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1. Introduction

This report is based on the chemical analysis of the waters from 93 springs and 9 wells. Springs, when free from metal plumbing, provide an uncontaminated source of the ground water and it was desired to obtain water uncontaminated with metals. A few wells were added to the list, usually because of their unique location in the sampling grid.

An uncontaminated ground water sample is of interest for its quality (purity), its subsurface temperature and its aid in mineral exploration. These three interests are covered in the main sections of this report which follow the experimental and geological sections.

Study Area I is a 135 x 80 km area which extends west from Hot Springs, Arkansas, to the Oklahoma line and it is located north of the 34° 42'30" N. latitude line. It encompasses the core area of the Ouachita Mountains. Area II is 135 x 23km and abuts Area I on the south. It is known as the Athens Plateau and includes some of the Gulf Coastal Plains. Figure 1-1 shows the location of the study area and the springs. Springs were located from notations on USGS topographic maps, from the literature on warm springs in Arkansas (Billingsley and Hubble; Miser and Purdue, 1929; Bryan, 1922) and from discussions with local inhabitants.

For convenience tables and figures are collected together in the rear of the report and titles with page location are summarized in the Table of Contents.

2. Experimental

In the collection, storage, and analysis of the water samples, the recommendations and procedures of the Environmental Protection Agency were followed. These procedures are outlined in EPA (1974) and APHA (1971). All samples were collected and stored in polyethylene containers. Some polyethylene caps for the 1 gallon containers are compounded with a filler. These types of caps were avoided and only clear polyethylene caps were used. All polyethylene containers were rinsed with concentrated nitric acid and allowed to stand capped from one to several hours, then rinsed several times with dionized distilled water before use.

At each site the routine was to collect 5 liters of raw water, 4 liters of which were immediately filtered through a 0.4μm (142mm) Nuclearpore filter and stored in a 1 gallon polyethylene container to which 12 ml of 1:1 HNO_3 were added. An additional 500 ml of 0.4 μm filtered water was stored in a polyethylene container at 4^oC for SiO_2, SO_4, Cl, PO_4, NO_3, and NH_3 analyses. Anion analyses were made within 3 days after collection. Alkalinity, pH, and conductivity were measured at the site on unfiltered samples.

A special filter devised by the Savannah River Laboratory was used for the filtrations. This filter was pressurizable to 40 psi with freon, used a 142 mm filter, and filtered one liter of water per filling. New filters were prewashed with at least 100 ml of raw water, via filtration to remove any soluble contaminants.

All cation analyses were by either atomic absorption (AA), spectrophotometry or flame emission. Both a Perkin Elmer Model 303 AA unit and a Jarrel Ash modernized Solid State Model 82-500 unit were used. The particular flames and other adaptations of these units are summarized in Table 1-1 along with the anion analytical schemes. Heavy metals (Fe, Co, Ni, Co, Zn, Pb) were first chelated and extracted by methyl isobutyl ketone after Nix and Goodwin (1970), before being determined by AA.

Temperature was measured by a mercury thermometer which was calibrated against an A.S.T.M. certified thermometer. The pH was measured with a Markson Model 80 pH meter. Conductivity was measured with a KCl (soln.) calibrated YSI Model 33 S-C-T conductivity meter. Total alkalinity was measured by titration to the methyl red end point using a methyl red- bromocrescol green mixed indicator and 0.02 N H_2SO_4. All measurements were made on the acidified raw water except for barium. For this element the acidified raw water was first concentrated 10-25 times by evaporation from a teflon beaker on a hot plate in order to improve the sensitivity. No loss in this evaporation technique was found for Na, K, and Mg. Therefore, no loss of Ba is expected.* However, Sb could not be retained by an evaporative concentration process and was always determined on the raw water.

Mercury was determined by atomic absorption using the flameless method (EPA, 1974, pp. 118). The samples of raw water were first treated with strong oxidizing agents to convert any organic mercury compounds to inorganic forms. The method thus measures organic and

---

*On a few samples with detectable Ba in the raw water no loss was found.

inorganic mercury. The oxidizing procedure was as follows: 1) add 5 ml of 5.6 N HNO_3 to 100 ml of the raw water sample (from 1 gallon polyethylene storage container which has been acidified with 1:1 HNO_3); 2) wait 15 seconds and add 5 ml of 18N H_2SO_4; 3) wait 45 seconds and add 15 ml of 5% potassium permanganate and 8 ml of a 5% aqueous solution of potassium persulfate; 4) heat 2 hours at 95^oC; 5) cool to room temperature, add 5 ml of hydroxylamine hydrochloride-NaCl solution (15 g/100 ml of each); 6) add 5 ml of stannous chloride solution (10%) and analyze immediately. A Perkin Elmer aerator and analyzer cell fitted to a Perkin Elmer Model 303 spectrophotomer were used.

Antimony was analyzed by the volatile hydride method after Fernandez (1973). A Perkin Elmer (PE) Hydride Generation Sampling System (303-0849) was adapted to a Jarrel Ash Solid State modernized Model 82-500 atomic absorption spectrophotometer. A 20 ml sample of spring water (from acidified storage sample) was added to the PE generator along with 8 ml of conc. HCl. A pellet (10/32 inch) of solid sodium borohydride (from Alfa Inorganic Division of Ventron Corp., Beverly, Mass. 01915) was added to the generator to form hydrogen and antimony hydrides which were fed to a hydrogen-nitrogen flame. Peak heights on a recorder were calibrated against antimony standards.

The following table gives a comparison of SiO_2 analysis by atomic absorption (DeVine and Suhr, 1977) and by the colorimetric method adopted for this work.

Spring No.	Colorimetric Method (ppm) Analysis 1	Analysis 2	Atomic Absorption Method (ppm)
501	7.7	8.7	7.7
502	3.2	4.4	7.2
503	18.3	19.1	23.0
504	12.1	13.5	15.6
505	7.7	9.1	12.2
506	12.1	13.9	15.6
507	13.7	9.5	11.6
508	7.7	10.0	11.6
509	10.3	8.8	11.2
510	6.6	3.7	6.1
511	10.2	8.1	8.9
512	8.9	9.3	8.9

Analytical data are summarized in Tables 1-2 to 1-4. Precision for most cation analyses in Table 1-2 to 1-4 is estimated at ±10%. This is generally true when the concentration being analyzed is several times the detection limit -- the "less than" values in the various columns. These detection limits may vary in a given column because of change in sample size, instrument noise at the time, or size of the blanks. Where the concentrations are low the per cent error is much larger and is given by (detection limit)/(concentration) x 100. The reproducibility of the various anion analyses in the hands of various investigators has been studied in part by EPA and APHA. Reproducibility for our median concentration ranges are given in the concluding lines of Table 1-2 using the precision data of EPA (1974) and APHA (1971) for this range when available.

3. Geology

The following two study areas were selected based on contrasting lithologies and mineralizations.

a. Area I: (Mn, Fe, Ba mineralization with minor Cu, Zn, Pb mineralization) As shown in Figure 1-1 this area includes parts of Montgomery, Polk, Pike, Howard, and Garland counties in west-central Arkansas. This is the core area of the Ouachita Mountains with relief of 152 to 304 m. and ridges 450 to 701 m above sea level. The region has some small farms, but is mostly forested and in the Ouachita National Forest.

A stratigraphic column for Area I is shown in Figure 1-2. Formations range in age from Cambrian to Carboniferous. Shales, Arkansas Novaculite (chert), and sandstone predominate with only minor limestone (in the Crystal Mountain and Womble Shale Formation). The upper member of the Arkansas Novaculite can be highly calcareous. Folding is intense and the east-to-west ridges have a corrogated surface due to the steeply dipping strata.

Manganese mineralization is widespread. Manganese oxide minerals lithiophorite ($Li_2Al_8Mn_{12}O_{35}.14\ H_2O$), cryptomelane ($K_xMn_8O_{16}$), psilomelane, $(Ba,\ H_2O)_4\ Mn_{10}O_{20}$, and pyrolusite ($MnO_2$) are scattered among over 100 manganese ore prospects and mines. These minerals particularly lithiophorite, may contain of the order of 1 wt. % each of the base metals Co, Ni, Cu, and Zn (Wagner, et. al., 1979). These minerals and iron oxides are found in the bedding planes and cracks of the lower and upper division of the Arkansas Novaculite. Native copper has also been found in the novaculite.

Two barite districts are known. In each case the barite is in the first few meters of the lower Stanley Shale Formation. The barite is formed as a result of replacement or fracture filling. Quartz veins in shale are associated with silver-containing sphalerite and galena in the eastern extremity of Area I.

b. Area II: (Hg, Sb, Sr, Ba mineralization with minor Zn, Pb mineralization) This area consists mainly of the Athens Plateau in the Gulf Coastal Region of Arkansas. Ages of the rocks vary from Mississippian (Stanley Shale), Pennsylvanian (Jackfork sandstone and Atoka sandstone, shale, and siltstone), Cretacous (Trinity limestone, gravel, siltstone, sandstone and some barite), and Quarternary (Terrace deposits and alluvium of gravel, sand, and silt). Along the northern edge there is a gradation from Area I to Area II type rocks. In the central part of the area there are kimberlite necks at Murfreesboro.

Three mineral districts exist. A mercury district with several mines covers essentially the central and eastern half of Area II (Clardy and Bush, 1976). An antimony district covers the western half of Area II with the antimony and mercury districts overlapping in the central part of Area I (Stroud et. al., 1969). Strontium ores have been mined in Howard county from the DeQueen Limestone member of the Trinity Formation. Similar deposits occur intermittantly across the area. Ore minerals for the three districts are mainly cinnabar (HgS), stibnite (Sb_2S_3), celestite ($SrSO_4$) and strontionite ($SrCO_3$). Some barite ($BaSO_4$) is found with the strontium area. In Howard and Pike counties barite occurs as a cementing material in gravels and sandstone.

Gypsum deposits occur in the central part of Area II.

Quartz veins in sandstone adjacent to Stanley Shale were mined for lead, zinc, and silver in two deposits in Sevier county, in the western part of Area II.

I. WATER QUALITY AND CHEMISTRY

1. Water Quality

a. Springs: The groundwater of the Ouachita Mountains of Arkansas is classed as a calcium bicarbonate type and generally is soft to moderately hard (Hem, 1970). The median hardness for all samples is about 60 ppm as $CaCO_3$. The total dissolved content is generally low, less than 100 ppm as $CaCO_3$ with Ca^{++} and HCO_3^- the major ions.

Samples included in this study occasionally exceed drinking water standards (Table I-1). Fifty-six of the samples have pH values below that recommended (WHO, 1971). In fact, the median value for all samples is 6.2 which is below the recommended value of 6.5. This recommended pH value is based on taste and corrosion properties of the water rather than health effects.

High values for NO_3^-, NH_3, and/or PO_4^{3-} are indicative of contamination and suggest that bacteria counts may also be high. Four samples (904, 922, 927, and 948) exceed the recommended NO_3^- value of 10 ppm as N (EPA, 1976). However, only one sample 948 (19.7 ppm) exceeds the limit by more than 4.5 ppm. Seven samples (Table I-1) exceed the recommended NH_3 value of 0.5 ppm as N (PHS, 1962) with the highest value at 1.52 ppm. Only one sample, 927, exceeds the recommended limits for both NO_3^- and NH_3. This site is an artesian well that may have its water affected by local surface contamination. Phosphate values are relatively low (Table I-1) with only three samples having PO_4^{3-} in excess of 0.3 ppm, yet just one sample, 927, exhibits either high NO_3^- or NH_3 in addition to the high PO_4^{3-} value.

