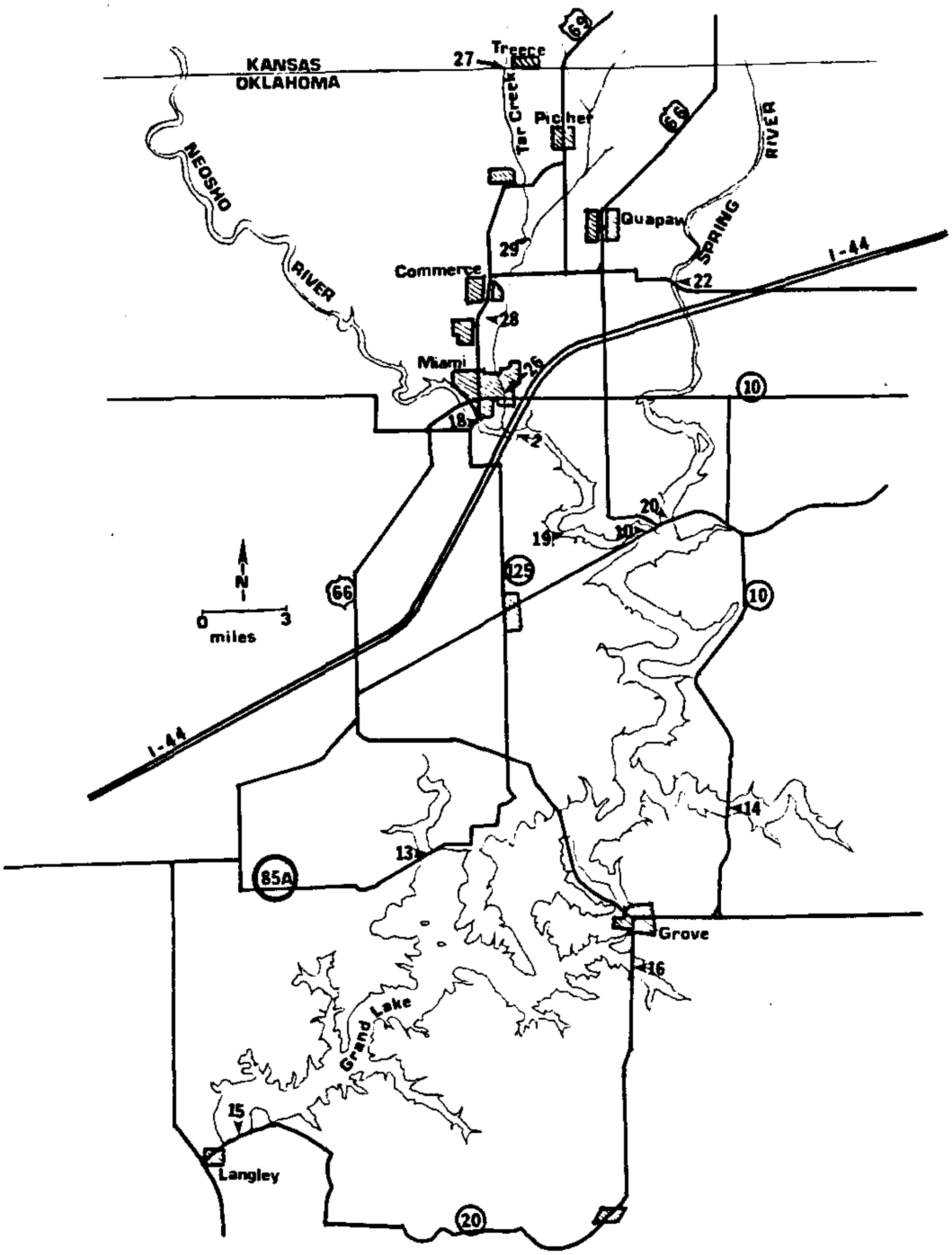

Figure 1. Map of study area with selected sites indicated.

TABLE 2. SUMMARY OF EPA'S MAXIMUM ALLOWABLE CONCENTRATIONS OF TRACE TOXIC METALS FOR PROTECTION OF AQUATIC LIFE IN RECEIVING WATERS

Parameter	Maximum Allowable Concentration* (mg/l)
Arsenic	0.44
Cadmium	0.05
Chromium	0.021
Copper	0.043
Lead	0.400
Nickel	3.100
Selenium	0.260
Zinc	0.570
Mercury	0.0000017

*Calculated for receiving waters with hardness of >200 mg/l (Fed. Reg. 45(231) 79317-79379, Nov. 28, 1980).

TABLE 3

RESULT OF ANALYSIS ON TAR CREEK, NEOSHO RIVER, SPRING RIVER AND GRAND LAKE SAMPLES*
BY DATE

		Ca	Mg	Fe	Pb	Zn	Cu	Cr	Ni	Cd	Mn	Se	Hg	As
Site 1														
08-11-83	Dis 2.5 m	44.1	10.0	<0.04	0.017	<0.05	<0.04	<0.01	<0.1	<0.005	<0.05	<0.01	<0.002	<0.01
08-11-83	Total 2.5 m	47.0	10.0	1.24	0.012	0.08	<0.04	<0.01	<0.1	<0.005	<0.05	0.01	<0.002	<0.01
Site 2														
08-11-83	Dis 2.5 m	41.1	8.6	<0.04	0.020	0.05	<0.04	<0.01	<0.1	<0.005	<0.05	<0.01	<0.002	<0.01
08-11-83	Total 2.5 m	46.5	11.0	1.37	0.005	0.06	<0.04	<0.01	<0.1	<0.005	<0.05	<0.01	<0.002	<0.01
Site 4														
08-11-83	Dis 1.0 m	55.3	5.2	<0.04	0.006	<0.05	<0.04	<0.01	<0.1	<0.005	<0.05	<0.01	<0.002	<0.01
08-11-83	Dis 3.0 m	49.2	5.1	<0.04	0.008	<0.05	<0.04	<0.01	<0.1	<0.005	<0.05	<0.01	<0.002	<0.01
08-11-83	Total 3.0 m	53.6	5.7	0.38	0.010	0.09	<0.04	<0.01	<0.1	<0.005	0.06	<0.01	<0.002	<0.01
08-11-83	Dis 6.0 m	45.0	11.6	<0.04	0.008	0.47	<0.04	<0.01	<0.1	<0.005	0.11	<0.01	<0.002	<0.01
Site 5														
08-11-83	Dis 6.0 m	45.9	10.6	<0.04	0.016	0.33	<0.04	<0.01	<0.1	<0.005	0.12	<0.01	<0.002	<0.01
08-11-83	Dis 4.0 m	31.6	5.2	<0.04	0.020	<0.05	<0.04	<0.01	<0.1	<0.005	<0.05	<0.01	<0.002	<0.01
08-11-83	Total 6.0 m	53.5	10.6	0.42	0.018	0.68	<0.04	<0.01	<0.1	<0.005	0.15	0.01	<0.002	<0.01
08-11-83	Total 4.0 m	40.1	6.9	<0.04	0.008	0.06	<0.04	<0.01	<0.1	<0.005	<0.05	<0.01	<0.002	<0.01
Site 7														
08-11-83	Dis	37.7	7.8	0.13	0.019	0.09	<0.04	<0.01	<0.1	<0.005	0.21	<0.01	<0.002	<0.01
08-11-83	Total	47.2	7.7	0.97	0.010	0.23	0.18	<0.01	<0.1	0.005	0.11	<0.01	<0.002	<0.01
Site 10														
10-22-83	Total	13.3	7.7	25.3	<0.005	0.31		0.04		<0.005	0.61			
03-06-84	"	24.8	10.4	16.80	<0.005	1.35		<0.01		<0.005	0.32			
05-20-84	"	51.7	11.0	1.10		<0.01	<0.04				0.12			

*Graphite furnace elements for 5-20-84 unavailable at time of report. Data for 6-23-84 forthcoming.

TABLE 3, continued

		Ca	Mg	Fe	Pb	Zn	Cu	Cr	Ni	Cd	Mn
Site 13											
08-11-83	Total	36.1	6.1	0.09	<0.005	<0.05	<0.04	0.03	<0.1	<0.005	<0.05
08-11-83	"	35.7	6.4	<0.04	<0.005	<0.05	<0.04	0.02	<0.1	<0.005	<0.05
10-22-83	"	37.4	6.7	0.30	<0.005	<0.01		<0.04		<0.005	0.02
10-22-83	"	38.6	6.9	0.30	<0.005	<0.01		<0.04		<0.005	0.02
03-06-84	"	32.7	7.6	0.48	<0.005	0.06		<0.01		<0.005	0.05
05-20-84	"	42.4	5.3	0.61		<0.01	<0.04				<0.05
05-20-84	"	35.2	5.2	0.73		<0.01	<0.04				<0.05
Site 14											
08-11-83	Total	39.6	6.1	<0.04	0.005	<0.05	<0.04	<0.01	<0.1	<0.005	<0.05
10-22-83	"	39.9	5.0	0.40	<0.005	0.08		<0.04		<0.005	0.02
03-06-84	"	29.5	3.2	2.20	<0.005	0.08		<0.01		<0.005	0.12
05-20-84	"	44.3	3.6	0.06		<0.01	<0.04				<0.05
Site 15											
10-22-83	Total	38.9	6.8	0.20	<0.005	0.08		<0.04		<0.005	0.04
03-06-84	"	37.9	17.9	0.55	<0.005	0.09		<0.01		<0.005	0.06
05-20-84	"	37.4	5.4	0.38		<0.01	<0.04				<0.05
Site 16											
08-11-83	Total	36.2	4.8	0.07	<0.005	<0.05	<0.04	<0.01	<0.1	<0.005	0.13
10-22-83	"	37.8	6.6	0.40	<0.005	0.17		<0.04		<0.005	0.05
10-22-83	"	38.8	6.8	0.50	<0.005	0.03		<0.04		<0.005	0.05
05-20-84	"	35.7	5.4	0.26		<0.01	<0.04				<0.05
Site 17											
08-11-83	Total	48.2	11.4	0.04	<0.005	<0.05	<0.04	<0.01	<0.1	<0.005	0.05
10-22-83	"	12.3	6.0	18.40	<0.005	0.10		<0.04		<0.005	0.34
Site 18											
03-06-84	Total	23.6	11.3	12.58	<0.005	0.09		<0.01		<0.005	0.33
05-20-84	"	52.7	12.4	2.17		<0.01	<0.04				0.16

TABLE 3, continued

	Ca	Mg	Fe	Pb	Zn	Cu	Cr	Ni	Cd	Mn
Site 19										
10-22-83	13.5	8.0	27.30	<0.005	0.31		0.05		<0.005	1.10
03-06-84	22.3	8.5	18.41	0.005	1.14		<0.01		<0.005	0.36
05-20-84	51.8	12.0	1.38		<0.01	<0.040				0.11
Site 20										
10-22-83	13.4	3.3	4.50	<0.005	0.27		<0.04		<0.005	0.12
03-06-84	19.4	6.0	13.21	0.154	0.45		<0.01		<0.005	0.47
05-20-84	48.8	4.6	0.97		<0.01	<0.040				0.34
Site 22										
10-22-83	14.3	3.2	5.50	<0.005	0.28		<0.04		<0.005	0.12
03-06-84	18.4	5.6	15.61	0.029	0.54		<0.01		<0.005	0.58
05-20-84	50.9	4.6	0.24		0.06	<0.040				0.12
Site 26										
10-22-83	1620.0	60.0	53.90	<0.005	48.30		<0.04		0.043	1.90
03-06-84	154.4	56.4	90.80	<0.005	47.37		<0.01		0.033	1.48
05-23-84	3040.1	793.9	10.61		62.32	0.016				2.89
Site 27										
10-22-83	2480.0	8.4	2.80	0.005	5.41		<0.04		0.027	0.12
03-06-84	43.0	8.5	5.59	0.006	2.83		<0.01		<0.005	0.18
05-23-84	2615.9	124.2	0.30		5.86	0.022				0.33
Site 28										
10-22-83	940.0	1350.0	533.00	<0.005	73.30		<0.04		<0.005	4.62
03-06-84	195.6	145.7	487.19	<0.005	1.01		<0.01		<0.005	4.37
05-23-84	1646.3	1414.0	455.51		47.17	0.020				4.32
Site 29										
10-22-83	1420.0	1600.0	433.00	<0.005	217.50		<0.04		0.104	7.32
03-06-84	174.6	238.8	396.93	0.008	235.33		<0.01		0.055	5.16
05-23-84	3747.1	2569.4	338.35		178.77	0.021				5.16

TABLE 4

General Water Quality Measurments for July-August, 1983

Site 1

	Depth meters	Temperature °C	Dissolved Oxygen mg/L	pH SU	Sp. Cond. umhos/cm
15 July	0	28.0	7.0	7.4	350
	1	27.5	7.1		350
	2	27.5	7.0		355
	3	27.0	6.6		358
	4	27.0	6.4		360
	5	27.0	5.7		360
	6	27.0	5.8		380
20 July	0	29.8	7.9		365
	1	29.3	6.5		370
	2	29.3	6.5		375
	3	28.9	5.9		380
	4	28.0	5.3		
	5	27.0	1.5		
1 August	0	30.9	5.7		431
	1	30.2	5.3		431
	2	30.3	5.2		432
	3	30.2	3.9		438

Site 2

	Depth meters	Temperature °C	Dissolved Oxygen mg/L	pH	Specific Conductance umhos/cm
15 July	0	29.0	6.5	7.2	360
	1	27.8	6.1		365
	2	27.8	5.9		368
	3	27.5	5.7		375
	4	27.5	5.7		380
	4.3	27.5	0.8		1000
20 July	0	31.0	8.5		380
	1	29.9	6.8		380
	2	29.5	6.2	6.8	382
	3	29.0	5.6		392
	4	28.0	4.3		850
	4.3	27.5	0.8		1080
1 August	0	31.2	5.5		441
	1	30.9	4.9		441
	2	30.7	4.6		447
	3	30.3	4.1		482