Thirty samples and thirty-five samples exceed the limits (EPA, 1976) for Fe (300 ppb) and Mn (50 ppb) respectively (Table I-1). Twenty-six samples exceed both of these limits. However, these limits are not set because of health reasons, instead they are set because of taste and staining problems. One sample, 932 (59 ppb) exceeds the Pb limit of 50 ppb, and the Hg limit of 2 ppb is exceeded by another sample 908 (2.27 ppb)(EPA, 1976). The concentration values of other elements are well below the limits set for other parameters with the exception of two samples, 929 and 944, which have Ba concentrations of 0.9 ppm which are close to the limit of 1.0 ppm (EPA, 1976). These samples are actually from the same spring at different times. Thus, the spring water of the Ouachita Mountains is potable, and the major problems are those associated with taste, corrosion and staining.

b. Comparison of Springs and Wells: The wells in the Ouachita Mountains of Arkansas have been analyzed previously in another project for major parameters (Albin and Stephens, 1963) and the analytical results of this study are compared with those of the present study in Table I-1. Values reported by Albin and Stephens for Fe and Mn have not been included as their water samples were not filtered prior to analysis (R. Sniegocki, personal communication, 1978). Therefore, their Fe and Mn values are considerably greater than those of the present study due to the presence of suspended material containing Fe and Mn. Although the waters from the springs and wells are generally similar, the high and low ranges and median values from well water are greater than spring water with the following exceptions. The warm springs samples (e.g. 915) have higher temperatures than the wells. The springs also have a higher median Ca^{++} concentration which may be due to the more alkaline nature of the well water. The higher pH values for well water may be related to chemical and physical reactions in storage tanks, e.g. the loss of carbon dioxide could raise the pH of the water causing precipitation. The springs median and upper range values for SiO_2 exceed those for the wells probably due to the high density of samples in the Caddo Gap area where some warm springs are located, and also the few wells samples were deep ones which could intersect thermal waters.

The higher values exhibited by the wells may be the result of more intimate contact of water with rocks or other factors. However, because the well water was not filtered, it is likely that the presence of suspended material has increased concentration values for many parameters. Thus, most of the differences between the well and spring waters in Table I-1 may simply reflect the differences between unfiltered and filtered groundwater.

2. Water Chemistry

The large number of analyses for a variety of elements and anions provides an opportunity to: 1) seek correlations among the various elements and 2) examine the saturation of the waters with respect to some of the more common minerals. These two facets are examined in the following subsections.

a. Base Metals: The manganese concentrations of the waters were found to correlate with their concentrations of Fe, Co, Ni and Zn. Correlation coefficients calculated after Lepeltier (1969) from Figures I-1 to I-11 are summarized below. The correlations are for Areas I and II as a whole.

	Correlation Coefficient	
Metal	With Mn	With Fe
Fe	0.652	-
Co	0.454	0.228
Ni	0.778	0.500
Cu	-0.050	0.034
Zn	0.430	0.391

Correlation of the base metals with Fe is somewhat poorer than with Mn as noted by the smaller correlation coefficients in the above table. Copper did not correlate with either Mn or Fe. These correlations with Mn are particularly interesting because base metal contents of stream sediments in this area were found in previous studies (Wagner, et al., 1978) to correlate with their Mn contents. Similar chemistries and perhaps similar source rocks account for the correlation between elements.

b. Alkaline Earth Metals (Ca, Mg, Sr and Ba): Calcium is by far the major element, in general, in the various spring waters. This is due to the widespread distribution of limestone and calcareous cements, both of which are mainly $CaCO_3$, in sedimentary rocks and the ready solubility of $CaCO_3$ in waters containing CO_2 via the equation:

$$CaCO_3(c) + H_2O + CO_2 = Ca(HCO_3)_2 \text{ (soln)}$$

The carbon dioxide (CO_2) is available from the air (0.03%) and soil (respiration and decay of plants).

The concentrations of other alkali metals correlate with the concentrations of calcium. The following table shows correlation coefficients calculated after Lepeltier (1969) from the plots in Figures I-12, III-12, III-13 and III-16.

Element	Correlation Coefficient with Ca
Mg	0.797 (Areas I and II)
Sr	0.925 (Areas I and II)
Ba	0.123 (Area I), 0.329 (Area II)

The chemistries of the four elements are similar and they have common sources, except for Ba. The barium ion does not fit into the $CaCO_3$ lettice, being too large. Mg^{++} and Sr^{++} are common impurities in limestone. Ba is more likely to come from barite, igneous rocks, or feldspar fragments in sedimentary rocks. These differences of Ba are reflected in the lower correlation coefficient.

Barium occurs widely in our study Area I as the manganese mineral psilomelane, $(Ba, H_2O)_4Mn_{10}O_{20}$. In stream sediments correlation coefficients for Mn-Ba were about 0.9 (Wagner, et al., 1978). No significant correlation has been found for Mn-Ba based on their concentrations in the waters of Areas I and II ($p = 0.164$). This contrasts to the Mn-base metals correlation which persists in sediments and groundwater, as noted in the previous subsection.

Skougstad and Horr (1963) have summarized a large number of Sr analyses for surface and groundwaters of the United States. The sulfates and carbonates of Ca, Sr, and Ba are relatively insoluble. It is of interest to determine the relative saturation of the spring waters with respect to the six minerals corresponding to these compositions. Table I-2 lists the minerals, their solubility products, the activity ratios for ions with minerals in equilibrium, and the median values for these quantities for Areas I and II. Equilibrium values of activity ratios when drawn on correlation log - log plots for the two ions show which springs are saturated with which mineral.

General statements can be made by comparing median values and equilibrium values of activity ratios. For the celestite ($SrSO_4$) = gypsum ($CaSO_4,2H_2O$) equilibrium the mean value of $a_{Sr^{++}}/a_{Ca^{++}}$ is greater than the equilibrium value in both Area I and II and indicates that celestite is generally the stable mineral, not gypsum. Barite ($BaSO_4$) is even more favored than gypsum and is thus the favored sulfate mineral. Calcite is the most favored carbonate mineral.

In Figure I-13 the solubility products of strontianite ($SrCO_3$) and calcite ($CaCO_3$) are plotted versus temperature. Figure III-11 has similar data for barite ($BaSO_4$) and celestite ($SrSO_4$). We have calculated for each spring using its surface temperature, the percent saturation with respect to the four minerals: barite, celestite, calcite, and strontianite. Median values and the ranges are shown in the following table. Activity coefficients were determined from ionic strength and the graph of Hem (1970), p. 21. Carbonate ion concentrations were determined from the $C_{HCO_3^-}$ (from alkalinity), pH, and the equilibrium constant for $K_{HCO_3^-}$ which is plotted versus temperature in Figure I-13A.

% Saturation of the Spring Waters with $BaSO_4$, $SrSO_4$, $CaCO_3$ and $SrCO_3$
At Surface Water Temperature

				% of Springs	
Mineral	Area	Median	Range	Above 10% Saturation	Above 50% Saturation
barite, $BaSO_4$	I	1.3*	0.16-96	15	7
	II	8.5*	0.40-97	45	16
celestite, $SrSO_4$	I	0.0075	<0.0001-0.50	0	0
	II	0.0047	0.0011-1.97	0	0
calcite, $CaCO_3$	I	0.065	0.000013-154	25	7
	II	0.022	0.00019-79	19	4
strontianite, $SrCO_3$	I	0.033	0.04×10^{-4} - 8	0	0
	II	0.002	0.002×10^{-4}-31	8	0

*Using all values and counting < values at ½ their < value.
Area I had a median of 2% using finite values only.
Area II had a median of 8% using finite values only.

Only barite and calcite show any appreciable saturation in the spring waters. In Area II there were 8% of the springs with over 10% saturation with strontianite but none were over 50%. Both barite and calcite have some springs over 50% saturated.

c. Alkali Metals (Li, Na, K): Figures I-14 to 18 show plots of Na versus Mg, K, Sr, Ca, and Li. Only Li shows a reasonably good correlation coefficient (p = 0.509) with Na. However, the Mg-Na, Sr-Na, and Ca-Na plots have a minimum envelope to the data. The reason for this is unknown at the moment but it is interesting that the minimum parallels more or less the concentration ratios for the ions in rain water. Curves A, B, and C depict in Figure I-14 the course of the ionic ratio of Mg/Na based respectively on A (absorption of Mg from rain water solution and replacement with Na), B (either addition of Mg or absorption of Na with no replacement by Mg) and C (addition of Na to the rain water with no change in Mg). Mere loss of water proceeds along the rain-ratio line. Since most of the points of Figure I-14 are above the rain-ratio line the combined process of water loss (by evaporation and transpiration) and Mg addition predominate. In Figure I-15 for K-Na, the process of water loss and K absorption predominate. Figure I-16 for Sr-Na is predominantly water loss and Sr addition. Figure I-17 indicates both Ca addition and Ca removal processes at work along with water loss.

A manganese mineral containing lithium, lithiophorite, with the formula $Li_2Al_8Mn_{12}O_{35}.14H_2O$ is widespread in our study area (Wagner et al, 1979). This mineral might provide both Li and Mn to groundwater. Figure I-5 shows a correlation plot for Mn-Li with p = 0.289, a rather poor correlation.

Vatin-Pérignon et al.(1979) has listed the Li/Na ratio of a large number of different kinds of waters .

II. GEOTHERMOMETRY

1. Introduction

A survey of spring water temperatures in Areas I and II has been carried out utilizing two methods: 1) the quartz geothermometer and 2) the surface temperature of the water. By this means areas of geothermal activity should be located. A third method, the Na-Ca-K geothermometer, was evaluated for the study area but it yielded erroneous results because it is designed for areas where feldspars are abundant. Feldspars are rare to absent in the rocks of the study area.

The approach taken was to construct histograms for the total study area (Areas I & II) of the temperature obtained from the SiO_2 and surface methods, calculation of the mean and standard deviation, assuming a normal distribution, and defining values greater than one standard deviation unit above the mean as being anomalous (Swanberg and Morgan, 1978). The details of the method are discussed below.

a. <u>Quartz Geothermometer</u>: Many papers have been published regarding the solubility of silica as an empirical function of temperature in an aqueous environment (Fournier, et al., 1974); (Fournier and Truesdell, 1973); (Mahon, 1966) and (Mariner and Willey, 1976). The relationship is expressed quantitatively according to the equation of Truesdell (Swanberg and Morgan, 1978):

$$T_{SiO_2} = \left[1315/(5.205 - \text{Log}_{10}\ SiO_2) \right] - 273.15$$

where T_{SiO_2} is the silica geotemperature in degrees centigrade and SiO_2 is expressed in parts per million. The method is useful in estimating reservoir base temperatures of geothermal systems. However, three principle assumptions must be made in order for the method to be utilized quantitatively (Swanberg and Morgan, 1978): 1) there is no mixing of non-thermal waters with the waters migrating from the geothermal reservoir to the surface, 2) equilibrium in the geothermal system must be established between the waters and the surrounding rocks, and 3) there is no silica precipitation. The general reluctance of quartz to precipitate from supersaturated solutions (Truesdell, 1976) and slow water-rock reactions at low temperatures (Rimstidt, 1977) aid in supporting these assumptions. It must be kept in mind that temperatures calculated from the SiO_2 concentrations are a minimum temperature due to the possibility of dilution taking place by waters encountered near the surface.

b. Surface Temperature: The surface temperature method involved establishing a mean surface temperature of the waters sampled in the study area. We assume after Swanberg and Alexander (1979) that waters at the surface having a temperature of one standard deviation above the mean may be of geothermal origin. Figure II-3 is a histogram of the surface temperatures of the study area. The modal value is 17^oC and compares with a mean value of 16.8^oC and standard deviation of 4.3^oC.

c. Heat Flow: Heat flow is defined as the product of the thermal conductivity of a substance and the thermal gradient in the direction of the flow of the heat (AGI Glossary, 1972, p. 326). Swanberg and Morgan (1978) showed that regional heat flow can be predicted from the silica concentration of groundwater by using the following empirical equation:

$$T_{SiO_2} = m'q + b, \tag{1}$$

where T_{SiO_2} is the silica geotemperature in degrees centigrade (^{o}C), q is heat flow in milliwatts (w) per square meter (m) and m´ and b are constants of $0.67^{o}Cm^2/w$ and $13.2^{o}C$, respectively. The physical significance of the intercept b is that this value should represent the national mean annual air temperature because the absence of heat flow implies that all thermal energy be solar in nature (Swanberg and Morgan, 1978).

d. Geothermal Gradient: The geothermal gradient represents the increase in the rock temperature per unit of distance as one proceeds from the surface of the earth downwards. It is expressed in the following equation:

$$\text{Geothermal Gradient} = \text{Heat Flow/Thermal Conductivity of the Rocks} \quad (2)$$

where the geothermal gradient is in ^{o}C per kilometer, heat flow is in milliwatts per square meter and the thermal conductivity is in milliwatts per kilometer per ^{o}C.