Site 4

	Depth meters	Temperature °C	Dissolved Oxygen mg/L	pH SU	Specific Conductance umhos/cm
July 17	0	26.5	6.7	7.0	360
	1	26.2	6.2		363
	2	26.0	6.2	6.9	370
	3	26.0	5.6		370
July 27	0	30.1	5.4		393
	1	30.1	5.2		400
	2	30.1	5.3		403

Site 5

	Depth meters	Temperature °C	Dissolved Oxygen mg/L	pH SU	Specific Conductance umhos/cm
July 20	0	32.0	10.5	6.7	355
	1	31.0	9.4		355
	2	29.5	7.6		370
	3	28.2	5.3		378
	4	28.2	5.1		398
	5	27.7	4.3		402
	6	27.3	3.0	6.6	400
	>6	27.2	3.4		421
July 27	0	31.2	7.9		380
	1	31.0	7.2		382
	2	30.6	6.6		380
	3	30.2	4.8		395
	4	29.8	3.0		398
	5	28.8	1.2		404
July 29	0	33.0	8.3		390
	1	32.0	6.6		390
	2	31.5	6.1		388
	3	31.2	5.8	7.3	385
	4	31.0	3.5		412
	5	30.1	2.0		430
	6	29.7	1.1		445

Site 6

	Depth meters	Temperature °C	Dissolved Oxygen mg/L	pH SU	Specific Conductance umhos/cm
July 20	0	31.5	12.6	7.2	270
	1	31.0	12.5		270
	2	31.0	12.6		272
	3	31.0	12.8		278
	4	29.0	5.9		290
	5	28.5	2.0		300
	6	28.2	2.5		350

Site 7

	Depth meters	Temperature °C	Dissolved Oxygen mg/1	pH SU	Specific Conductance umhos/cm
July 20	0	31.0	10.7		320
	1	30.8	10.0		325
	2	30.5	10.0		327
	3	30.0	7.5		329
	4	29.0	6.4		329
	5	28.9	6.0		330
	6	27.9	1.7	6.9	325
	7	27.3	1.3		332
	8	27.2	1.0		330
	>8	27.1	0.8		465
July 29	0	30.9	6.4		312
	1	30.7	6.3		320
	2	30.5	6.0		322
	3	30.3	5.8		325
	4	30.1	5.6	7.3	325
	5	30.1	5.8		327
	6	30.0	5.1		330
	7	29.7	2.7		324
	8	29.0	1.0		338

Site 10

	Depth meters	Temperature °C	Dissolved Oxygen mg/L	pH SU	Conductance umhos/cm
July 15	0	29.0	6.6	7.0	360
	1	29.0	6.2		360
	2	28.3	5.5		360
	3	28.0	5.4		360
	4	28.0	5.4		360
	5	28.0	5.1		360
	6	28.0	5.2		362
	7	28.0	5.2		365
	>7	28.0	0.6		370

Site 12

	Depth meters	Temperature °C	Dissolved Oxygen mg/L	pH SU	Specific Conductance umhos/cm
July 29	0	32.0	8.2		259
	1	31.0	6.3		261
	2	31.0	5.4		263
	3	30.6	4.4	6.8	267
	4	30.0	2.7		278
	5	29.3	1.1		293
	6	28.5	0.9		420

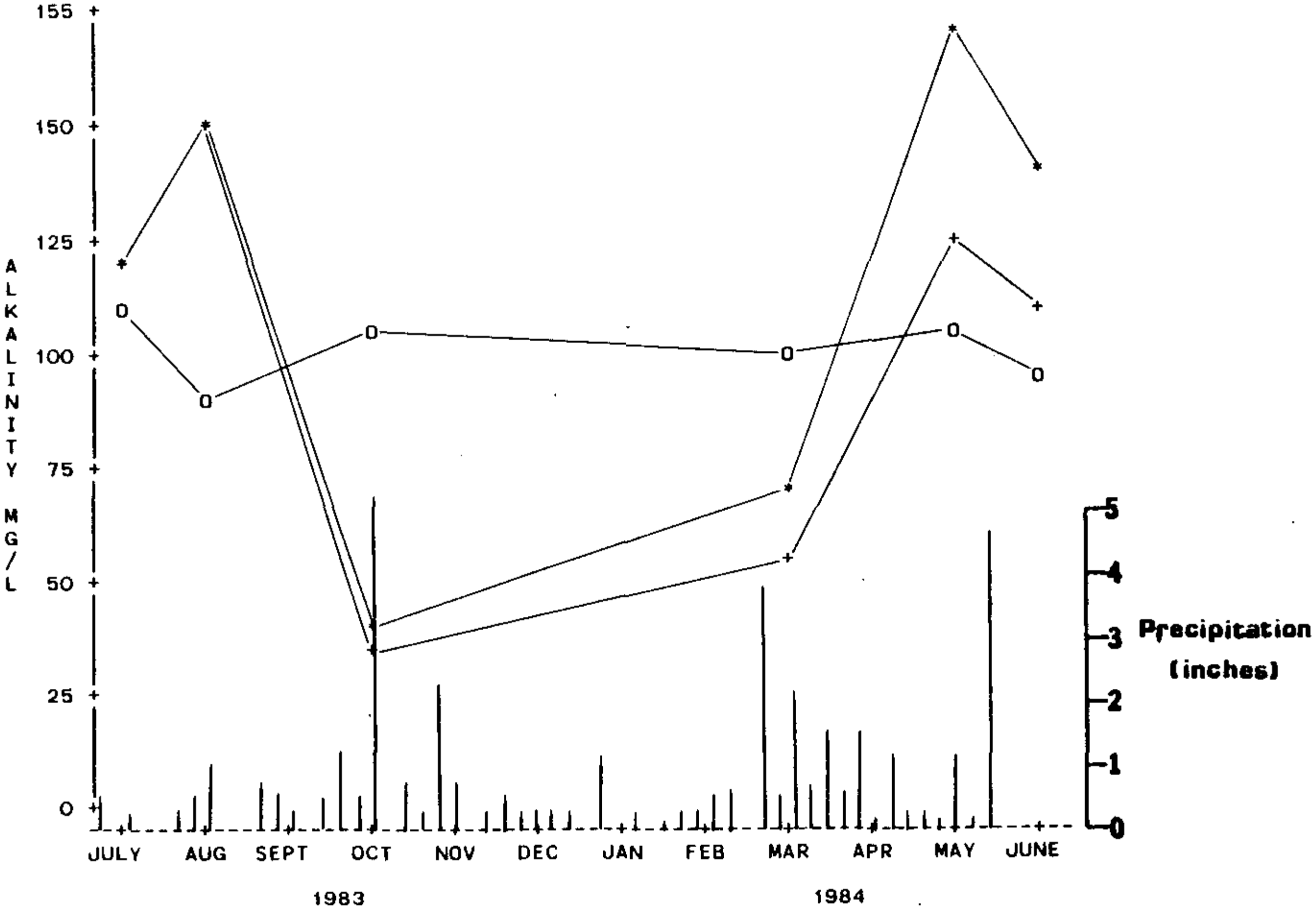

Figure 2. Plot of mean alkalinity (as CaCo3) values over time. Grand Lake sites (0), Neosho River sites (*) and Spring River sites are shown.

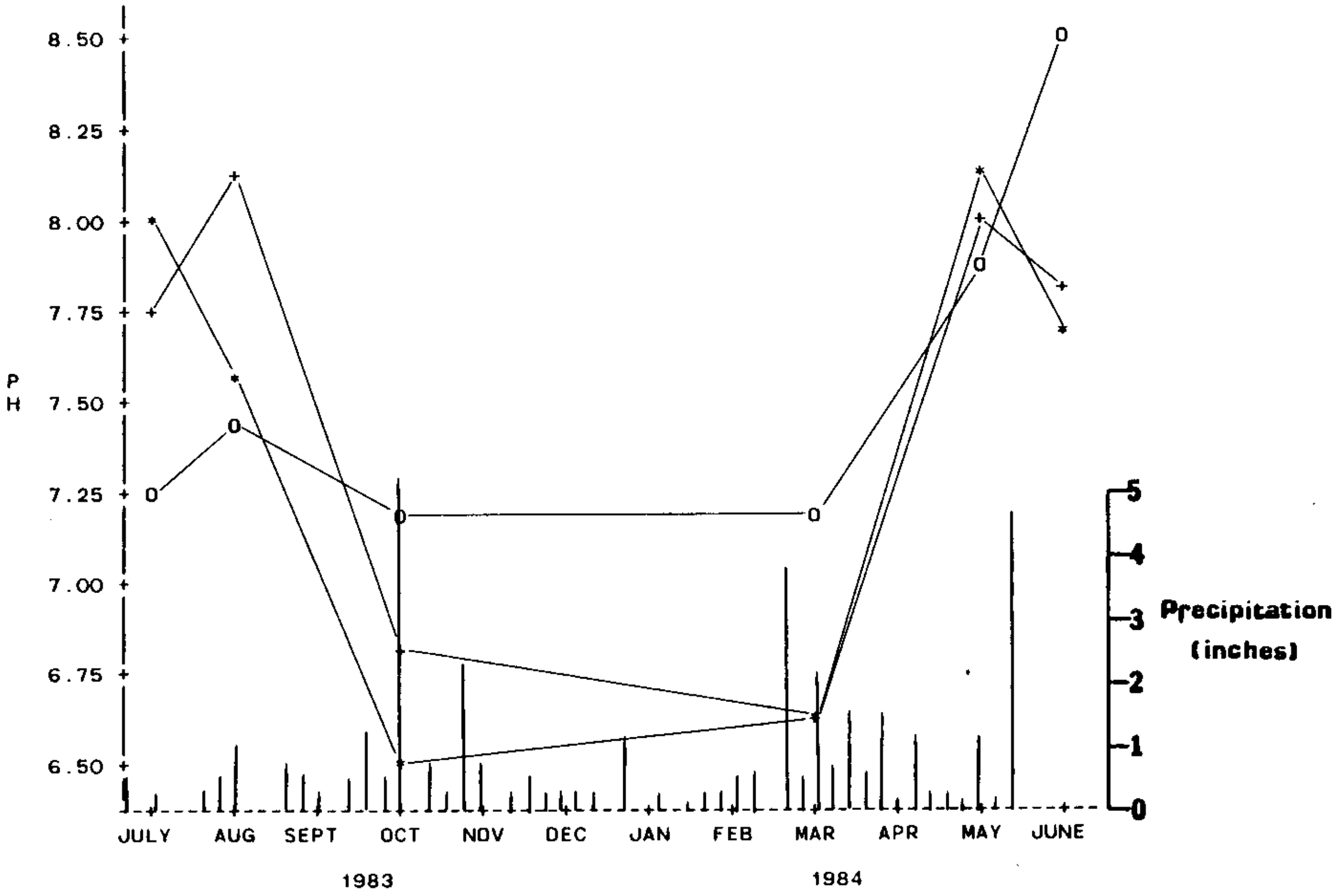

Figure 3. Plot of mean pH values over time. Grand Lake sites (0), Neosho River sites (*) and Spring River sites (+) are shown.

TABLE 5

CORRELATION COEFFICIENTS FOR ALL DATA
n=number of observations

	PARAMETER						
	ALK	CA	MG	MN	FE	PB	ZN
PH	0.59	0.72	0.065	-0.48	-0.66	-0.20	-0.61
n=	60	32	32	32	32	23	32
ALK		0.84	0.34	-0.47	-0.62	-0.22	-0.52
n=		31	31	31	31	23	31
CA			0.48	0.45	0.25	-0.08	0.49
n=			61	61	61	52	61
MG				0.83	0.31	-0.08	0.60
n=				61	61	52	61
MN					0.73	-0.06	0.63
n=					61	52	61
FE						-0.04	0.65
n=						52	61
PB							-0.09
n=							52

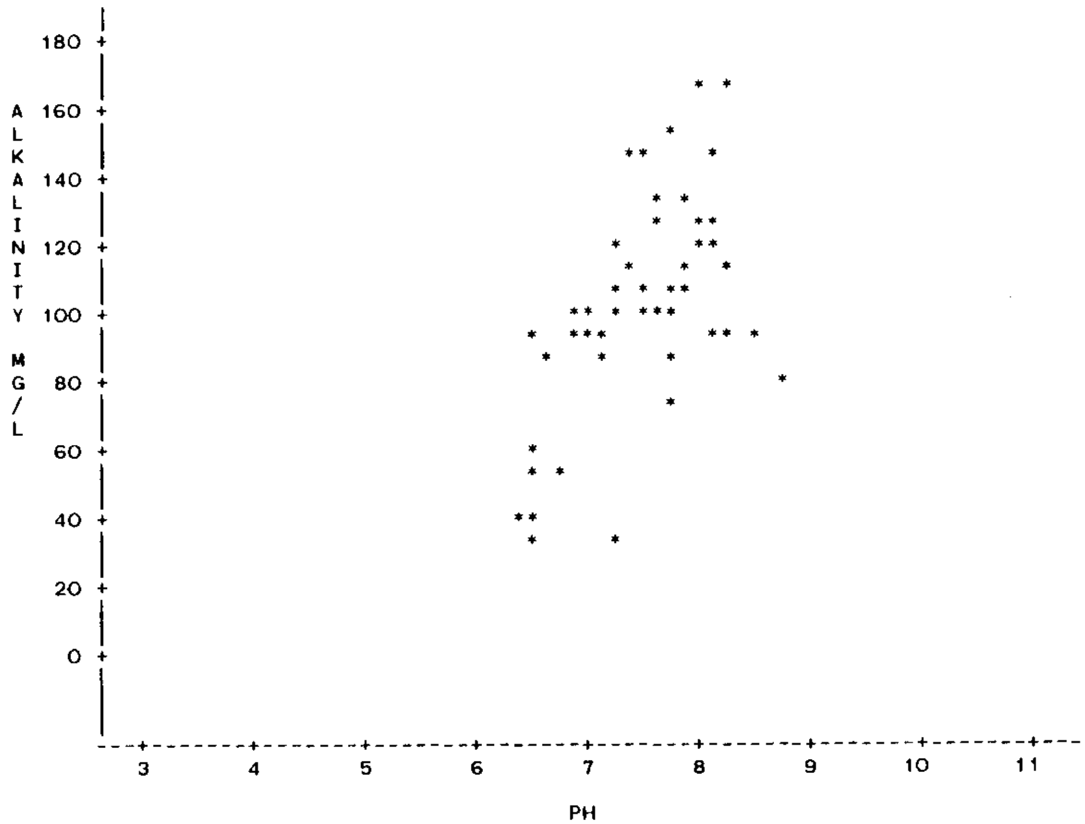

Figure 4. Plot of alkalinity (mg/L as CaCO3) and pH.

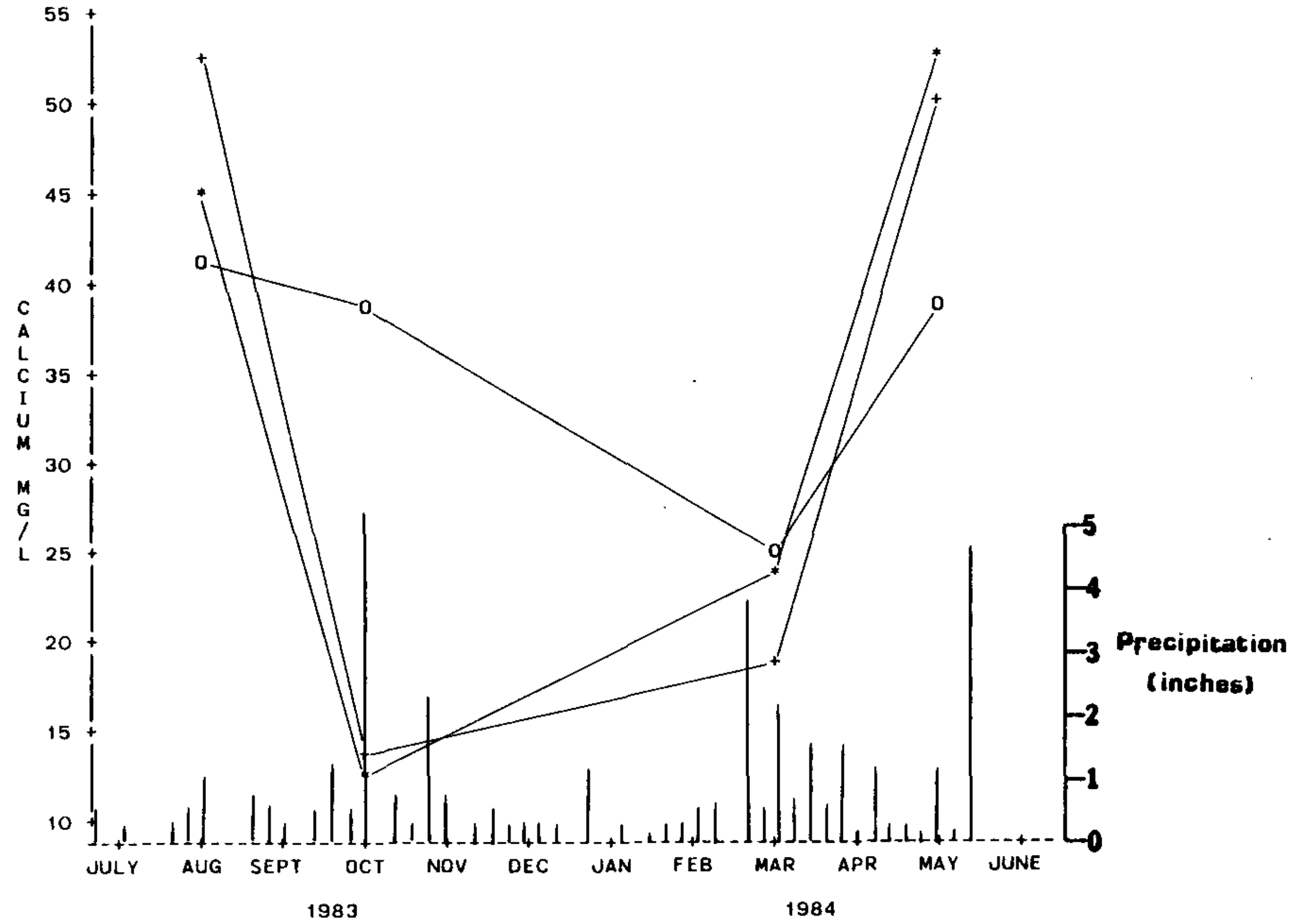

Figure 5. Plot of mean calcium values over time. Grand Lake sites (0), Neosho River sites (*) and Spring River sites (+) are shown.

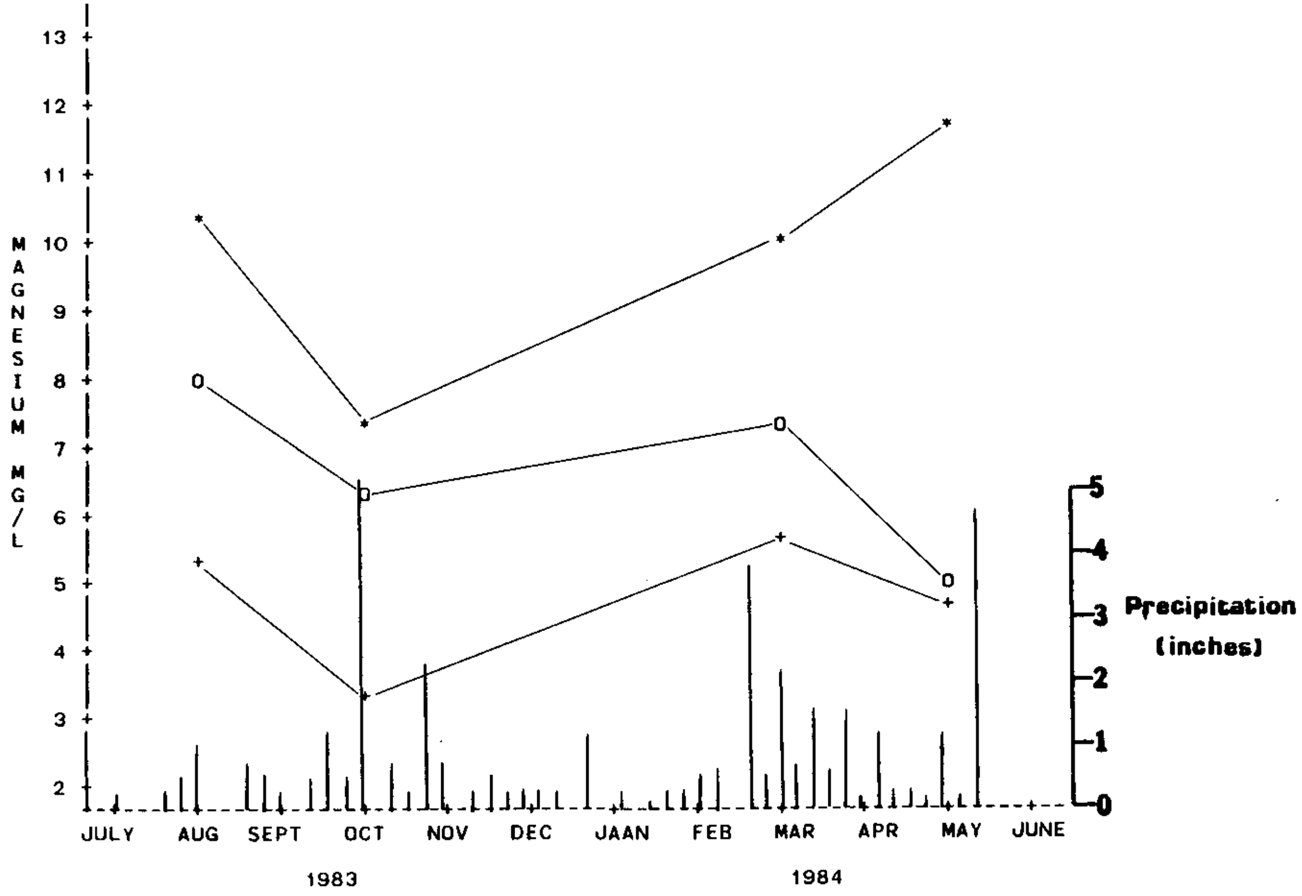

Figure 6. Plot of mean magnesium values over time. Grand Lake sites (0), Neosho River sites (*) and Spring River sites (+) are shown.

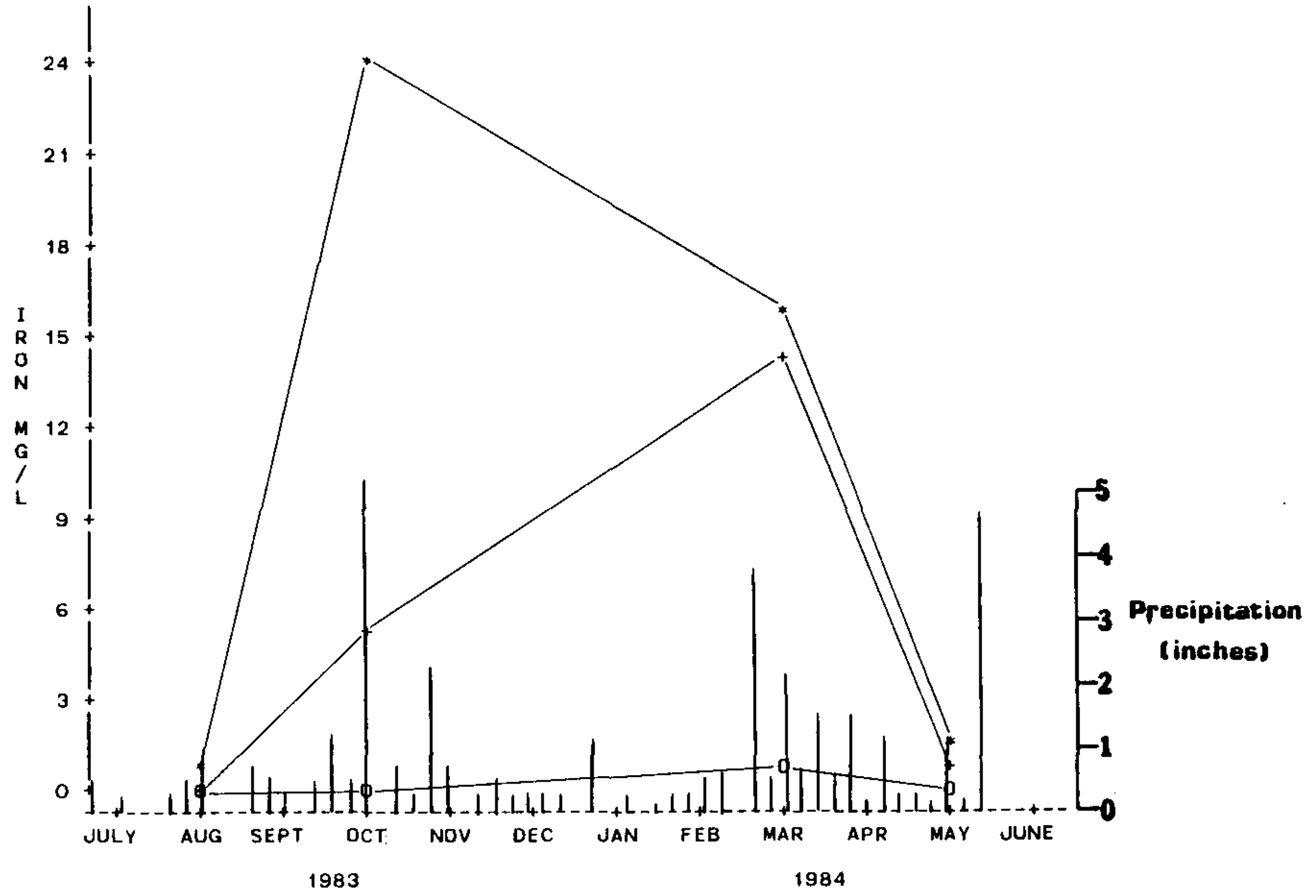

Figure 7. Plot of mean iron values over time. Grand Lake sites (O), Neosho River sites (*) and Spring River sites (+) are shown.