The stratigraphic column of the study area (Figure 1-2) includes numerous strata of variable thicknesses. The dominant rock types in the area are sandstones, shale, and chert. The thermal conductivities of sandstone and shale are quite similar (Handbook of Chemistry and Physics, 1972-1973). The thermal conductivity value of chert could not be located and was estimated at $1.2w/km^{o}C$. Due to the relatively small difference in the thermal conductivities of the three rock units and also due to the actual thicknesses of the rock units in the Ouachitas being unknown, an approximate thermal conductivity value of $1.3w/km^{o}C$ was assigned to the Ouachita sediments.

e. Circulation Depth: It is not known to what depth the waters from the springs are circulating, or to which formations they are confined. However, based on the mean SiO_2 temperature and the mean geothermal gradient, a mean depth of circulation can be calculated by the following equation:

$$\text{Depth} = (T_{SiO_2} - A)/(\text{Geothermal Gradient}) \qquad (3)$$

where depth is in kilometers, T_{SiO_2} is in °C, the geothermal gradient is in °C/km, and A is the mean surface temperature. The surface temperature of the rock is assumed to be the same as the surface temperature of the spring water.

2. Results and Discussion

The frequency distribution of the silica concentrations found in the Ouachita spring samples is shown in Figure II-1. It can be seen that the bulk of the samples can be accounted for in the 5-15 ppm range. The calculated mean was 11.5 ppm and the modal value was 10 ppm. Geotemperatures calculated from silica concentrations are shown in Table II-1 and represented in a frequency plot in Figure II-2. The mean silica geotemperatures in the study are was 44.3°C with a modal value of 37.5°C. Because the mean and the modal values are approximately equal and the 14.1°C standard deviation less than the 25°C suggested by Swanberg and Morgan (1978), the value of 44.3°C is taken to be representative of the entire Ouachita Province (Areas I & II). The provinces that most closely resemble the Ouachita Province in Swanberg and Morgan's (1978) paper are the Eastern United States (North), Eastern United States (Central), and Middle Rocky Mountains (Wyoming). In the North and Central Eastern United

States, the silica concentrations are slightly less than the Ouachita Province, which indicates a slightly lower calculated subsurface temperature. In contrast, the Rocky Mountain region yielded slightly higher silica values than the study area corresponding to higher subsurface temperatures.

According to Swanberg and Morgan (1978), geotemperatures of greater than one standard deviation unit above the mean (i.e. greater than 58.4°C in this case) is an effective cut-off temperature in searching for geothermal areas. Using this criteria, there are approximately 14 springs out of the 102 water sites sampled that are possibly of "thermal origin or have a component of thermal water". Table II-2 lists these springs and their associated silica geotemperatures.

Using the surface temperature method, 7 springs (Table II-2) have temperatures of one standard deviation above the mean (i.e. greater than 21.1°C in this study). Only two springs, 923W and 924 in the Caddo Gap area, have both anomalous surface and geotemperatures. The two hottest springs, based on surface temperatures, 915(35°C) and 921(30°C) also in the Caddo Gap area do not have anomalous geotemperatures.

The data show that low temperatures at the surface need not be indicative of low temperatures calculated from the SiO_2 concentrations. This observation can be explained by considering the path taken by the waters on their way to the surface. Once silica is in solution it is reluctant to precipitate out even though the temperature of the water drops as would be the case for a long distance of travel. If only a short distance of travel is involved, the silica concentration should remain constant;

however, the water temperature should be higher. Such a case then should be indicative of a heat source near the surface. However, it must be kept in mind that the silica geotemperature values represent a minimum temperature due to the possiblity of the waters being diluted on their way to the surface.

Due to faulting being so intense in the study are, it is believed that the anomalous silica values are associated with faults which penetrate, stratigraphically, deeper than their surrounding counterparts.

Minimum heat flow was calculated using the method of Swanberg and Morgan (1978), as stated above. Table II-1 shows the results of these calculations. Sample 502 gave an unrealistic negative value. This sample is extremely low in silica and is interpreted as containing primary meteoric water.

Figure II-4 shows a contour map of the heat flow in the study area. Areas of highest heat flow are located in the vicinity of Caddo Gap, the Cossatot Mountains, Lake Greeson, Mena and east of Dierks Lake in Sevier County. In the Lake Greeson area, the high heat flow is believed to be associated with the epithermal Hg deposits.

Table II-1 shows the geothermal gradient values calculated for the study area. In general, the geothermal gradient in the study area ranges from 20-50 ^{o}C/km and has a mean value of 35.7. Due to the lack of wells drilled in the study area, the geothermal gradients given by the AAPG are only rough extrapolations, yet based on the AAPG values through the middle of the study area, their average of 30.08 ^{o}C/km corresponds quite well with our mean of 35.7 ^{o}C/km.

Equation (1) was developed for regional use where T_{SiO_2} and q have mean values for the region being studied. In Table II-1 we have applied the equation to the calculation of heat flow, q, for individual springs. Using the mean value for our study area (Area I & II) for T_{SiO_2} we now calculate the mean value of q using equation (1), and from equation (2) and (3) the mean heat flow, geothermal gradient and depth of circulation for our study area. These values are summarized below:

Parameter	Symbol	Mean for Area I & II	Units
Subsurface Spring Water T	T_{SiO_2}	44.3	^oC
Heat Flow	q	46.4	milliwatts/m^2
Geothermal Gradient	-	35.7	^oC/km
Surface Spring Water T	A	16.8	^oC
Depth of Circulation of Spring Water	-	0.77	km

The mean circulation depth of 0.77 km seems reasonable for our study area.

3. Comparison of Historical Data and Present Work

Miser and Purdue (1929) and Bryan (1922) have previously recorded data on warm springs in Area I. Although Miser's data were published in 1929, the temperature measurements were made in 1910 and 1916. As will be noted in the comparison on the next page of these previous measurements with ours, there has been no significant temperature changes in the springs. Our spring 921 is possibly not the same as Barton's spring and may be ¼-½ mile to the south of it. We locate 921 at SW¼, NW¼, sec. 26, T4S, R25W. The references list it as "along sec. 23-26 line.

Present No. Spring	Past Name	(1) T^{o}C(year)	(2) T^{o}C(year)	Present Work,
945	(Little Missouri River Bank)	23.3(1916)	-	23.0
915	(Bed of Caddo River, North Spring)	35.0(1910)	-	35.0
		34.4(1916)		
	(Bed of Caddo River, South Spring)	35.4(1910)		
		36.0(1916)		
921	W. B. Barton	listed, no T	31.7(?)	30.0
924	Redland Mountain	25.0(1916)	-	25.0

(1) Miser and Purdue, 1929; Bryan, 1922

(2) Billingsley, et al.

Miser and Purdue (1929) list some chemical data on two of the springs which are compared below to our data. All data are in ppm.

	Caddo River Springs			Barton's Spring	
Analysis	N. Spring	S. Spring	Our Data	Miser and P.	Our Data
SiO_2	18.7	15.0	17.2	15.4	10.5
Ca	41.7	38.9	42.0	39.8	50.4
Mg	4.2	2.2	2.45	2.3	2.38
Na	3.4	7.5	5.4	9.1	3.83
K	0.000	0.000	1.00	1.3	1.10
SO_4	2.32	1.42	0.70	8.3	3.2
Cl	7.1	4.8	3.5	8.0	2.5
Li	-	-	-	0.6	0.0046

The data on the Caddo River Spring are in close agreement, except for K and SO_4. Only Mg and K are in close agreement for Barton's Spring. The literature data acknowledged some contamination with other waters during the Barton Spring sampling. Also, as pointed out earlier, our spring 921 while in the same area as Barton's Spring may be ¼-½ mile south of it.

It is of interest to compare our data in a very general way with that of the hot and warm springs near Hot Springs, Arkansas. The hot springs have a uniform SiO_2 concentration of about 42 ppm which corresponds to a subsurface temperature of 94°C (Bedinger, et al., 1974). The average concentration of SiO_2 for the warm springs (i.e. greater than 20°C) near Hot Springs was 23.6 ppm, corresponding to an average source temperature of 70.6°C. These warm springs have a fairly uniform elemental concentration which indicates a common source. The warm springs in our study areas varied substantially in chemical composition which indicate a variety of sources.

4. Summary

The area around Caddo Gap has the springs with the higher surface temperatures (30 and 35°C). Other warm springs, Redland Mt. (25°C) and a "warm" spring (23°C) are the next hottest. Miser first measured the temperatures of these springs in 1910 and 1916. The temperatures are the same today (1979).

Subsurface temperatures of the various spring waters based on the silica geotemperature were highest in the Fancy Hill barite district (911W with 91.2°C T_{SiO_2}), next highest in the Lake Greeson mercury district (907W with 89.2°C T_{SiO_2}) next highest in the Caddo Gap area (923W with

82.9°C T_{SiO_2}) and next highest in the antimony area of Sevier County (951W with T_{SiO_2} of 78.3°C). The preponderance of wells in this list is to be noted.

These data are of geologic interest and are discussed further in the Exploration Section III. In economic terms the hottest springs might be of balneological or direct heating use. They cannot be used for power generation which requires about 180°C for turbine power generation (Muffler, 1973).

III. EXPLORATION

1. Introduction

Stream sediments and soils have received much attention in geochemical exploration for mineral deposits. In general, mineral deposits have indicators in nearby sediments and soils either through clasts or chemical solutioning and reprecipitation. Chemical analyses of sediments and soils detect the element of interest and the vector of the amount of the element points, in theory, toward the deposit.

Analyses of surface and ground waters have likewise been used for exploration (see p. 271 of Hawkes and Webb, 1962). Water samples are generally very dilute in mineral content compared to solid samples and analytical schemes are strained. Surface waters have an advantage of traveling far and with strategic sampling can be used to broadly survey a large drainage basin. Surface waters have a disadvantage of being in contact with air and converting some metallic ions, Fe^{2+} and Mn^{2+} for example, into the less soluble "ic" forms. It is not unusual to see this process in operation via the precipitation of iron and manganese oxides where a seep or spring flows into air or a stream. Precipitation of Fe_2O_3 or MnO_2 coprecipitates many trace metals and removes them from solution.

For geochemical exploration, ground water has certain advantages over surface waters: 1) lower Eh and greater solubility for certain metallic ions in the "us" form; 2) longer contact with rocks and soils with greater chance of equilibrium and higher metallic content;

3) higher CO_2 content due to organic decay processes which give it a lower pH and more dissolving potential; 4) more concentrated in mineral content due to no dilution by direct rainfall or surface runoff and, in forested areas, a 2X to 3X concentration due to evaporation and transportation; 5) in a faulted or steeply dipping strata, spring waters may have a deeply buried conduit and in the process "sample" buried rock structures and minerals which have no surface exposure. This last advantage is also a disadvantage for springs in that all the rock units to which spring waters have been exposed are unknown.

In the present work about 100 springs were sampled in west-central Arkansas (see Figure 1-1). This is a highly mineralized area as described above in the "Geology" section and consists of two areas of distinct mineralization. Thus, an opportunity is provided for testing the potential of spring waters in these areas as an exploration tool. Chemical analyses of the waters are summarized in Tables 1-2 through 1-4.

Analyses were made for the following elements:

1) Base metals (Fe, Mn, Zn, Cu, Co, Ni, Pb, Hg, and Sb)
2) Alkaline earth metals (Ca, Mg, Sr, and Ba)
3) Alkali metals (Na, K, and Li)
4) Anions (NO_3, NH_3, PO_4, SO_4, Cl, and SiO_2)

In addition, the following measurements were made: water temperature, pH, specific conductivity, and alkalinity.

The scheme for testing spring water analyses as an exploration tool is to compare the location of springs of anomalously high concentrations of metal content with the location of known mineral deposits of the same metal. This will be done on a district (Areas I and II), as well as on a fractional section basis using Stroud et. al. (1969) for the location of mineral deposits.

We are using section, township, and range for locating springs and mineral deposits. Spring locations are based on the latest U.S.G.S. topographic maps and field observations. Stroud, et. al. (1969) also uses section, township, and range for locating mineral deposits. Any other system would be awkward as would any distance unit other than mile, due to sections being 1 mile square. All distances given in the discussion of individual springs are in miles.

To determine anomalous values, the concentration of each metal for the various springs was plotted graphically as cumulative frequency curves after Lepeltier (1969). Anomalous values were those exceeding threshold, the 95% value on the high side. Figures III-1 through Figure III-5 compare several of these cumulative frequency curves for Areas I and II. Figures III-6 through Figure III-10 show several additional cumulative frequency curves for the areas. These curves shown are illustrative of the types of curves exhibited by Areas I and II and are not meant to be complete.

Most of the cumulative frequency curves for Areas I and II show two segments of similar slopes which are slightly offset. This indicates that there are two types of aquifers in the areas with slightly different chemistries. Several reasons such as different lithologies, depths, and temperature could explain the different chemistries. Although the slopes and intercepts are different for Areas I and II, the general shape of the curves for a given element are remarkably similar for the two areas. An exception is the PO_4 curve for the Area II which is quite linear with a single branch. Area I curves are based on 71 data sets whereas Area II curves are based on only 31. It is of interest to note that in both areas the data follow a lognormal distribution which is a requirement for linearity in this type of plot. To our knowledge, the lognormal distribution of chemical data on a natural water system has not been previously reported.

Threshold values and anomalous values determined from the above plots are summarized by analysis or measurement in Table III-1. Median, threshold, and anomalous values are compared for Area I and Area II, element by element in this table.

Before examining Table III-1, the different mineralizations of the two areas are worth repeating. Area I has Mn, Fe, Ba mineralization with minor Cu, Pb, and Zn mineralization. Area II has Hg, Sb, Sr, and Ba mineralization with minor Zn and Pb mineralization.

2. Background Values of Non-Mineralizing Elements

Median values which reflect the backgrounds for Areas I and II are compared below for temperature, pH, specific conductivity, and alkalinity with the ranges of the values given in parenthesis.

	Water Temperature (^oC)		pH	Sp. Cond.	Total Alkalinity
	Surface	Subsurface*	Units	μ mhos/cm(25^oC)	mg/L $CaCO_3$
Area I	17(5-35)	40.0(7.1-91.2)	6.4(3.8-7.9)	107(14-385)	60(0-291)
Area II	16(8-25)	45.9(11.2-89.2)	5.8(4.1-8.7)	61(<5-563)	15(0-265)
II/I (%)	94	115	91	57	25

calculated from SiO_2 content.

The median subsurface water temperature is slightly higher for Area II, but the hotter individual springs were in the eastern part of Area I. Other parameters in the above table are comparable or lower for Area II. The lower median pH for Area II should favor higher concentrations of most elements. This is countered by the higher electrolyte content (and thus lower activity coefficients) of Area I as indicated by its higher median specific conductivity. Higher electrolyte content would favor the solubility of barite, which was found in several cases to be near its saturation value.

Anion concentrations for the two areas are compared in the following table which gives median values and ranges in parenthesis.

Anion Median (Range) Concentrations (ppm)

	NO_3 as N	NH_3 as N	PO_4 as P
Area I	0.66(<0.01-5.5)	0.1(<0.01-1.52)	0.07(<0.01-0.54)
Area II	1.0(0.06-14.3)	0.2(0.02-1.52)	0.10(0.02-0.41)
II/I (%)	151	200	143

	SO_4	Cl	SiO_2
Area I	2.3(<0.3-32)	2.3(0.25-87)	10.3(3.2-34.9)
Area II	3.2(0.3-55)	3.5(0.5-9.5)	12.1(5.4-37.1)
II/I (%)	139	152	117

In all cases, Area II has the greater median anion concentration but the ranges are comparable, except for chloride. For NO_3, NH_3, and PO_4 this is most likely due to the greater agricultural and silviculture activities of Area II.

Other ions to be considered for background purposes for the present study are shown below. Median values, with ranges in parenthesis, are shown for Areas I and II.

Alkali and Alkaline Earth Ions, Median (Range) Concentrations

	Na	K	Ca	M
Area I	1.8(0.95-152)	0.56(0.04-2.9)	13.5(0.03-70)	1.9(0.1
Area II	3.9(0.85-162)	1.10(0.21-8.5)	2.7(0.6-78)	1.4(0.1
II/I (%)	217	196	20	7

Ranges for these four ions are comparable for the two areas but median values for Na and K for Area II are about twice those for Area II and for Mg and Ca much less for Area II.

In summary, for the non-mineralizing ions in the spring waters of the two areas, no order of magnitude differences are found. The greatest difference is in the median value of Ca ion which for Area I is five times the value in Area II. It is generally the most abundant ion in Area I, controls alkalinity (through HCO_3), specific conductance, and ionic strength. In Area II, Na competes more strongly with Ca and Mg ions for control of these parameters.

3. Mineralizing Elements

a. <u>Base Metals</u>: Median values, with ranges in parenthesis, are given below for nine base metals found in the spring waters for Areas I and II. Seven of these, Fe, Mn, Zn, Cu, Hg, Sb, and Pb, have primary mineral deposits in at least one of the areas. All, except Pb, Hg, and Sb, may be associated with Mn oxide minerals in Area I. Median values are given with ranges in parenthesis.

Base Metal Median (Range) Concentrations (ppb)

	Fe	Mn	Zn	Cu	Co
Area I	56(2-5220)	19(1-1220)	18(2-144)	4(1-85)	5(<2-31)
Area II	49(7-10082)	14(4-370)	9.5(2-48)	3(4-14)	11(2-39)
II/I (%)	87	74	53	75	220

	Ni	Hg	Sb*	Pb
Area I	9(2-39)	<0.1(<0.1-2.1)	<0.2(<0.2-0.3)	10(1-37)
Area II	20(2-54)	0.2(<0.1-1.2)	<0.5(<0.2-0.5)	30(<10-59)
II/I (%)	222	>200	--	300

*Based on a limited number of only 8 samples for Area II

For Fe, Mn, Zn and Cu, Area II Has a lower median and a lower range (except for Fe). For the other five metals the ranges are comparable for the two areas but with Area II having a higher median. Considering the differences in sample densities, 71 samples for Area I and 31 for Area II, and the analytical difficulty in these low ppb ranges, these differences are judged to be small. Manganese which is decidedly more abundant as manganese oxide minerals in Area I does have a much higher range in Area I, but only about a 25% greater median. Hg which has a definite mineralized area in Area II, but none in Area I has a higher median but lower range in Area II. Threshold values are decidedly greater for Fe, Mn, Zn, and Cu in Area I as shown in the following table.

Base Metals, Threshold Concentrations*(ppb)

	Fe	Mn	Zn	Cu	Co	Ni	Pb
Area I	5000	900	100	11	20	28	31
Area II	580	220	33	7	32	37	42
II/I (%)	12	24	33	64	160	132	135

*95% values on the high side of cumulative frequency curve, except Hg=1 ppb.

Hg and Sb are not included in the above table. They have too few finite analytical values for each area for a cumulative frequency treatment. Arbitrarily, we define the threshold value for Hg as 1 ppb. Sb will not be treated further in this discussion except to say that in spite of good definite Sb mineralization in Area II we have been unable by our chemical methods to detect any significant finite amounts of Sb in the spring waters of Area II.

The number of anomalous springs and their average anomalous concentrations are summarized in the following table for Area I and II.

Base Metals Average Anomalous Concentration (ppb)
(Number of Anomalous Springs in Parenthesis)

	Fe	Mn	Zn	Cu	Co	Ni	Hg	Pb
Area I	5222(2)	1220(1)	134(4)	34(4)	27(4)	36(4)	2.0(2)	35(2)
Area II	6399(4)	353(3)	46(2)	12(3)	38(2)	54(1)	1.1(3)	59(1)
II/I (%)	122	29	34	35	141	150	55	169

Area I has the higher anomalous values for Mn, Zn, and Cu. In summary, a higher metal content for Area I is indicated for Fe, Mn, Zn, and Cu when using median, threshold and average anomalous concentrations (except Fe) as criteria. Manganese which is well documented to have more mineralization in Area I gives the best indication of this in the threshold and average anomalous values, not the median value. Area II has a higher median for Hg but lower anomalous average.

We now examine specific springs for the correlation of their water chemistry with the local mineralization. Table III-1 lists by analysis the springs in Area I and II which are anomalous for that analysis. Table III-2 for Area I and III-3 for Area II lists the springs in order of sample number which have anomalous analyses. Those springs having anomalous base metal values are summarized in the following table along with any other anomalous measurements or analyses for that spring. The anomalous elements and their concentrations are listed.

Springs with Anomalous Base Metal Concentrations

Area I

ng No. r l (W)	Related Mineralization in Local Area of Spring*	Measurement (Value) for Which Spring Is Anomalous
1	A	Cu (85 ppb)
3	D	Cu (15 ppb), SiO_2 and subsurface temperature (63.2°C)
7	B	Mn (1220 ppb), Cu (21 ppb), Ni (29 ppb), PO_4 (0.54 ppm), SO_4 (12 ppm)
OW	A(Ba)	Pb (33 ppb), NH_3 (0.64 ppm), Li (23 ppb), Ba (420 ppb)
3	B	Cu (14 ppb), surface temperature (22°C)
8	D	Hg (21 ppb)
6	A	Zn (143 ppb)

sing Stroud, et al. (1969) and Miser (1917)
A =within1 mile of mineralization related to the anomalous metal concentration
B = " 2 " " " " " " " " "
C = " 4 " " " " " " " " "
D = over 4 miles from " " " " " " "

Spring No. or Well No.	Related Mineralization in Local Area of Spring*	Measurement (Value) for Which Spring Is Anomalous
537	B	Zn (110 ppb)
544	D	Hg (1.9 ppb)
900	A	Zn (137 ppb)
911	C	Zn (144 ppb), PO_4 (0.28 ppm), Sn (500 ppb)
916W	A	Fe (522 ppb), Co (23 ppb), Ni (39 ppb), Pb (37 ppb), SO_4 (13.1 ppm), subsurface temperature (91.2°C)
938	A	Co (22 ppb), Ni (36 ppb)
939	A	Co (30 ppb), NO_3 (4.8 ppm)
943	B	Co (31 ppb), Ni (39 ppb)
		Area II
904	D	Cu (14 ppb), Zn (48 ppb), pH (4.1 units), NO_3 (14.3 p Cl (9.5 ppm)
908	A	Fe (10082 ppb), Co (39 ppb)
909	A	Hg (1.1 ppb)
910	B	Hg (1.2 ppb), SiO_2 and subsurface temperature (62.9°C
919	D	Cu (13 ppb), surface temperature (21°C)
920	A	Cu (9 ppb), subsurface temperature (68.8°C)
924	A	Mn (345 ppb), surface temperature (25°C), SiO_2 and subsurface temperature (60.4°C)
928	A	Fe (4218 ppb), Mn (345 ppb), SiO_2 and subsurface tempe (75.8°C)
932	D	Fe (1375 ppb), Pb (59 ppb), SiO_2 and subsurface temper (73.4°C)
936	D	Mn (370 ppb), Co (38 ppb), Ni (54 ppb), SiO_2 and subs temperature (70.0°C)
937	D	Fe (9930 ppb), Li (86 ppb), pH (8.7 units), sp. cond. (563 μ mhos), alkalinity (265 mg/L $CaCO_3$)
948	D	Zn (45 ppb), pH (4.1 units), Cl (8.0 ppm)

Stroud, et al. (1969) has a comprehensive listing of the known mineral prospects and mines for Areas I and II and their locations by 1/16 sections. Table III-4 lists the 1/16 section locations for the springs sampled in this study. Using Table III-4 and Stroud, et. al. (1969) the anomalous springs in the above table will be checked for known mineralization in their local area.