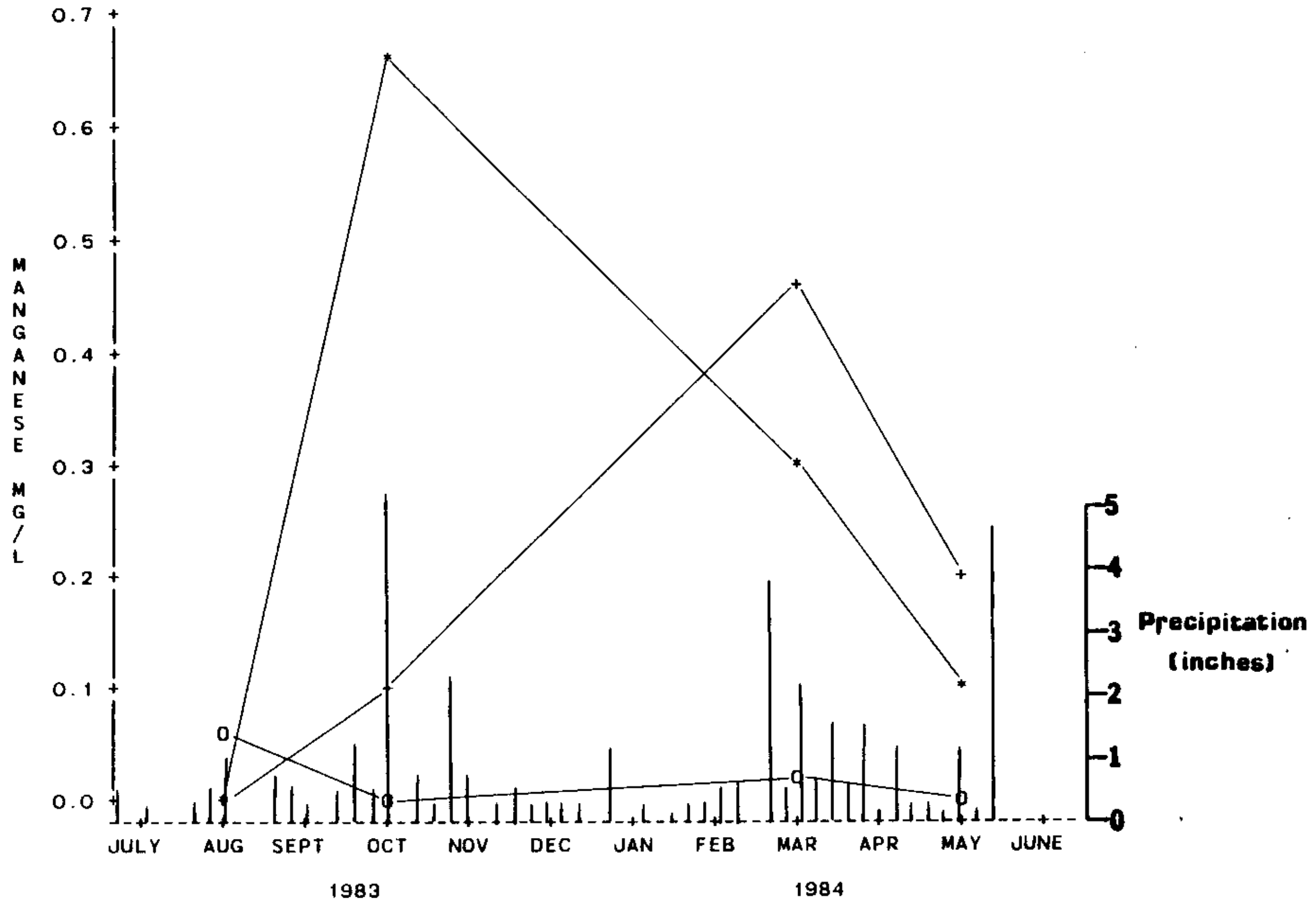

Figure 8. Plot of mean manganese values over time. Grand Lake sites (O), Neosho River sites (*) and Spring River sites (+) are shown.

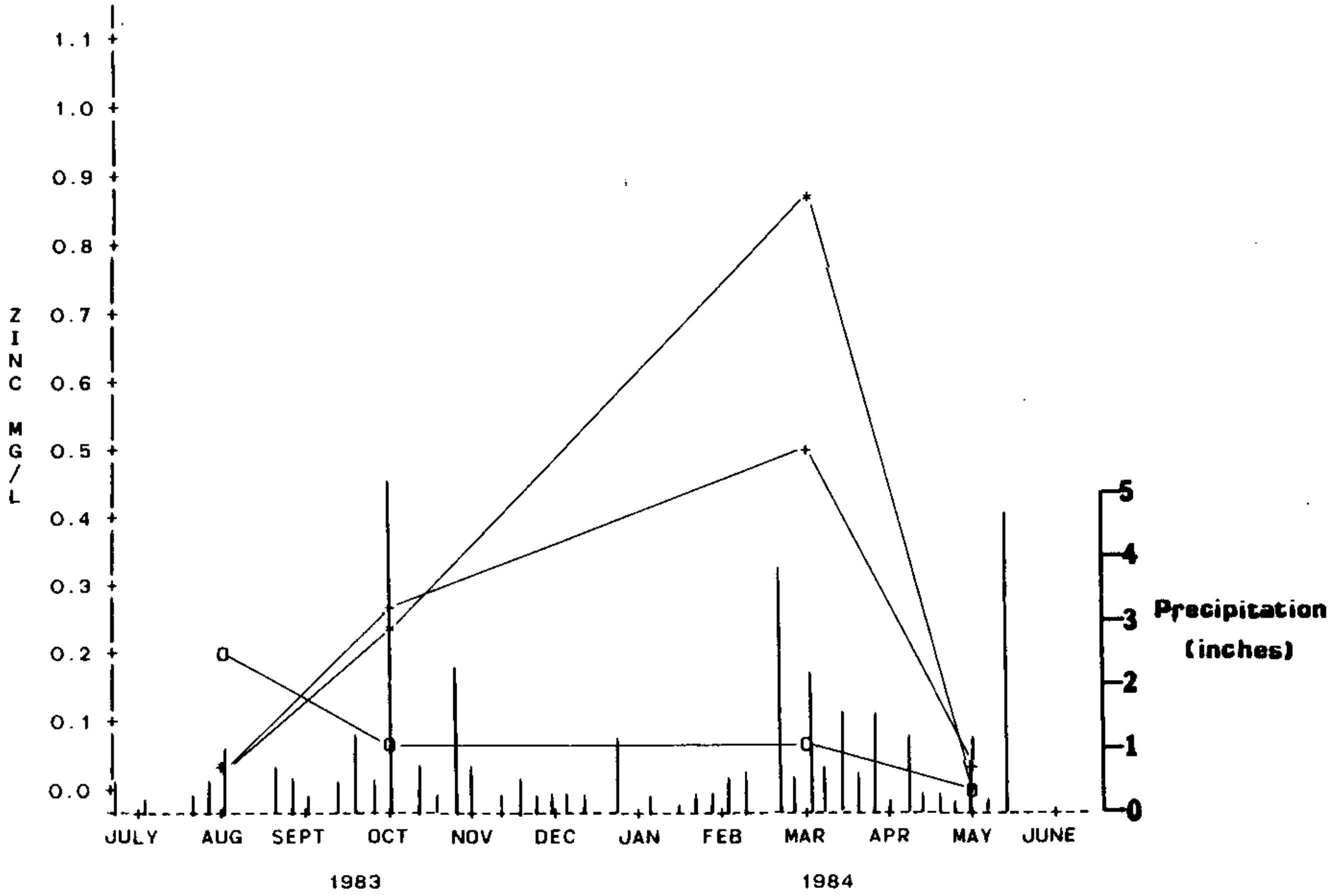

Figure 9. Plot of mean zinc values over time. Grand Lake sites (0), Neosho River sites (*) and Spring River sites (+) are shown.

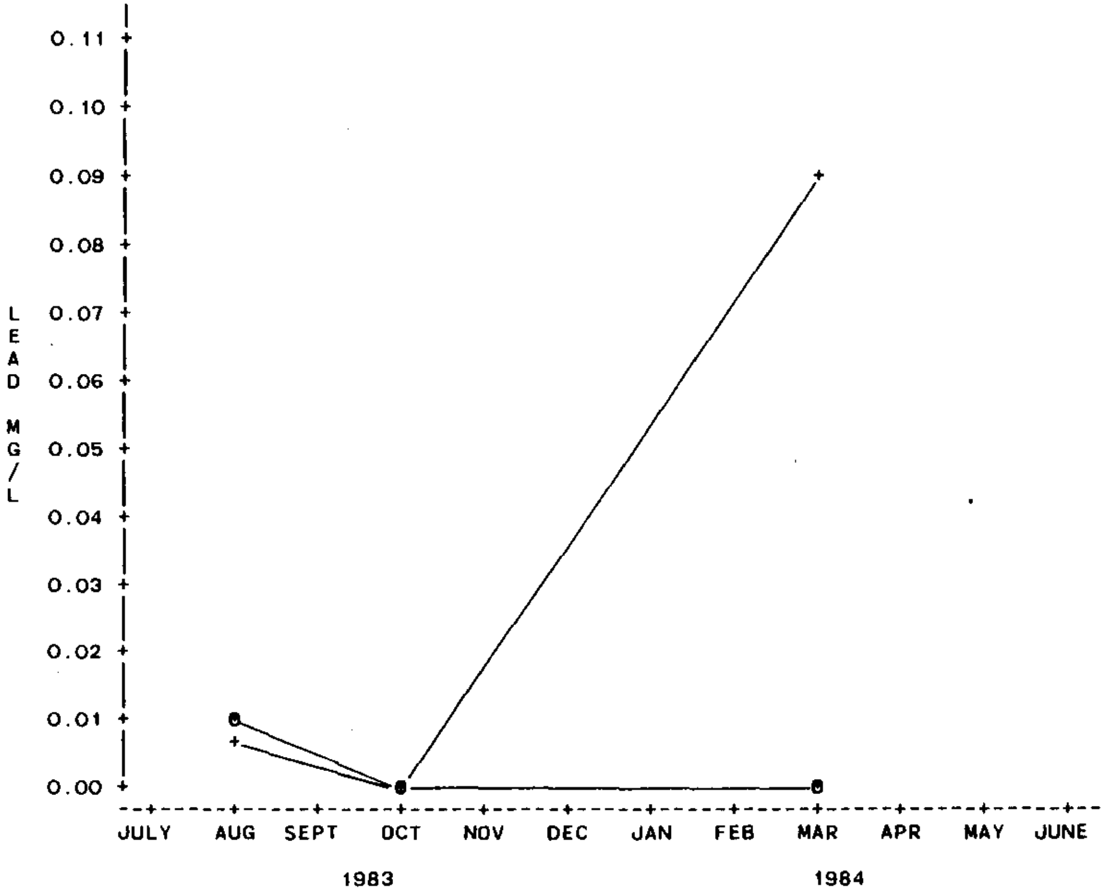

Figure 10. Plot of mean lead values over time. Grand Lake sites (0), Neosho River sites (*) and Spring River sites (+) are shown.

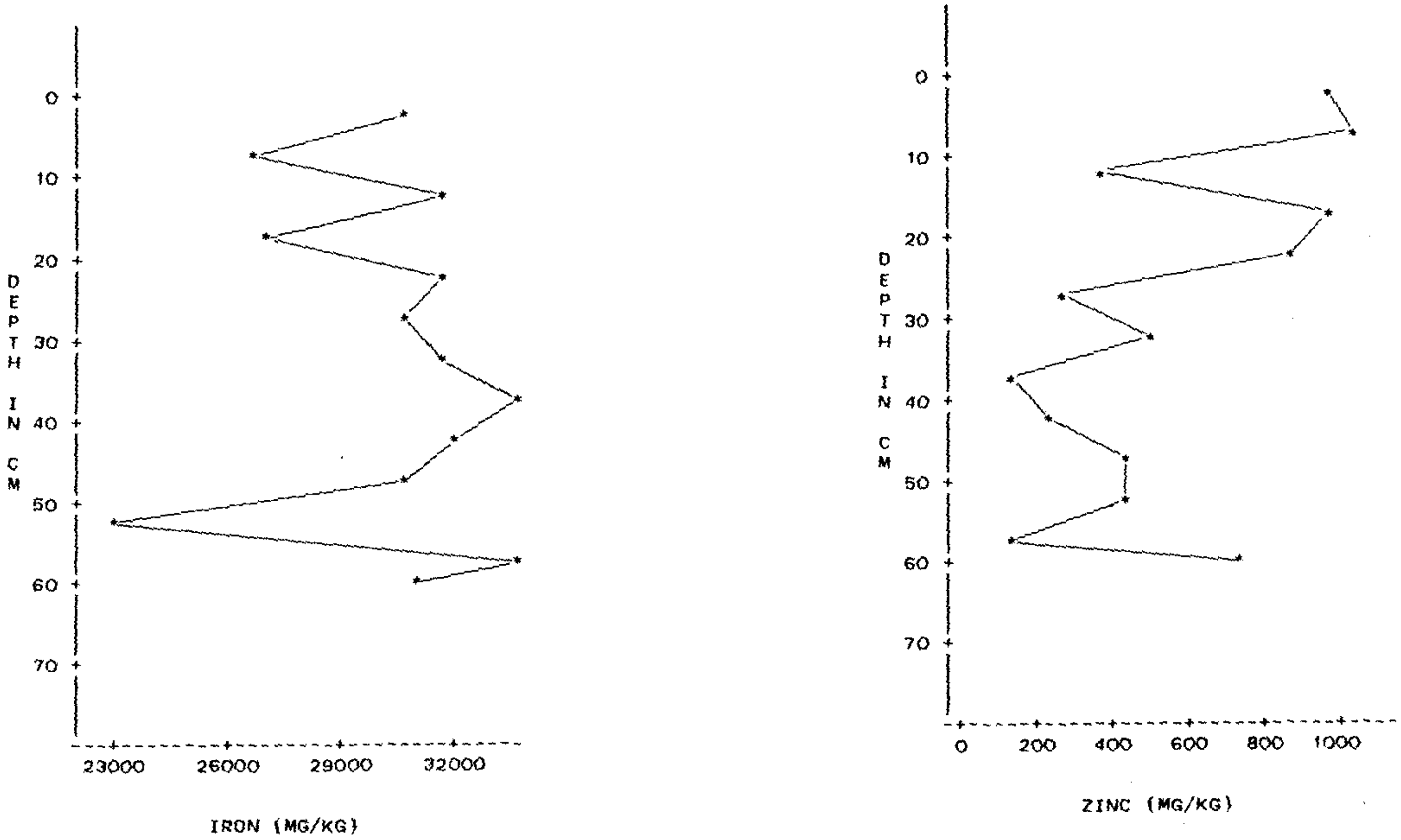

Figure 11. Plot of iron (mg/kg) and zinc (mg/Kg) from core sample by depth.

TABLE 6

HEAVY METAL CONCENTRATIONS IN PLANKTON IN THE NEOSHO AND SPRING RIVERS, AND CORRESPONDING ENRICHMENT FACTORS IN PARENTHESES.