For spring 511 located NE 1/4 SW 1/4 Sec. 14, T3S, R29W we quote from Stroud p. 329, "Fractures in Arkansas Novaculite in T3SRs28-30W, and T4S, R31W, contain stains and thin seams of malachite, azurite, chrysocolla, chalcopyrite, and native copper".

Although there is no known mineralization in spring 517's section, there is a phosphatic manganese deposit 3 1/2 miles due south.

520W is in a barite district. Pb mineralization in unknown locally, but is represented by several small mines 10 miles due north at Silver, Arkansas.

Spring 523 is not in an area of known Cu mineralization, However, a small galena mine, now abandoned, is 2 1/2 miles due west. Spring 528 is in a Mn district and within 1 mile of a hematite deposit (Pointed Rock Tunnel) and at least one Mn prospect (E. S. White) containing psilomelane. No Hg minerals are known in this area.

Spring 536 is in the same 1/16 section as an abandoned Mn mine (manganite and psilomelane minerals). No Zn mineralization is known in the local area, but manganese oxide minerals, particularly cryptomelane, can have 1 wt. % of Zn (Wagner, et al., 1979).

Spring 537 is not in an area of known Zn mineralization, but is only 1 1/2 miles northwest of spring 536. The comments on 536 would apply here as to a source of Zn in cryptomelane.

Spring 544 is within 1 1/2 miles of two known Mn oxide mineral deposits. One 1 1/2 miles to the west has produced several tons of ore. The deposit to the southwest is associated with limonite. No Hg minerals are known in the area.

Spring 900 is within a mile of an abandoned Pb, Zn, and copper mine and mill.

Spring 911 is not in an area with local Zn mineralization. However, manganese deposits with possible Zn are located 4 miles to the south.

Artisian well 916W is in a barite district. Manganese minerals occur with the barite at the McKnight Claim, 1 mile away. The Mn minerals contain appreciable Fe, Co, and Ni.

Spring 938 is located 1 mile southeast of the abandoned Featherstone Mn Mine (psilomelane and limonite). Co and Ni are known trace metals; up to 1 wt. % in many Mn minerals of the area (Wagner, et al., 1979).

Spring 939 is 1 mile northeast of a Mn prospect (U.S. prospect) which might contain Co. A similar Mn prospect is 1 1/2 miles to the southeast.

Spring 943 is in a barite district with no locally known Co or Ni mineralization. Mn ores which might contain Co and Ni are known 3 miles northeast and 3 miles northwest.

Spring 904 has no known minerals adjacent, but it is 2 1/2 miles north of the kimberlite at Murfreesboro. This deposit of peridotite has some barite veins associated with it, but no known Cu or Zn minerals.

Spring 908 is in a mercury district with ore minerals being cinnabar and associated minerals of Fe (pyrite and marcasite), Cu (sulfides) and As (arsenides). Co due to a similar chemistry to Fe would probably come from the Fe minerals.

Spring 909 is within 1/2 mile of a Hg mine (section 32 mine) which has produced over 600 flasks of Hg from cinnabar.

Spring 910 is 4 miles south and down dip of a Hg district.

Spring 920 is in a barite and mercury district. Copper sulfides are found with cinnabar ores.

Spring 924 is less than 1/4 mile from two Mn prospects (psilomelane, manganite and iron oxides).

Spring 928 is on the southeast edge of a titanium sands and clay district with ilmenite ($FeTiO_3$) the main ore minerals. The sands have a ferrogenous cement.

Springs 936 and 937 on the northern edge of a Hg district with cinnabar the main ore mineral and small amounts of Cu (sulfides), Fe (pyrite and marcasite) and As (arsenides). Mn minerals which could account for the Mn, Co, and Ni are 10 miles north. Sb minerals (stibnite) are included in some of the Hg deposits.

Spring 948 has no known mineral deposits nearby. Pb and Zn minerals (sphalerite) are known in a prospect 9 miles to the northwest. Sb minerals are known 7 miles to the northwest in an antimony district. Barite minerals are known 3 miles to the south as a cement in sand and gravel.

In summary, 41% of the springs with anomalous base metal concentrations were within 1 mile, 18% were within 2 miles, and 7% within 4 miles of known mineralization containing the anomalous elements. The remainder of the springs, 31%, had no known related mineralization within 10 miles.

b. Barium: Barite ($BaSO_4$) is prevalent in both Area I and Area II. The deposits differ in type. In Area I the barite ore is either replacement or open space fillings in Stanley Shales. Area II has this type plus two other types: 1) barite veinlets penetrate peridotite and intrusive breccia of Cretaceous igneous rocks, 2) barite veins, concretions, and cement in gravels and sandstone as a principal mineral. Area I contains several Mn oxide mineral deposits with psilomelane $(Ba, H_2O)_4Mn_{10}O_{20}$.

In the following table, medians, ranges, thresholds, and the average of the anomalous concentrations are summarized for Areas I and II.

Ba Concentrations (ppb) in Spring Waters of Areas I and II

	Median (Range)	Threshold	No. of Anomalous Values	Average Anomalous Concentrations
Area I	<15(1-420)	320	1	420
Area II	40(10-920)	320	2	915
II/I (%)	>267	100	-	218

Area II has a higher median, range, and average anomalous value than Area I. Both areas have few springs with anomalous concentrations considering the widespread mineralization of barite in each area. Both areas have similarly shaped cumulative frequency curves (Figure III-4) and the same threshold (95% value on the high side).

Barite is only very slightly soluble in pure water (2.6 ppm of $BaSO_4$ which is equivalent to 1.5 ppm of Ba^{++} and 1.1 ppm of SO_4 at 25^oC). The solubility product, defined as follows, is a constant.

$$M_{Ba^{++}} \times M_{SO_4^=} = \text{constant} = 1.24 \times 10^{-10} \text{(at saturation, } 25^oC)$$

where $M_{Ba^{++}}$ and $M_{SO_4^=}$ are gram moles/kg

A consequence of this relationship is that when $SO_4^=$ concentrations increase the saturation concentration of Ba^{++} decreases. For example, in a solution containing 11 ppm of $SO_4^=$ at 25^oC, the maximum or saturation concentration of Ba^{++} becomes 0.15 ppm.

In water containing other ions the solubility product becomes an activity product, defined as follows:

$$\begin{aligned} &a_{Ba^{++}} \times a_{SO_4^=} = \text{constant} \\ &a_{Ba^{++}} = \gamma_{Ba^{++}} \times M_{Ba^{++}} \\ &a_{SO_4^=} = \gamma_{SO_4^=} \times M_{SO_4^=} \end{aligned} \qquad (1)$$

$\gamma_{Ba^{++}}$ and $\gamma_{SO_4^=}$ are the activity coefficients respectively of barium ion and sulfate ion. The solubility of barite increases in the presence of other ions due to a decrease in the activity coefficient. The amount of other ions is measured by ionic strength. See Hem (1970) for a more complete discussion of the relationship.

In view of the dependence of Ba^{++} concentration on sulfate concentration, presence of other ions (ionic strength) and, of course temperature, high concentrations of Ba^{++} alone may not be a good relative indicator for barite among various localities. This would be particularly true if the solutions are near saturation and equilibrium is a limiting factor on solubility.

For the above reasons the % saturation of the various spring waters with $BaSO_4$ were calculated using the following relationship which considers the factors of sulfate concentration, ionic strength, and temperature.

$$\% \text{ saturation} = 100\ (a_{Ba^{++}} \times a_{SO_4^=})_T / (\text{solubility product of } BaSO_4)_T$$

where the subscript T indicates that activities and solubility products are for the same temperature. Activity coefficients were read graphically from page 21 of Hem (1970) using ionic strengths calculated from our analyses for the various ions. Substituting activity coefficients and the measured concentrations of Ba^{++} and $SO_4^=$ into equation (1) above gave the corresponding activities. The solubility products used as a function of temperature were taken from the literature and are shown geographically in Figure III-11.

The % $BaSO_4$ saturation at the water temperature at the surface and at the subsurface were calculated. Subsurface temperatures of the spring waters were calculated from silica solubilities as described in section II of this report. In the following table, the medians, ranges, thresholds, and average anomalous values for % $BaSO_4$ saturation for Areas I and II are summarized.

% $BaSO_4$ Saturation of Spring Waters for Area I and II

	Median (Range)		Threshold	No. Springs Anomalous	Average Anomalous %
	Surface T	Subsurface T	Surface T	Surface T	Surface T
I	2(0.16-96)	1.1(0.09-39)	70	2	91
II	8(0.40-97)	6.5(0.24-38)	84	2	94
(%)	400	591	120	100	103

Only finite values ("less than" values not used) were used in deriving the above table. This gave 31 data sets (out of 71 possible) for Area I and 27 sets (out of 31 possible) for Area II. The above analysis may be considered a cumulative frequency curve analysis of the highest population for Area I.

Area II has the greater % saturation median and threshold. This is possibly a consequence of the highly disseminated nature ($BaSO_4$ cement) of some of the Area II barite deposits whereas those in Area I are veinlets and less exposed to groundwater. The ranges, number of anomalous values and average anomalous values are about the same for the two areas.

It is interesting to note that many of the spring waters have X% or more of $BaSO_4$ saturation. Note in Table III-5 that springs are saturated with $SrSO_4$ to median saturation of only 0.00X%.

Figures III-12 and III-13 show a broadly defined correlation between the concentration of Ba and Ca in Areas I and II. Due to the similar chemistry of Ba and Ca and perhaps similar source rocks, this might be expected. Those few points which lie outside the envelopes of these data are considered to represent anomalous springs. The same goes for springs whose data plot outside the envelope of the Ba^{++}-Sr^{++} concentration data (Figure III-14) and Ba^{++} concentration vs specific conductivity data in Figure III-15.

Five definitions of anomalous springs have been given above. Using these five definitions, the anomalous springs are summarized below:

Sample No. of Springs with Anomalous Ba

	Definition of Anomalous	Area I	Area II
1.	Ba^{++} concentration exceeds threshold	520W	929, 944
2.	% $BaSO_4$ saturation exceeds threshold	916W, 943	927W, 932
3.	Ba^{++}-Ca^{++} concentration outside area norm	930	908, 929, 944
4.	Ba^{++}-Sr^{++} concentration outside area norm	902	908, 929, 944
5.	Ba^{++}-specific conductivity outside area norm	930	929, 944

520W is an artisian well in a barite district (Pigeon Roast Mountain). It is interesting to note that spring 519 in the same 1/16 section is not anomalous in Ba but has 110 ppb which is well above the mean of <15 for Area I.

916W is in the barite district of Fancy Hill. Although the % $BaSO_4$ saturation is anomalous the concentration is not. However, the 200 ppb concentration is well above the <15 ppb mean for the area.

Spring 943 is in the Pigeon Roost Mountain barite district and in the same 1/16 section as 520W. The Ba^{++} concentration of spring 943 while not anomalous is high, 190 ppb.

Spring 930 is in an area of no local mineralization. However, the Pike Gravels are present which 5 miles to the southwest have a barite cement in appreciable quantities. Three miles to the southeast of 930 there are barite veins in periodotite, the Murfreesboro kimberlite. Spring 930 has 60 ppb of Ba.

Spring 902 is in the same 1/16 section an an abandoned mine for Pb, Zn, and Cu. Galena, sphalerite, pyrite, chalcopyrite, silver and gold are the minerals in quartz veins along a fault. The nearest barite deposits are 7 miles east in the Pigeon Roost District.

Springs 929 and 944 are the same spring, sampled at different times, 3-4-79 (929) and 5-16-79 (944). This spring abuts an abandoned mine based on barite cement in Pike Gravels. Interestingly, the spring is anomalous based on 3 of the 4 definitions. Only the % saturations of 45.1 and 63.1 are not anomalous. Perhaps the threshold value (84%) is too high a criterion.

Artesian well 927W is not in an area of known Ba mineralization. The nearest barite deposits are 15 miles to the north. Titaniferous sands (ilmenite) are located 4 miles to the west of 927W. The Ba^{++} concentration of 927W is 80 ppb.

Spring 932 has no known barite deposits nearby. The nearest deposit is 8 miles east. The Ba^{++} concentration of this spring is high, 260 ppb, and almost to threshold (320 ppb).

Spring 908 is in a mercury district with no known barite deposits nearby. The nearest known deposits of barite are 10 miles northeast. Spring 907 which is 2 miles southwest of 908 (60 ppb Ba) had a reasonably high barium concentration of 270 ppb.

In summary, only definition (1) identified solely springs near or in barite deposits. Each of the other definitions selected springs in barite areas which were missed by definition (1). However, definitions (2), (3), and (4) also selected some springs not in known barite mineralization. All springs selected by each criteria had rather high concentrations of Ba and would have been selected by definition (1) with a smaller threshold value.

c. Strontium: Strontium mines and prospects are in the central part of Area II. Celestite ($SrSO_4$) is the main ore mineral with minor amounts of strontionite ($SrCO_3$). No strontium ores are known in Area I.

Median values, ranges, thresholds, and anomalous concentrations for springs of the two areas are summarized below.

Sr Concentrations (ppb) in Spring Waters of Areas I and II

	Median (Range)	Threshold	No. of Anomalous Values	Average Anomalous Concentration
Area I	55(2-2200)	380	5	987
Area II	30(<10-1400)	150	2	857
II/I (%)	55	39	40	87

All values are greater in Area I. This is not believed to be due to the small number of spring water samples from the strontium district in Area II. Four of the springs (933, 934, 935, 948) are within 2 miles of known Sr mineral deposits but four of the springs (904, 920, 929, 930) are only a few miles from the Sr district.

Strontium concentration in the spring waters increases as the calcium concentration increases as shown in Figure III-15. These two alkaline earths have similar chemistries and usually common source rocks. Thus, those concentrations outside the envelope of the data on the high side in Figure III-16 may be defined as anomalously high in Sr. Using this definition and the usual one of above threshold concentration gives the following springs which are anomalously high in Sr. We have not used % saturation of the waters with $SrSO_4$ as a criterion of anomalous springs because the waters are very unsaturated with $SrSO_4$ (see Table III-5), so much so that equilibrium saturation is not a barrier to dissolving. There is essentially no $CO_3^=$ in the spring waters.

Springs with Anomalously High Concentrations (ppb) of Sr

	Sample No. of Springs	
Anomalous Definition	Area I	Area II
1. Sr^{++} concentration exceeds threshold	501W, 526, 527, 911, 913	927W, 951W
2. Sr^{++}-Ca^{++} concentration outside area norm	526, 527, 913	920, 927W, 929, 944

Definition (1) includes two springs in Area I not selected by definition (2). The opposite is true in Area II.

Well 501W is not in an area of known Sr mineralization. Quartz crystal mines are within 1 mile.

Springs 526 and 527 are not in an area of Sr mineralization. A barite prospect in which Sr may be in secondary minerals, is about 1 mile away.

Spring 911 is not in an area of known Sr mineralization. About 4 miles south of spring 911 is a barite district.

Spring 913 is not in an area of known Sr mineralization. A barite district lies 6 miles south.

Spring 920 is not in an area of known Sr mineralization. A known barite deposit is less than 1 mile away. Known Sr deposits (celestite) are 6 miles to the southwest and gypsum deposits, in which Sr minerals occur to a minor extent, are 6 miles to the southeast.

Well 927 is not in an area of known Sr mineralization.

Spring 929 and 944 are the same spring sampled at different times. This spring is adjacent to a barite deposit.

The following are springs which did not have anomalous Sr concentration but are within 2 miles of known Sr mineralization: 933 (6 ppb), 934 (23 ppb), 935 (13 ppb), and 948 (92 ppb).

In summary, no spring with anomalously high Sr concentration was near known Sr mineralization. Rather, Sr acted as an indicator for barite in which Sr minerals occur. Figure III-14 notes a correlation of Ba with Sr.

d. Lithium and Potassium: Each of these metals exists in Area I as essential elements of two frequently encountered manganese oxide minerals -- lithiophorite ($Li_2Al_8Mn_{12}O_{35}.14H_2O$) and cryptomelane ($K_xMn_8O_{16}$) (see Wagner, et al., 1979). Other sources for these two elements are clays and igneous rocks.

Listed below are the median values, ranges, thresholds, and anomalous concentrations for Li in springs of Areas I and II.

Li Concentrations (ppb) in Spring Waters of Areas I and II

	Median (Range)	Threshold	No. of Anomalous Values	Average Anomalous Concentration
Area I	2.5(<1-70)	18	4	46
Area II	2.3(<1-86)	54	2	72
II/I (%)	92	300	50	156

The median values and ranges are essentially the same for Areas I and II. Threshold and average anomalous concentrations are higher for Area II. There is no indication of higher Li concentrations in Area I resulting from or favoring the formation of lithiophorite.

Springs which have anomalously high Li concentrations are listed below.

Springs With Anomalously High Li Content

ing No.	501W	520W	526	527	927W	937
Concentration (ppb)	21	23	70	70	58	86
Concentration (ppm)	48.4	6.5	131	152	80	162
Na Weight Ratio ($X10^3$)	0.43	3.5	0.53	0.46	0.72	0.53

Na Weight Ratio ($X10^3$) (Median for Area) 1.4 0.59

520W, 526, and 527 of the above waters are near (1-2 miles) Mn mineralization and barite. The others are not near Mn mineralization. A common denominator of the above waters is a high Na content. When judged as a Li/Na ratio these high Li waters are not so abnormal.

Listed below are the medians, ranges, thresholds, and average anomalous values for the K content of springs in Areas I and II.

K Concentration (ppm) in Spring Waters of Areas I and II

	Median (Range)	Threshold	No. of Anomalous Values	Average Anomalous Concentration
Area I	0.56(0.04-2.9)	1.35	3	2.0
Area II	1.10(0.21-8.5)	6.0	1	8.5
II/I (%)	196	444	33	425

Area II has greater values in all categories, except number of anomalous values. There are no indications of higher Area I values due to the occurences of cryptomelane in Area I.

The individual springs with anomalous K content are given below.

Springs With Anomalously High K Concentration

	Area I			Area II	
Spring No.	506	520W	922	948	904
K Concentration (ppm)	1.70	1.40	2.90	8.5	3.8

Spring 506 is within 1 mile of abandoned Mn mines. The Mn mineralization of this area contains cryptomelane. Slate deposits are also nearby. None of the other springs are in areas of Mn mineralization or have anomalous manganese concentrations.

4. Springs with Anomalous Temperatures

In Section II of this report the springs with anomalously high surface and subsurface temperatures were determined. Subsurface temperatures were determined based on the concentration of SiO_2. These springs are summarized below along with their anomalous concentrations of metal ions, if any, and local mineralization, if any.

ng No.	Anomalous Temperature	Metals With Anomalous Concentrations	Known Local Mineralization
503	Subsurface (60.4°C)	none	none
613	Subsurface (63.2°C)	Cu	none
623	Surface (22°C)	Cu	Pb, Zn mineralization in 2 miles
548	Surface (22°C)	none	Mn mineralization in 1-2 miles
907W	Subsurface (89.2°C)	none	Hg and Sb mineralization in 1-2 miles
910	Subsurface (62.9°C)	Hg	Hg mineralization in 1-2 miles
914	Subsurface (60.7°C)	none	none
915	Surface (35°C)	none	Mn mineralization in 1 mile
916W	Subsurface (91.2°C)	Fe,Co,Ni,Pb	Mn, Fe, Co, Ni, Bi mineralization in 1 mile
920	Subsurface (68.8°C)	Cu	Ba, Hg with minor Cu in 1 mile
921	Surface (30°C)	none	none
923W	Surface (22°C)	none	none
	Subsurface (82.9°C)	none	none
924	Surface (25°C)	Mn	Mn mineralization in 2 miles
	Subsurface (60.4°C)	Mn	Mn mineralization in 2 miles
927W	Subsurface (65.7°C)	Sr,Li	none
928	Subsurface (75.8°C)	Fe,Mn	ilminite sands in 1-2 miles

Spring No.	Anomalous Temperature	Metals With Anomalous Concentrations	Known Local Mineralization
932	Subsurface (73.4°C)	Fe,Pb	none, Hg district 5 miles aw
936	Subsurface (70.0°C)	Mn,Co,Ni	Hg mineralization in 1-2 mil
945	Surface (23°C)	none	Mn, Cu mineralization in 1-2
951W	Subsurface (78.3°C)	Sr	Sb mineralization in 1 mile
952	Surface (24°C)	none	Pb, Zn, Sb mineralization in

From the above table we find the following:

	% With Anomalous Concentration Of Some Metals	% With Local Mineralization	% With Anomalou Concentration Wi Local Mineralizat
Surface T Anomalous	25	75	100
Subsurface T Anomalous	71	57	60
All Other Springs, Areas I & II	31	--	54

*relevant minerals within 2 miles

Springs with anomalously high subsurface temperatures are: 1) more likely (71% frequency) to have an anomalous concentration of some metal than springs generally (31%) or springs with an anomalously high surface temperature (25%), 2) as likely (60% vs 54%) as other springs to indicate known, local mineralization by these anomalies. Thus overall springs with anomalously high silica content are more likely than other springs to indicate local mineralization.