STATION	METAL CONCENTRATION (MG/KG or PPM) IN PLANKTON		
	CADMIUM	LEAD	ZINC
NEOSHO ABOVE TAR CREEK (22A)	2.96 (1096)	2.0 (200)	33.0 (68)
NEOSHO BELOW TAR CREEK (22B)	17.40 (8286)	115.6 (11,560)	91.7 (282)
NEOSHO PRIOR TO SPRING RIVER	20.92	120.9	84.2
SPRING RIVER PRIOR TO NEOSHO RIVER (24)	446.06 (446,060)	481.3 (17,826)	274.6 (1154)
UPPER END OF GRAND LAKE (26)	78.96	41.4	192.9

FROM AGGUS, L.R., VOGELE, L.E., RAINWATER, W.C., AND D.I. MORAIS. 1983 EFFECTS OF ACID MINE DRAINAGES FROM TAR CREEK ON FISHES AND BENTHIC MACROINVERTABRATES IN GRAND LAKE, OKLAHOMA. PREPARED FOR THE TAR CREEK ENVIRONMENTAL EFFECTS SUBCOMMITTEE.

$$\text{ENRICHMENT FACTOR} = \frac{\text{[METALS PHYTOPLANKTON]}}{\text{[METALS IN WATER]}}$$

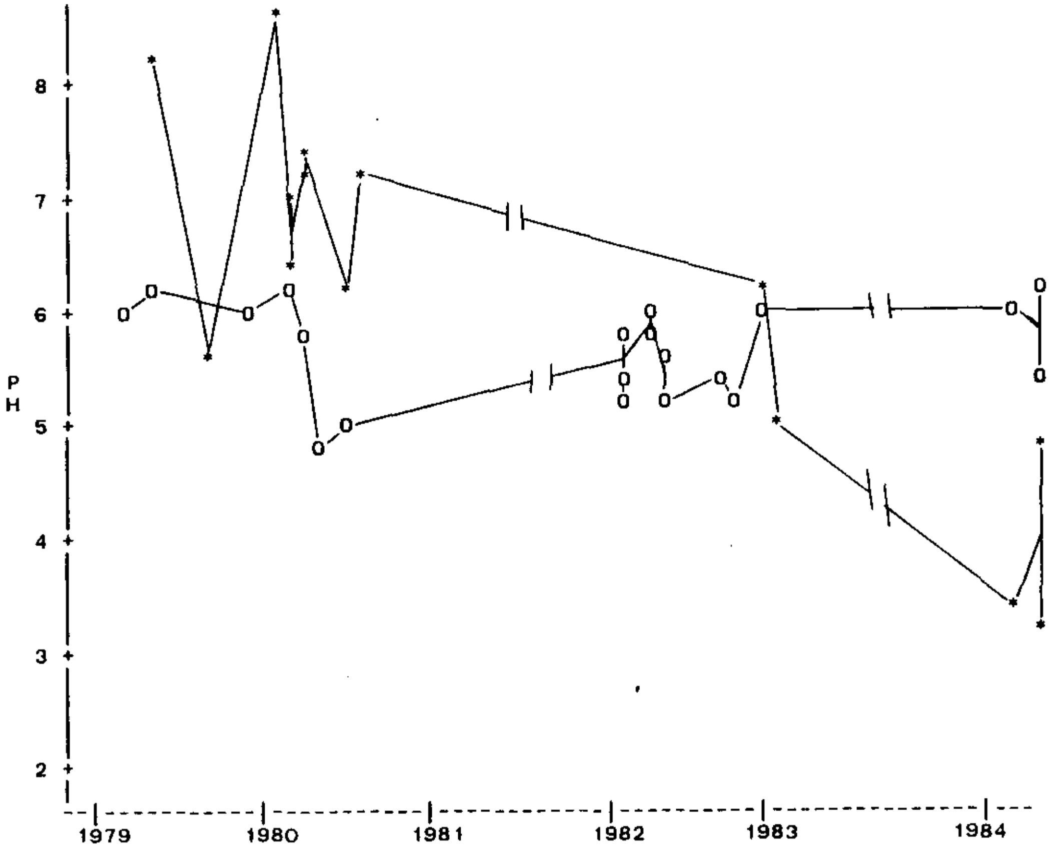

Figure 13. Plot of pH values over time. Tar Creek site 26 (*) and mine discharge site 28 (0) is shown.

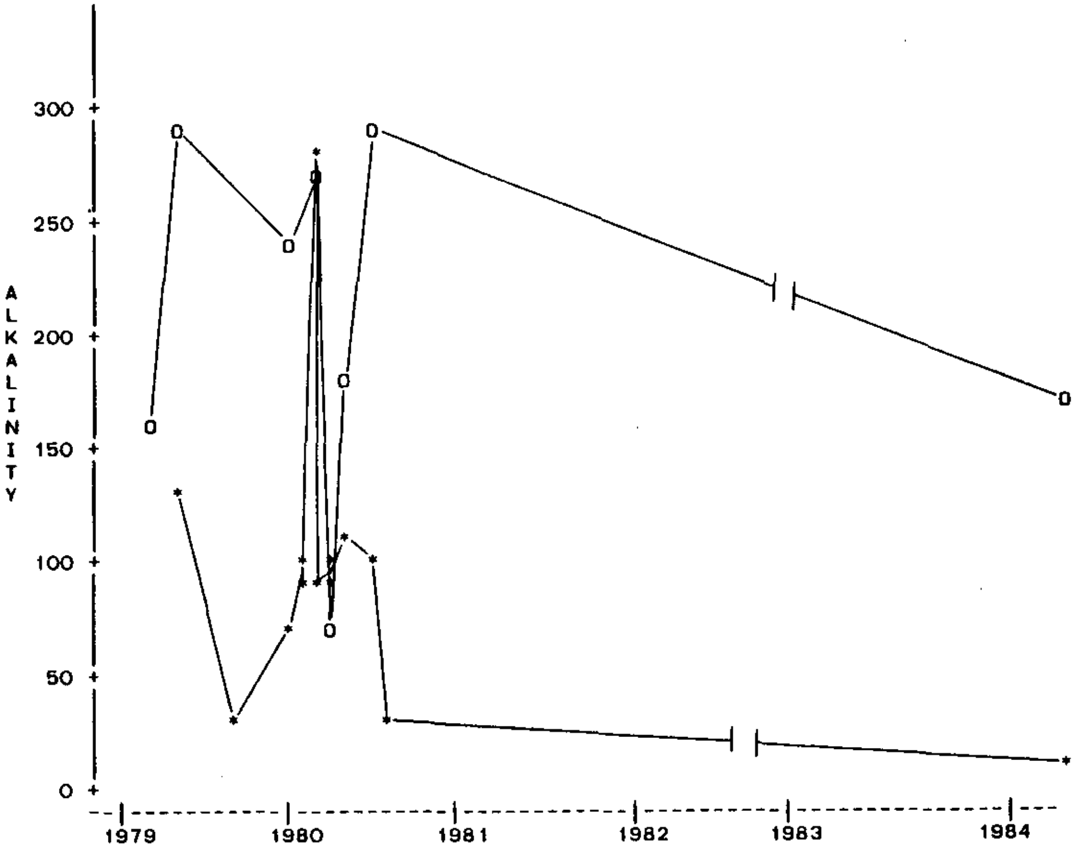

Figure 14. Plot of alkalinity (mg/L) over time. Tar Creek site 26 (*) and mine discharge site 28 (O) are shown.

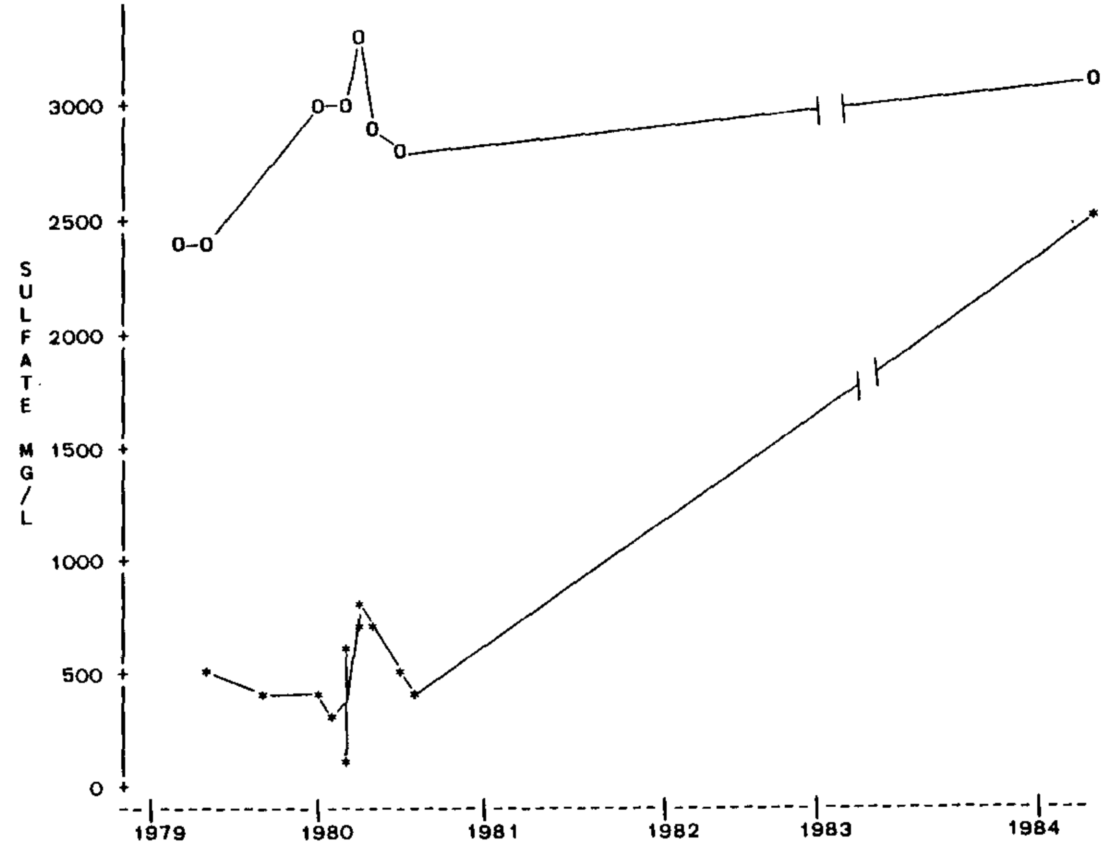

Figure 15. Plot of sulfate concentration (mg/L) over time. Tar Creek site 26 (*) and mine discharge site 28 (0) are shown.

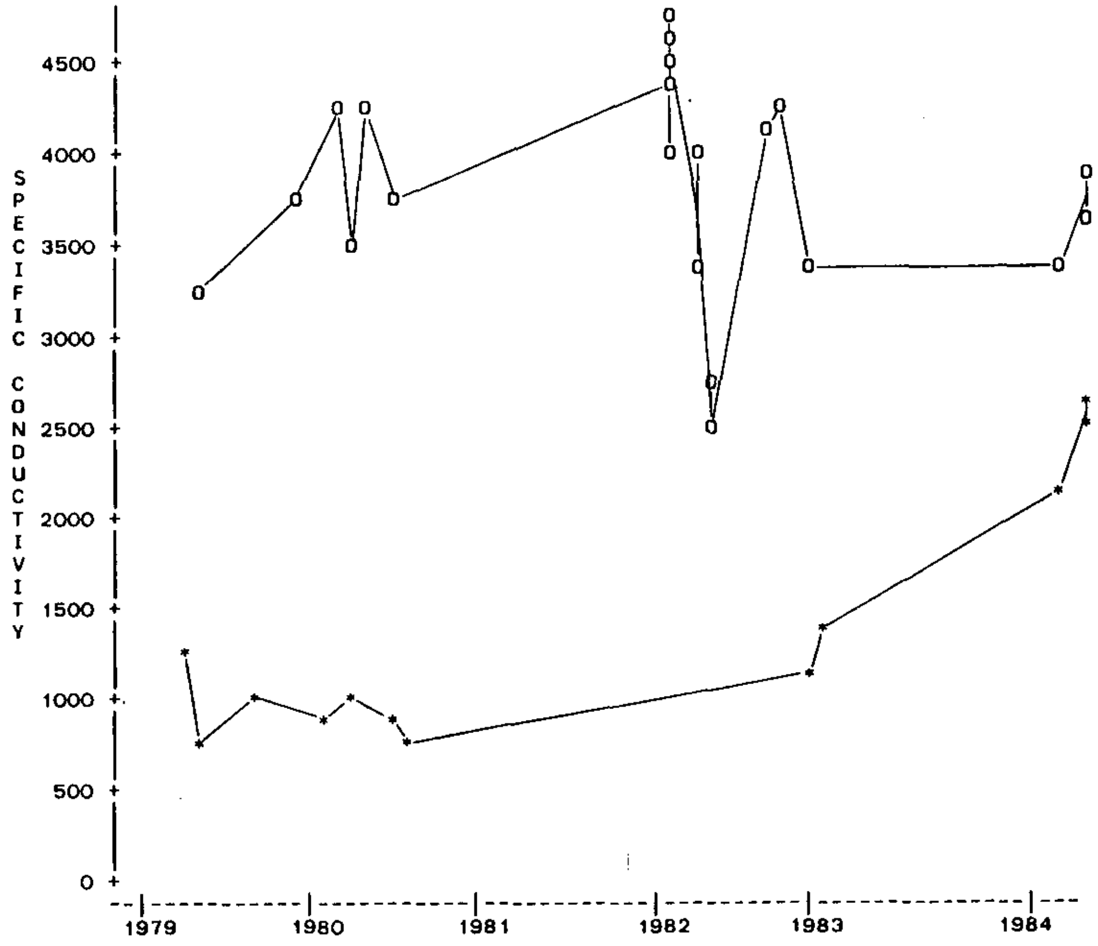

Figure 16. Plot of specific conductivity (umhos/cm) over time. Tar Creek 26 (*) and mine discharge site 28 (0) are shown.