5. Summary:

   a. A number of parameters and elemental concentrations for spring waters gave a lognormal distribution which were amenable to cumulative frequency curve analysis for median (50%), threshold (95% and anomalous (>95%) concentrations.

b. Threshold and anomalous concentrations of Mn, Zn, and Cu in the spring waters of Area I were greater than in Area II and reflected better than median or concentration ranges the more frequent mineralization of these metals in Area I. Hg concentrations in spring waters of the Hg-mineralized Area II had a higher median value and springs with anomalously high concentrations were near Hg mineralizations. However, in non-Hg-mineralized Area I the two springs with anomalously high Hg concentrations had no known Hg mineralization nearby.

c. Individual springs with an anomalous concentration of a base metal were in 41% of the cases within 1 mile, and 18% of the cases within 2 miles, of known mineralization of the anomalous element.

d. Spring waters of both Area I and Area II were commonly saturated to X% and above with $BaSO_4$ (barite) whereas the median $SrSO_4$ saturation was only 0.00X%.

e. Ba and Sr concentrations in the spring waters correlated with Ca concentration.

f. High Ba concentrations in spring waters were more reliable for detecting nearby barite mineralization than criteria based on: 1) % $BaSO_4$ saturation,
2) Ba/Ca concentration ratio above area norm,
3) Ba/Sr concentration ratio above area norm.

g. More Sr mineralization in Area II was not reflected in greater median or threshold concentrations of the area's spring waters. Springs within 2 miles of known Sr mineralization (celestite) did not have anomalously high concentrations of Sr. Anomalous Sr concentrations were an index of nearby barite mineralization, in which Sr minerals occur as minor constituents.

h. Concentrations of Li and K in Area I spring waters were not high and gave no indications of the frequently uncountered lithiophorite and cryptomelane of this area. Li tended to increase with Na in both Areas I and II.

i. Springs with anomalously high silica content have a high incidence of anomalous high metal concentrations and are more likely than other springs to indicate local mineralization.

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TABLES

Table 1-1
Summary of Analytical Methods

Anions

Measurement	Method	APHA (1971) Page
NO_3	Cd reduction	--
NH_3	Nessler	226
PO_4(ortho, dissolved)	Ascorbic acid	532
SO_4	Turbidimetric	334
SiO_2	Colorimetric	303,336
Cl	Mercuric nitrate	97
Alkalinity(total)	Titration to methy red end pt.	52

Table 1-1
Summary of Analytical Methods
(continued)

Cations

Element	Instrument*	Mode	Flame	Additive
Na	JA	emission	H_2 - N_2	none
K	"	"	"	"
Li	"	"	"	"
Ca	"	absorption	C_2H_2 - N_2O	NaCl
Mg	"	"	"	"
Sr	"	emission	"	"
Ba	"	concentration	"	KCl
Fe	"	absorption	C_2H_2 - Air	via chelation
Co	"	"	"	" "
Ni	"	"	"	" "
Cu	"	"	"	" "
Zn	PE	"	"	" "
Pb	PE	"	"	" "
Hg	PE	"	flameless	**
Sb	JA	hydride generation absorption	H_2 - N_2	***

* PE = Perkin Elmer Model 303 Atomic Absorption Spectrophotometer
JA = Jarrel Ash modernized Model 82-500 Atomic Absorption Spectrophotometer

** method of EPA(1974), p. 118

*** method of Fernandez (1973)

Table 1-2

Chemical Analyses of Ouachita Spring Waters

Anion Analyses and Miscellaneous Measurements

Name of Spring or Well(W)	Lab No.	Water T °C	pH units	Sp. Cond. µmhos per cm 25°C	Total Alkalinity mg/l as $CaCO_3$	NO_3 as N ppm	NH_3 as N ppm	PO_4 as P ppm	SO_4 ppm	Cl ppm	SiO_2 ppm
Iron (W)	501	15.0	7.4	252	291	2.28	0.11	0.03	0.3	0.3	7.7
Iron	502	5.0	6.5	14	2	<0.01	0.02	0.04	0.3	1.8	3.2
Black	503	15.0	7.5	324	10	<0.01	0.05	0.04	32.0	0.3	18.3
Collier	504	16.5	6.7	61	44	<0.01	<0.02	0.06	1.1	2.3	12.1
Caddo Valley	505	15.0	7.3	168	225	<0.01	<0.02	0.13	1.4	0.3	7.7
Crystal A	506	18.0	7.6	197	162	<0.01	0.42	0.08	1.1	0.3	12.1
Goat Brown	507	13.0	6.7	89	60	0.06	0.04	0.04	1.1	3.5	13.7
Bogg	508	13.0	7.2	372	130	0.06	0.02	0.05	2.3	0.5	7.7
Queen Wilhelmina S. Park	509	10.0	5.8	29	5	2.02	0.09	0.02	2.6	1.8	10.3
Queen Wilhelmina S. Park	510	9.0	6.4	66	2	2.68	0.13	0.05	0.6	3.8	6.6
Silver World	511	16.0	6.9	109	90	<0.03	0.06	0.03	4.7	1.5	10.2
Abernathy	512	16.0	7.0	144	70	0.37	0.09	0.12	2.0	1.0	8.9
Three Sisters	513	16.0	6.9	244	150	0.76	0.05	0.12	6.9	3.5	19.4
(No Name)	514	18.0	5.6	21	5	1.07	0.04	0.03	0.9	1.5	10.2
(No Name)	515	17.0	6.0	21	5	<0.02	<0.02	0.09	1.3	2.0	9.6
(No Name)	516	21.0	6.3	103	66	0.02	0.11	0.13	4.0	2.0	12.0
Wyatt	517	17.0	5.7	64	12	<0.02	0.25	0.54	12.0	2.5	12.0
(No Name)	518	15.0	5.8	18	5	0.65	0.12	<0.01	0.6	2.0	10.6
(No Name)	519	18.0	6.6	135	84	0.08	0.33	0.01	2.9	2.0	9.4
Pigeon Roost*(W)	520	17.0	7.2	208	160	0.02	0.64	0.03	2.6	1.8	13.5
Dripping	521	17.0	5.6	26	10	0.54	0.29	0.03	1.9	2.0	9.6
Strawn	522	18.0	7.3	228	125	0.05	0.38	0.03	4.0	2.3	9.5
(No Name)	523	22.0	3.8	37	0	-	0.09	0.04	<0.3	2.0	12.0
(No Name)	524	15.5	5.1	30	30	<0.02	0.44	<0.01	<0.3	3.0	15.5
(No Name)	525	15.0	6.1	48	25	0.15	0.05	0.05	3.0	2.0	9.7
Gillham A	526	17.0	7.5	383	170	0.37	0.54	0.06	0.3	86	16.8
Gillham B	527	17.5	7.6	385	230	0.04	0.47	0.11	<0.3	87	16.8
Bard	528	15.5	6.8	184	140	0.03	0.22	0.07	7.6	1.3	16.2
(No Name)	529	17.5	6.4	35	50	2.30	0.08	0.08	<0.3	1.5	9.2
(No Name)	530	15.0	6.8	42	12	--	0.08	0.05	3.0	1.5	9.2

Table 1-2 Con't

	No.	T°C	pH	Sp. Cond.	Alkalinity	NO_3	NH_3	PO_4	SO_4	Cl	SiO_2
McClaine A	531	17.5	6.9	175	90	--	0.09	0.14	4.8	2.0	10.1
McClaine B	532	18.0	6.4	80	50	2.30	0.08	0.08	3.4	2.3	9.7
McClaine C	533	17.5	7.3	230	90	0.05	0.09	0.05	4.8	2.5	10.1
McClaine D	534	15.5	5.5	27	10	--	0.15	0.05	2.0	1.8	7.0
W. Jones	535	16.0	6.4	41	20	--	0.11	0.03	0.3	1.3	7.6
Jones Valley	536	18.0	7.0	274	90	2.50	0.04	0.12	5.6	1.8	9.2
Buttermilk A	537	15.0	4.4	24	40	2.30	0.08	0.07	3.0	1.5	8.3
Buttermilk B	538	19.0	6.5	118	80	2.50	0.11	0.18	6.0	2.0	8.6
(No Name)	539	17.0	4.4	23	0	1.10	0.07	0.06	3.4	2.0	7.6
Mcellhanon	540	18.0	4.6	23	20	0.92	0.07	0.03	0.3	2.3	7.2
(No Name)	541	16.0	4.7	24	20	0.75	0.05	0.07	1.3	2.5	8.8
(No Name)	542	16.0	5.1	17	10	0.79	0.04	0.05	1.0	2.3	8.5
Crystal B	543	20.0	7.1	259	180	0.55	0.11	0.10	4.5	4.0	9.7
Brogdams A	544	18.0	7.3	274	160	--	0.06	0.07	2.3	3.0	10.1
Brogdams B	545	20.0	7.6	279	230	0.79	0.07	0.10	1.3	1.3	9.7
Brogdams C	546	21.0	7.3	234	130	0.92	0.04	0.13	5.6	2.5	10.1
Brogdams D	547	20.0	7.5	266	180	--	0.09	0.08	3.4	2.5	10.4
Brogdams E	548	22.0	7.0	263	60	1.70	0.17	0.02	4.1	2.0	10.4
Burrous	899	17.0	7.9	104	150	0.63	0.10	0.06	<0.3	2.7	10.8
Lead Mine Road A	900	18.0	6.2	34	100	0.87	0.13	0.06	0.3	1.8	9.3
Lead Mine Road B	901	18.0	6.9	131	112	0.19	0.21	0.04	1.4	1.8	9.1
(No Name)	902	20.0	6.4	28	50	0.67	0.16	0.08	0.7	3.8	10.5
(No Name)	903	18.0	6.3	108	70	0.76	0.14	0.10	1.0	2.5	11.6
(No Name)	904	18.0	4.1	108	0	14.3	0.10	0.13	3.6	9.5	8.7
Womack, W	905	20.0	6.2	303	125	1.35	0.13	0.20	2.8	4.5	9.9
Womack	906	20.0	4.3	55	10	1.62	0.05	0.30	1.7	4.5	5.4
Lolla Bell, W	907	19.0	6.2	196	67	0.31	0.19	0.11	5.9	2.8	37.1
(No Name)	908	18.0	7.1	57	25	1.20	1.39	0.04	2.1	2.3	11.9
(No Name)	909	19.0	7.2	17	5	0.68	0.21	0.08	2.8	3.0	13.2
(No Name)	910	18.0	5.8	57	2	0.83	0.47	0.20	12.6	5.0	19.3
(No Name)	911	16.0	5.4	183	175	1.19	0.47	0.28	5.1	2.3	11.6
(No Name)	912	16.5	5.8	135	70	1.07	0.38	0.21	4.0	1.5	9.3
Sulfur	913	17.0	4.1	267	135	0.68	1.08	0.25	1.4	3.5	14.0
Elliott	914	20.0	5.5	46	22	0.42	0.10	0.09	0.3	3.0	18.2
Caddo River	915	35.0	5.7	200	122	0.17	0.16	0.08	0.7	3.5	17.2
Artesian* Well(W)	916	18.0	5.8	97	40	0.11	0.20	0.24	7.6	3.0	34.9
Artesian* Well(W)	917	18.0	7.2	57	17	0.67	0.10	0.14	10.2	3.0	11.6
(No Name)	918	20.0	5.7	55	37	0.97	0.02	0.08	2.5	2.5	8.7
(No Name)	919	21.0	5.9	81	12	3.77	0.20	0.08	0.7	6.5	17.2