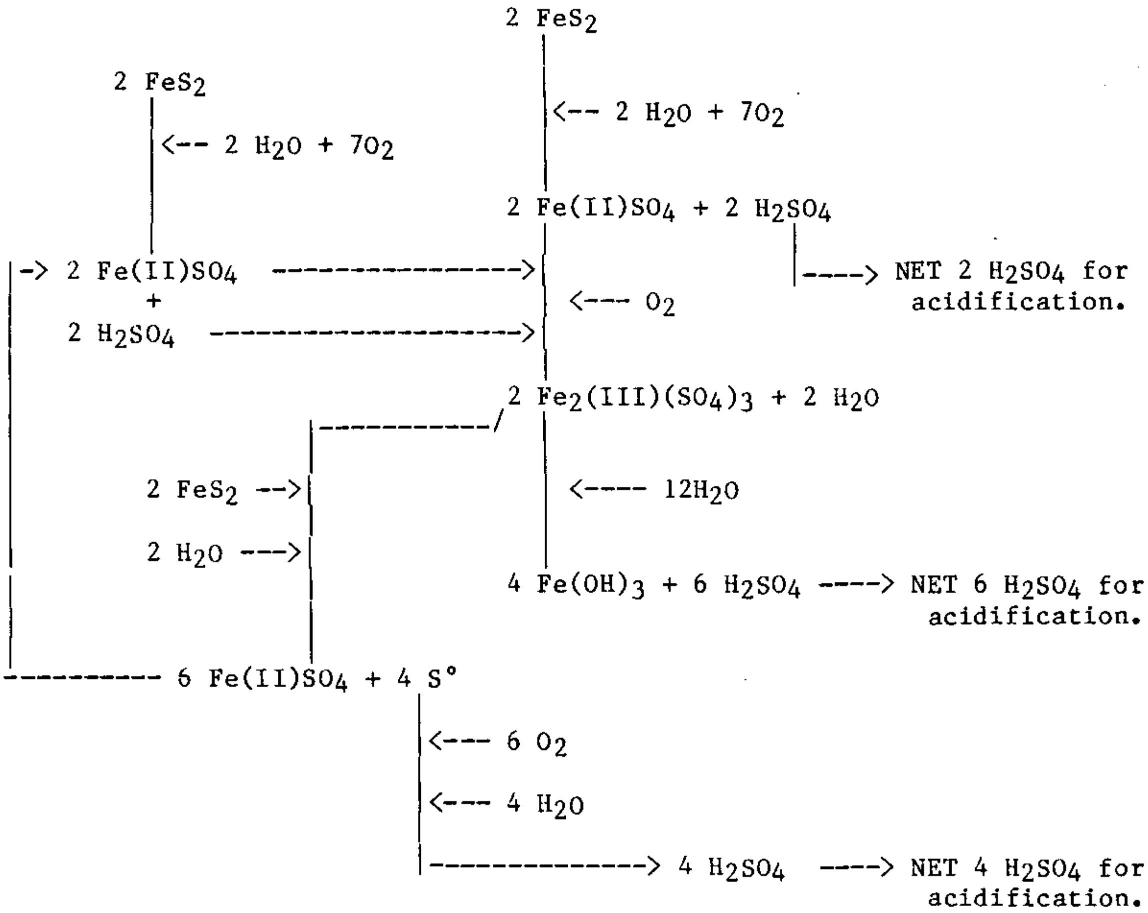

Figure 12. Summary of chemical reactions of iron sulfide with oxygen and water.

PART II:

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

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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.

REFERENCES

Mcknight, E.T., and Fischer, R.P., 1970, Geology and Ore Deposits of the Picher Field, Oklahoma and Kansas, U.S. Geological Survey Professional Paper 588.

Reed, E.W., *et.al.*, 1955, Ground Water Resources of Ottawa County, Oklahoma, Oklahoma Geological Survey Bulletin 72.

Table 1

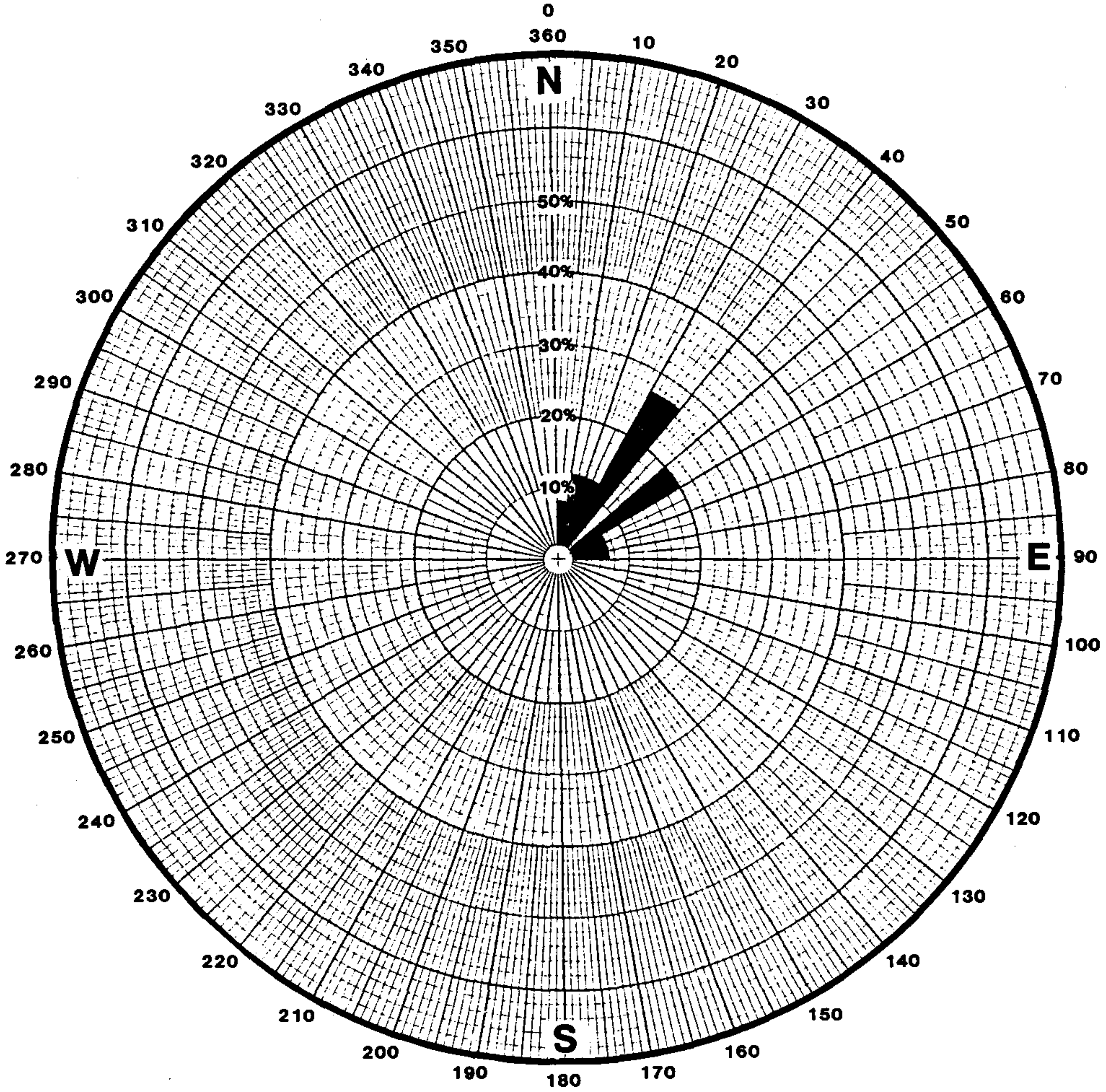
Site Descriptions

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

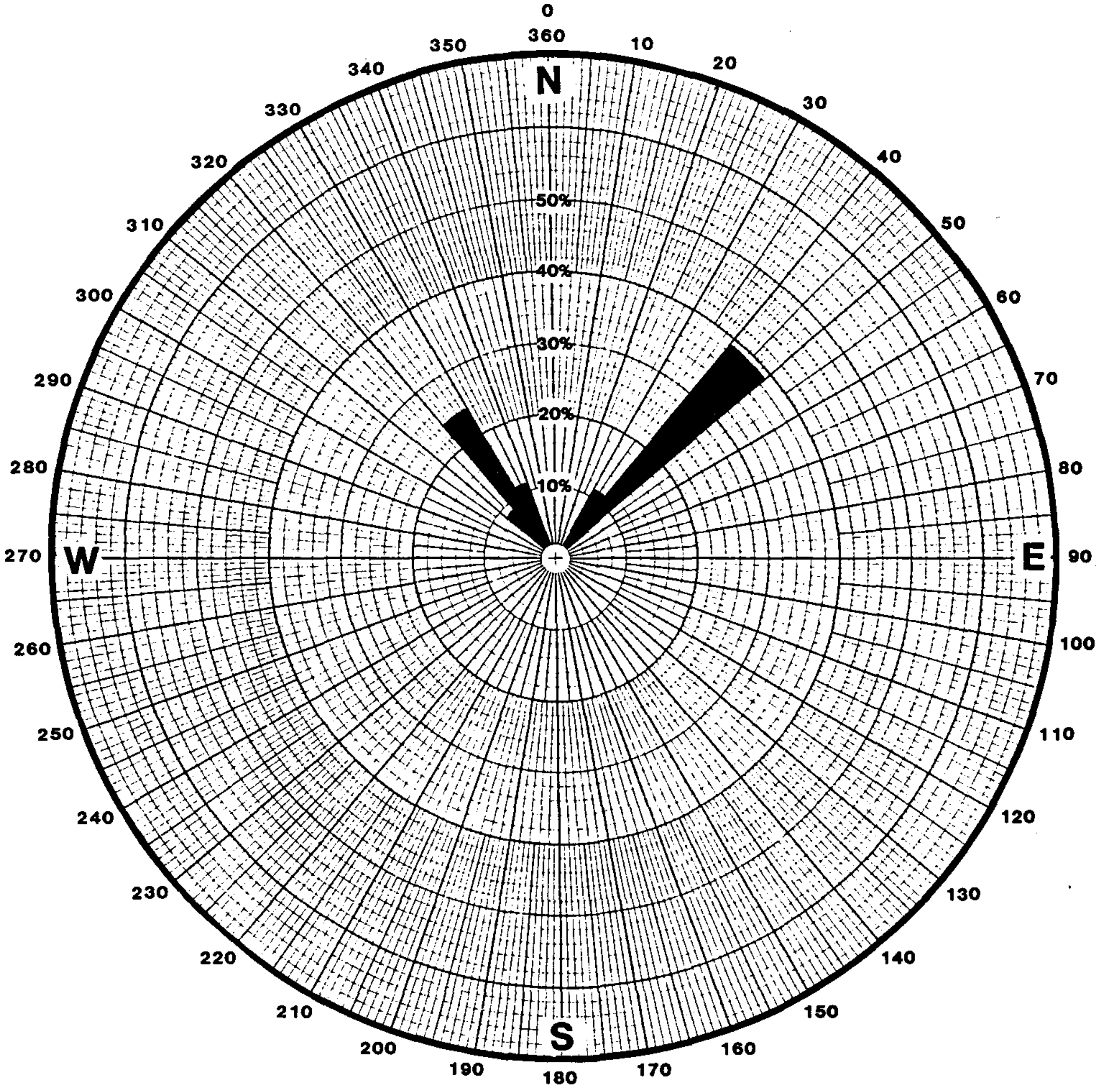
Fracture Statistics

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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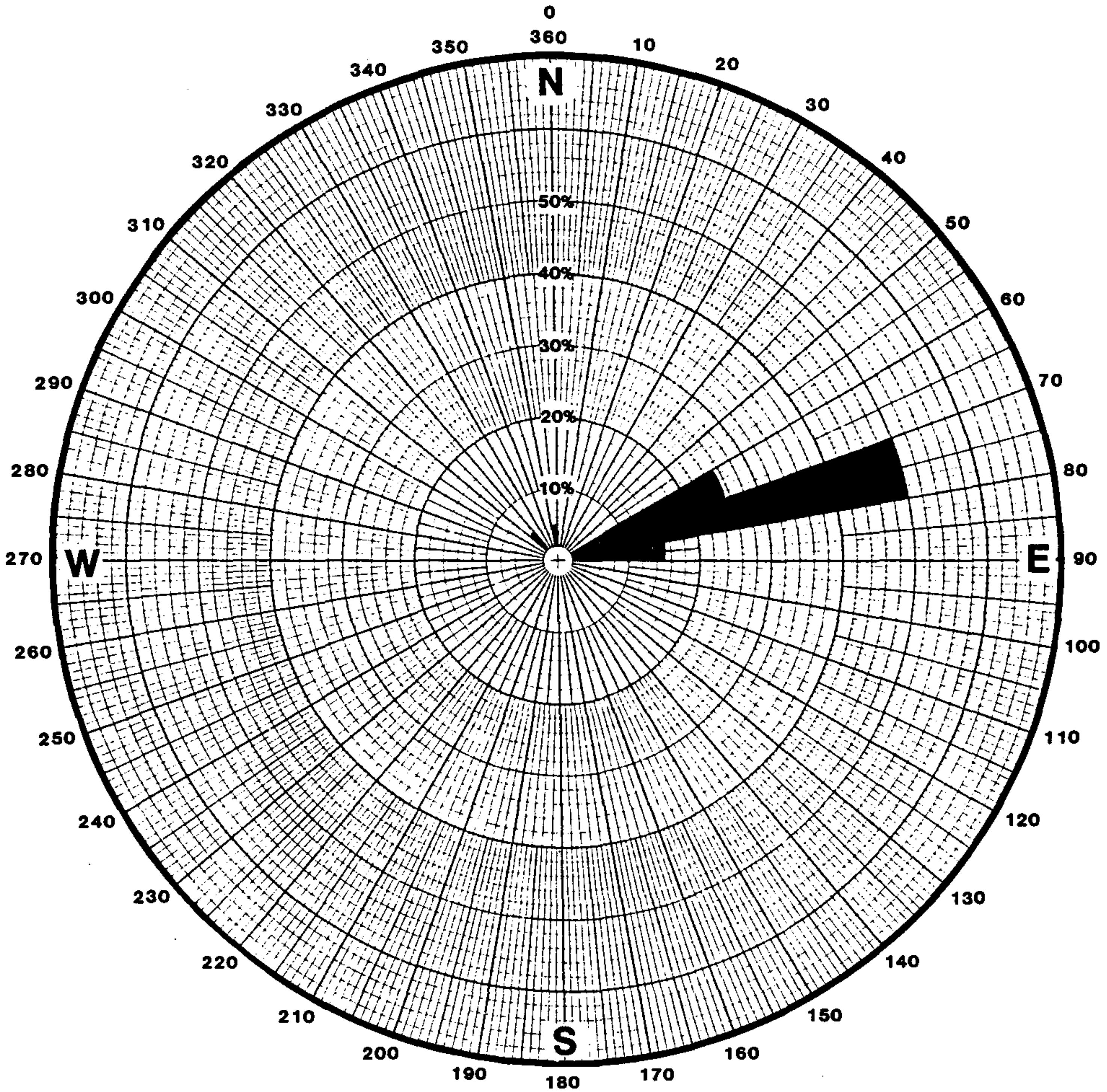
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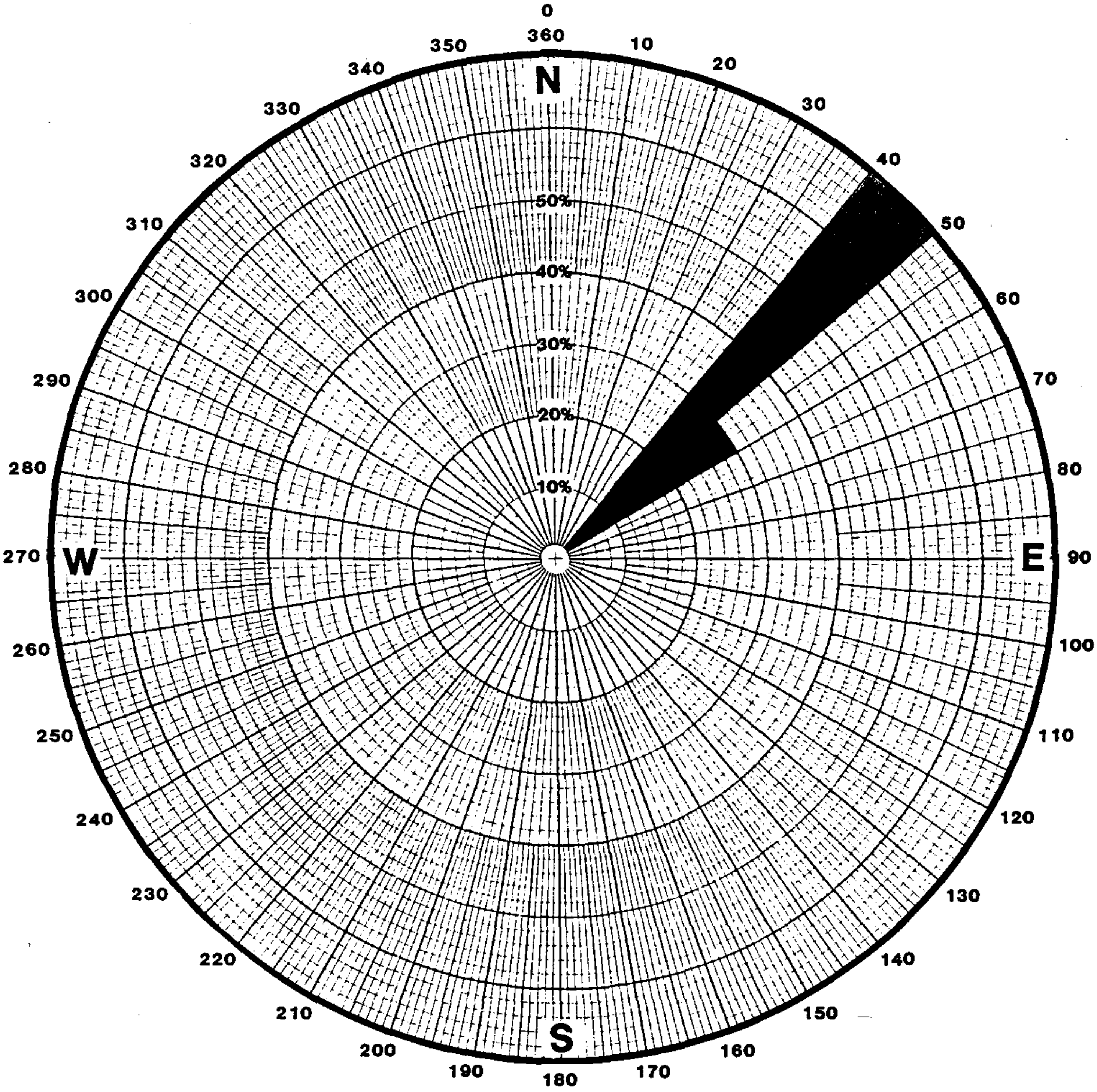
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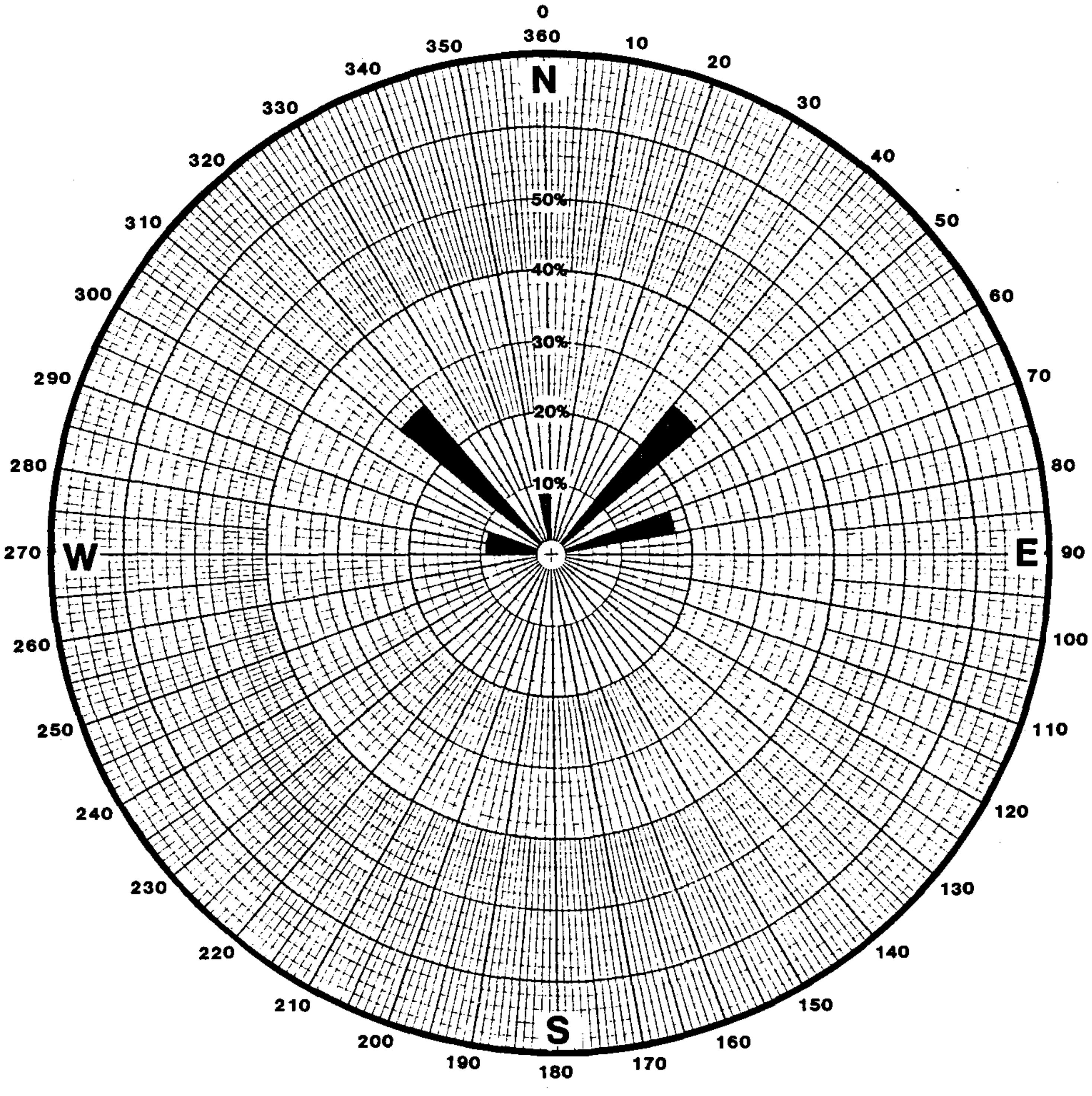

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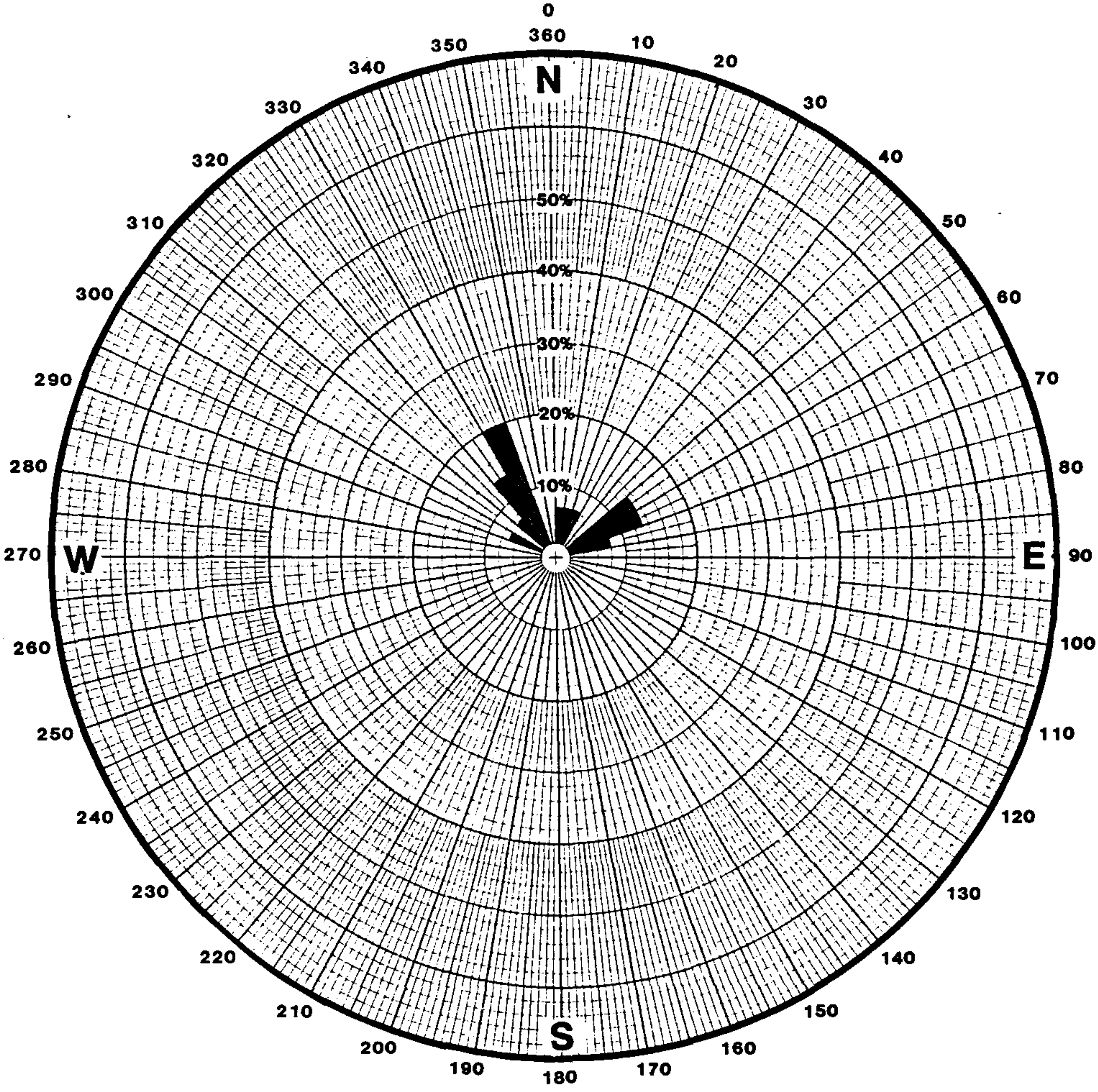

SPRING TRENDS

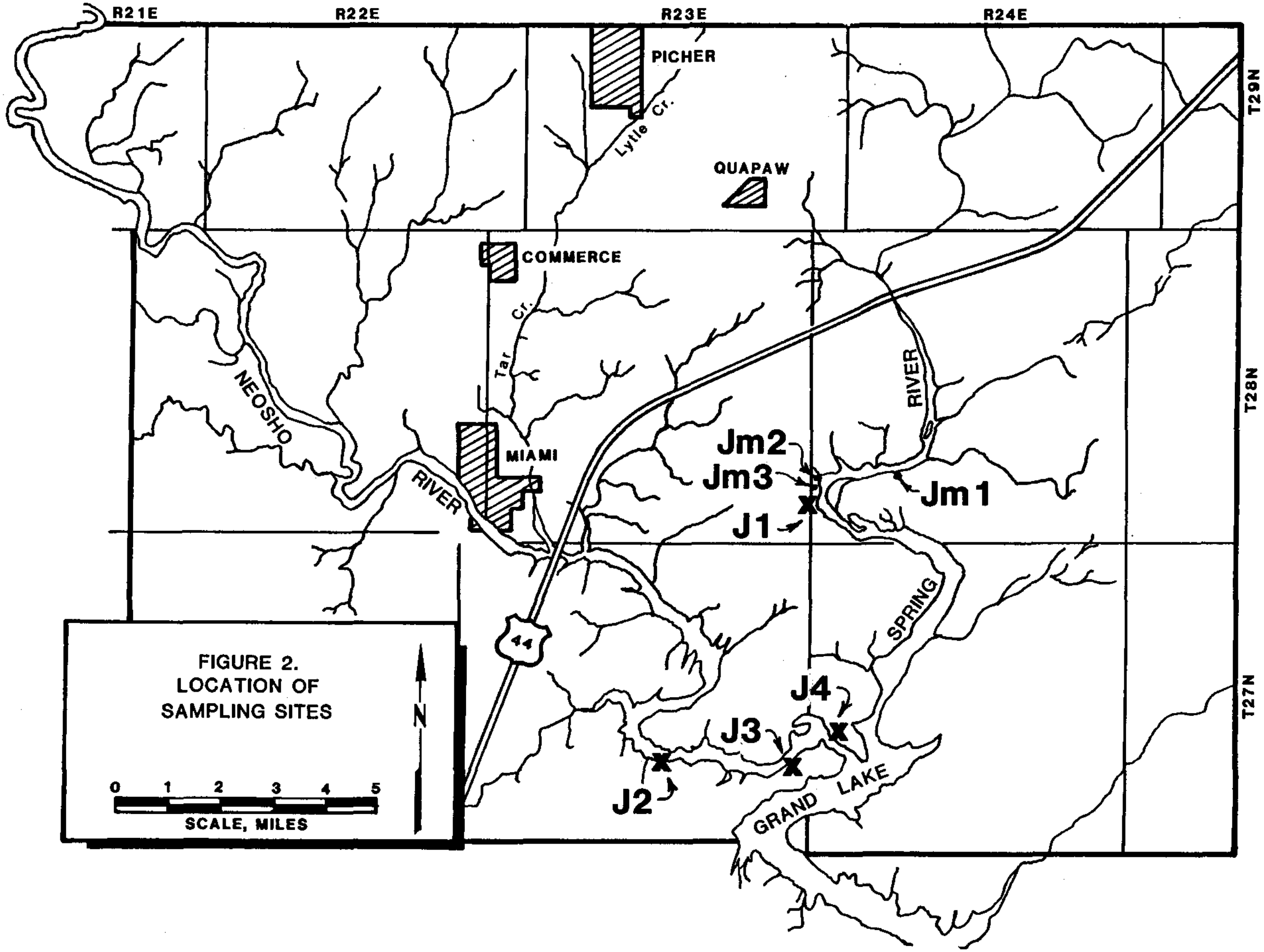

FIGURE 2.
LOCATION OF
SAMPLING SITES

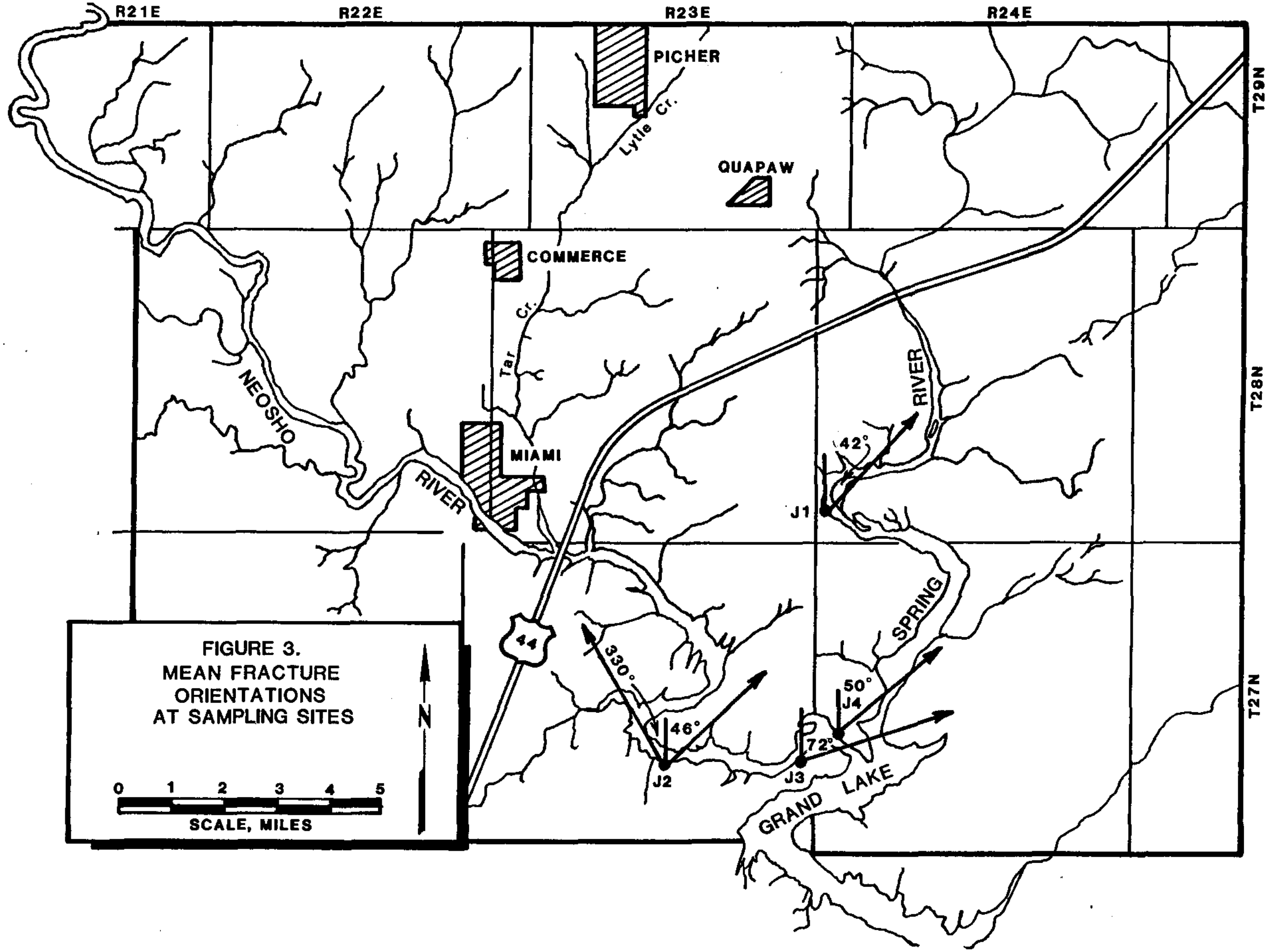

FIGURE 3.
MEAN FRACTURE ORIENTATIONS AT SAMPLING SITES

PART III.

Lineaments in Northeastern Oklahoma: A Preliminary Assessment

by

John D. Vitek
Department of Geography &
Graduate College

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^{o} East of North) and a secondary trend (120-130^{o} 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 interrelationships 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.

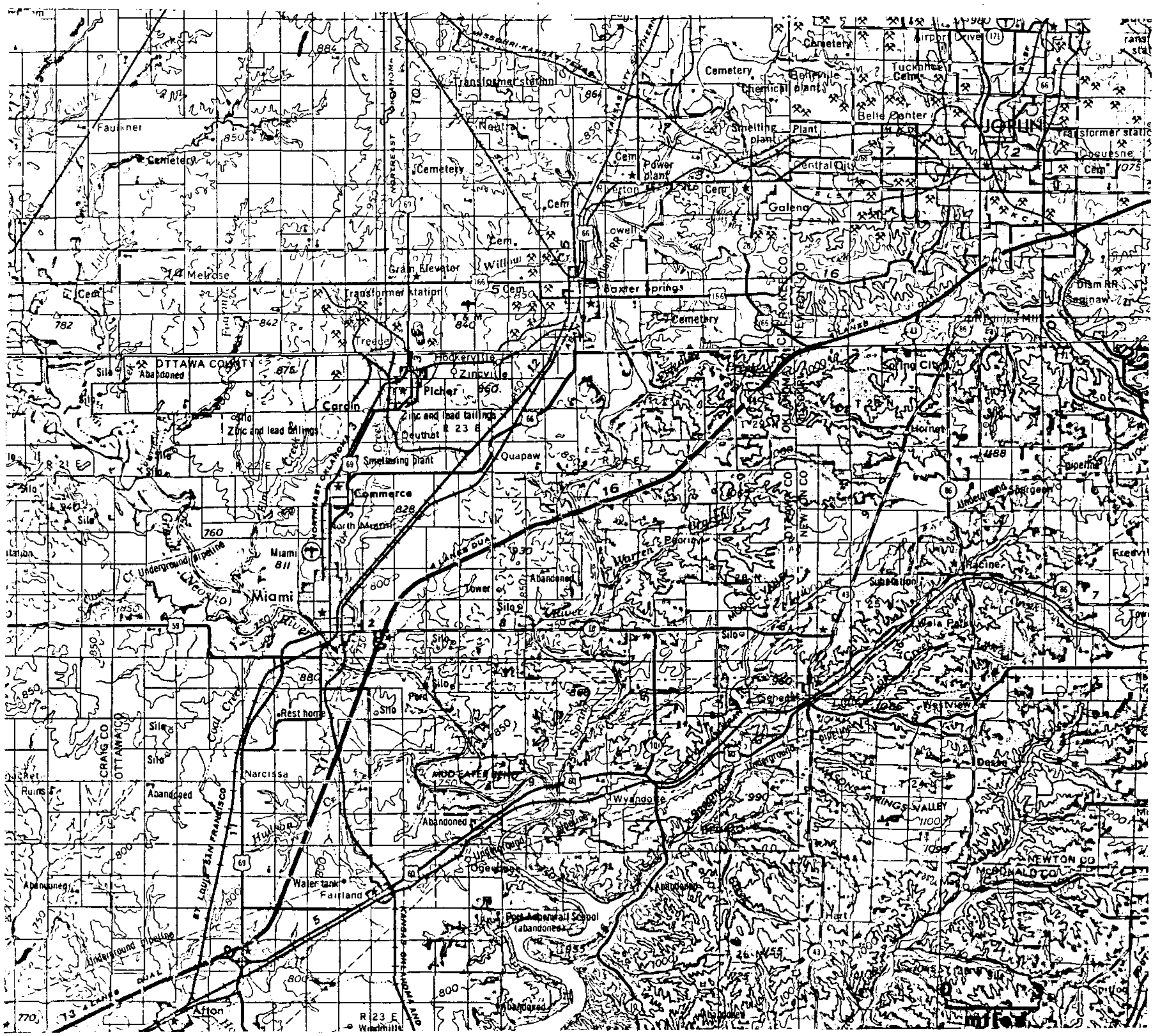

FIGURE 1. The location of the study area in Oklahoma, Kansas and Missouri

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

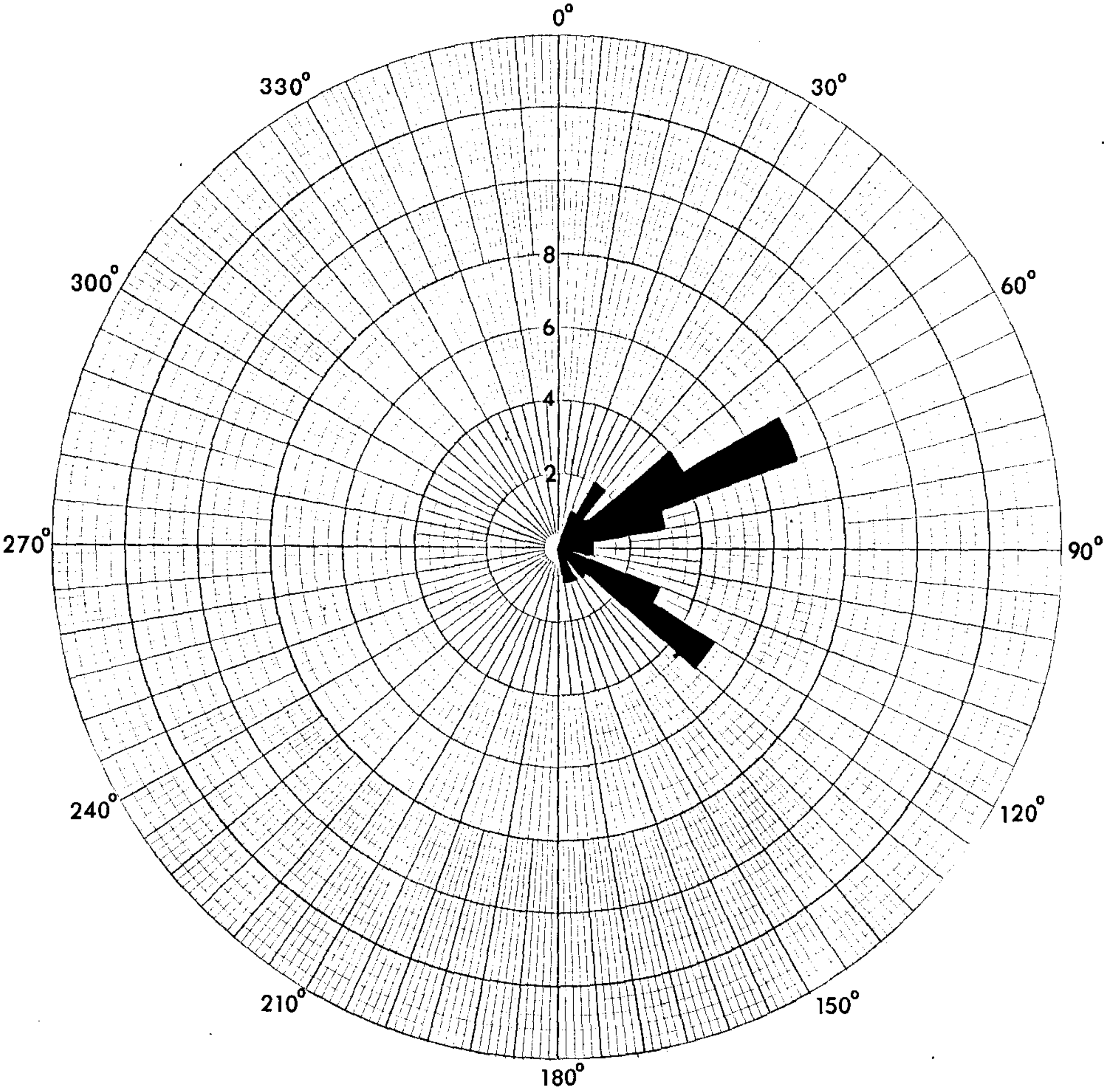

FIGURE 3. Directional tendency of the lineaments portrayed on Figure 2. The values on the graph represent the number of lineaments observed in each 10 degree interval.

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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