Table 1-2 Con't

	No.	T°C	pH	Sp. Cond.	Alkalinity	NO_3	NH_3	PO_4	SO_4	Cl	SiO_2
(No Name)	920	20.0	4.8	<5	5	0.77	0.21	0.03	0.3	5.0	22.9
(No Name)	921	30.0	6.4	227	130	3.26	0.10	0.12	3.2	2.5	10.5
Chalybeate	922	10.0	6.2	107	6	12.0	0.28	0.05	4.6	13.0	7.7
Caddo Gap (W)	923	22.0	7.4	138	100	0.98	0.23	0.15	5.0	2.5	31.9
Redland Mt.	924	25.0	7.2	210	144	3.86	0.22	0.08	9.7	1.5	18.5
Lolla Bell A	925	12.0	7.2	19	11	0.53	1.52	0.04	5.5	3.0	10.5
Lolla Bell B	926	12.0	7.0	19	9	0.53	1.52	0.04	6.8	1.5	10.0
Artesian Well (W)	927	18,5	7.6	373	186	10.50	1.02	0.34	29.5	3.5	21.3
Mineral	928	16.0	6.9	65	21	0.13	0.52	0.08	5.9	3.0	27.3
Barite Pit	929	10.0	5.0	20	1	0.53	1.31	0.02	0.51	2.5	10.5
Murfreesboro Area	930	11.0	5.1	19	1	1.02	1.52	0.03	4.1	3.0	7.2
Murfreesboro Area	931	11.0	5.0	15	2	0.83	0.36	0.09	8.7	0.8	4.8
Lake Greeson Area	932	13.0	6.8	112	58	0.38	0.23	0.14	5.5	4.8	25.6
Dierks Area	933	10.0	4.8	39	0	1.06	0.30	0.08	5.9	5.0	7.6
Cox Residence	934	12.0	4.7	63	0	1.36	0.29	0.06	5.5	4.0	7.4
Dierks Area	935	10.0	5.1	13	0	5.23	0.15	0.05	2.8	1.5	6.6
L. Greeson, Sulfur	936	11.0	6.8	109	56	--	0.50	0.18	4.1	3.5	23.5
L. Greeson, Possum	937	8.0	8.7	563	265	0.55	0.42	0.10	3.7	1.5	12.1
Salem Area	938	12.0	6.9	107	50	0.80	0.25	0.05	8.2	2.5	9.9
Bethesda	939	19.0	7.1	224	121	4.80	0.10	0.09	2.4	2.0	13.2
Mine Creek Area	940	16.0	5.9	248	170	0.20	0.00	0.13	2.9	2.5	9.2
Rock	941	17.0	6.5	299	176	1.24	0.05	0.09	4.3	3.0	13.2
West	942	15.0	5.3	36	24	1.24	0.10	0.06	1.3	1.5	7.9
Pigeon Roost	943	15.0	5.5	218	42	0.30	0.02	0.12	7.1	2.0	11.4
Barite Pit	944	18.5	4.6	23	12	0.08	0.06	0.10	1.0	3.0	10.8
"Warm"	945	23.0	7.1	116	73	5.50	0.00	0.15	2.6	2.5	11.1
Athens Area	946	16.0	5.8	18	24	1.91	0.04	0.23	2.6	2.8	13.6
Umpire Area	947	18.0	5.6	23	18	2.70	0.09	0.13	0.5	1.8	12.4
S. Cox	948	16.0	4.1	177	0	19.7	0.07	0.05	1.0	8.0	8.0
Cossatot	949	13.0	4.7	37	24	0.89	0.20	0.12	1.5	2.5	16.0
Church	950	18.0	4.7	205	18	4.70	0.14	0.10	2.6	5.0	12.4
Defore (W)	951	16.0	7.4	484	200	0.09	0.02	0.41	55.0	3.5	29.0
(No Name)	952	14.0	4.7	61	12	5.00	0.05	0.13	1.0	5.5	12.9
Mena Park	953	16.0	4.5	71	12	2.41	0.00	0.12	8.5	6.0	12.9
Median	-	16.5	6.2	85	37	0.9	0.15	0.08	3	2.9	11
EPA or APHA precision data		-	0.15	4	3.2	-	0.06	<0.01	0.3	-	≃2

* Cored, plastic piping

Table 1-3

Chemical Analyses of Ouachita Spring Waters
Alkali and Alkaline Earth Metals

Name of Spring or Well(W)	Lab No.	Na ppm	K ppm	Li ppb	Ca ppm	Mg ppm	Sr ppm	Ba ppm
Iron (W)	501	48.40	0.50	21.0	43.20	12.60	0.597	0.04
Iron	502	0.95	0.12	2.0	0.60	0.81	0.003	<0.01
Black	503	10.00	0.30	8.0	60.80	14.30	0.356	<0.01
Collier	504	2.00	1.25	3.0	8.30	1.95	0.020	0.02
Caddo Valley	505	1.10	0.21	2.0	40.00	1.31	0.140	<0.01
Crystal A	506	1.50	1.70	8.0	40.20	6.21	0.062	<0.01
Goat Brown	507	2.20	0.30	4.0	17.70	1.47	0.031	0.02
Bogg	508	2.80	0.34	3.0	41.50	1.89	0.063	<0.01
Queen Wilhelmina Park	509	2.00	0.42	1.0	1.52	0.93	0.014	<0.01
Queen Wilhelmina Park	510	2.40	0.48	1.0	1.47	1.11	0.011	0.02
Silver World	511	1.30	0.12	1.0	24.50	0.97	0.117	<0.01
Abernathy	512	1.10	0.31	2.0	32.70	1.12	0.138	<0.01
Three Sisters	513	3.10	0.80	7.0	41.20	6.33	0.089	<0.01
(No Name)	514	1.10	0.42	1.9	1.47	0.84	<0.002	<0.01
(No Name)	515	1.10	0.38	2.2	1.47	0.79	<0.002	<0.01
(No Name)	516	1.60	1.05	4.0	14.70	3.02	0.027	<0.01
Wyatt	517	1.20	0.78	3.7	4.25	1.08	<0.002	<0.01
(No Name)	518	1.50	0.23	1.0	0.73	0.62	0.004	<0.01
(No Name)	519	6.00	1.30	3.7	25.00	2.92	0.105	0.11
Pigeon Roost* (W)	520	6.50	1.40	23.0	37.70	3.18	0.317	0.42
Dripping	521	0.95	0.30	1.9	1.91	0.95	0.008	<0.01
Strawn	522	1.80	0.49	4.2	54.40	2.86	0.234	<0.01
(No Name)	523	2.60	0.45	1.9	1.06	0.83	0.012	0.02
(No Name)	524	4.30	1.05	1.9	4.64	1.50	0.015	0.01
(No Name)	525	1.50	0.37	2.2	9.53	1.04	0.033	<0.01
Gillham A	526	131	1.20	70.0	9.99	3.06	0.838	0.22
Gillham B	527	152	1.10	70.0	9.77	3.18	0.802	0.23
Bard	528	6.20	0.72	3.0	31.00	12.40	0.140	<0.01
(No Name)	529	1.50	0.44	1.6	4.05	1.22	0.012	<0.01
(No Name)	530	1.50	0.46	1.6	4.52	1.96	0.016	<0.01
McClaine A	531	2.10	0.80	4.6	44.20	2.73	0.131	0.01
McClaine B	532	1.80	0.58	2.6	17.30	1.56	0.072	0.01
McClaine C	533	2.10	0.75	4.6	50.80	2.95	0.160	<0.01
McClaine D	534	1.20	0.56	<1.0	3.13	0.76	0.018	0.02
W. Jones	535	1.10	0.37	<1.0	6.24	0.68	0.035	<0.01
Jones Valley	536	1.40	0.48	2.4	39.70	2.16	0.197	<0.01
Buttermilk A	537	1.30	0.29	<1.0	1.91	0.35	0.013	<0.01
Buttermilk B	538	1.50	0.40	1.9	35.60	1.22	0.168	<0.01
(No Name)	539	1.30	0.29	<1.0	1.46	0.32	0.010	<0.01
Mcellhanon	540	1.80	0.57	<1.0	2.37	0.46	0.014	<0.01
(No Name)	541	1.60	0.31	<1.0	1.09	0.46	0.003	<0.01
(No Name)	542	1.20	0.04	<1.0	0.033	0.15	0.002	<0.01
Crystal B	543	1.70	0.48	2.6	66.5	2.04	0.161	<0.02
Brogdams A	544	1.90	0.36	2.6	60.1	2.54	0.150	<0.01
Brogdams B	545	1.80	0.46	3.1	61.3	2.14	0.167	<0.02
Brogdams C	546	2.10	0.51	3.3	56.4	2.16	0.143	<0.02

Table 1-3 Con't

Name of Spring or Well(W)	Lab. No.	Na ppm	K ppm	Li ppb	Ca ppm	Mg ppm	Sr ppm	Ba ppm
Brogdams D	547	2.20	0.48	3.1	58.9	2.33	0.141	<0.02
Brogdams E	548	2.30	0.55	2.9	61.3	2.41	0.149	<0.02
Burrows	899	3.25	0.50	3.8	53.3	2.17	0.119	0.03
Lead Mine Road	900	1.31	0.24	<1.0	5.60	0.89	0.010	0.06
Lead Mine Road	901	1.75	0.37	1.9	35.90	6.16	0.089	0.01
(No Name)	902	1.80	0.24	2.2	2.36	1.08	0.003	0.04
(No Name)	903	1.70	0.24	2.2	25.40	1.21	0.045	0.01
(No Name)	904	10.00	3.80	1.9	4.97	3.05	0.057	0.18
Womack Well (W)	905	82.5	1.15	28.5	8.56	2.67	0.148	0.02
Womack	906	5.15	4.30	<1.0	2.36	1.15	0.018	0.07
Lolla Bell (W)	907	20.00	1.00	16.5	13.10	19.60	0.101	0.27
(No Name)	908	2.10	0.62	7.5	1.30	3.48	0.004	0.06
(No Name)	909	1.00	1.40	1.8	0.75	0.88	0.002	0.02
(No Name)	910	0.85	0.67	14.0	4.47	1.00	0.011	0.08
(No Name)	911	1.50	0.20	2.5	70.10	2.83	0.500	0.06
(No Name)	912	1.23	0.27	1.0	25.20	1.13	0.160	0.02
Sulfur	913	16.50	0.90	17.3	27.54	14.92	2.200	0.07
Elliott	914	1.55	0.24	4.0	1.37	1.91	0.015	0.02
Caddo River	915	5.40	1.00	11.5	42.05	2.45	0.051	0.03
Artesian*Well (W)	916	2.00	0.95	10.0	7.30	2.52	0.044	0.20
Artesian* Well (W)	917	1.13	1.05	8.2	4.18	1.91	0.035	0.08
(No Name)	918	1.65	0.27	2.1	6.83	1.61	0.032	0.08
(No Name)	919	7.60	2.80	4.3	4.18	2.90	0.048	0.08
(No Name)	920	1.23	0.46	2.1	0.60	0.74	0.070	0.02
(No Name)	921	3.83	1.10	4.6	50.41	2.38	0.100	<0.01
Chalybeate	922	10.00	2.90	2.1	6.68	7.75	0.080	0.15
Caddo Gap (W)	923	13.00	0.65	12.5	18.30	2.80	0.088	0.10
Redland Mt.	924	2.50	0.95	7.0	53.35	23.70	0.071	0.02
Lolla Bell A	925	2.00	0.70	2.0	1.54	0.96	0.016	0.02
Lolla Bell B	926	2.50	0.38	2.0	0.91	1.15	0.011	0.03
Artesian Well (W)	927	80.00	5.20	58.0	26.68	4.31	1.44	0.08
Mineral	928	4.60	3.90	20.0	2.66	1.40	0.049	0.01
Barite Pit	929	2.40	0.21	2.1	0.91	0.30	0.032	0.91
Murfreesboro Area	930	1.60	0.38	1.0	1.22	0.61	0.013	0.06
Murfreesboro Area	931	0.90	0.49	1.6	0.91	0.64	0.007	0.02
Lake Greeson Area	932	10.50	1.41	26.0	8.60	4.55	0.042	0.26
Dierks Area	933	3.20	2.11	1.0	1.07	0.77	0.006	0.03
Cox Residence	934	2.60	1.75	1.0	4.51	1.86	0.023	0.03
Dierks Area	935	1.25	0.45	1.6	0.91	0.58	0.013	0.03
Lake Greeson, Sulfur	936	11.00	2.60	17.5	5.57	3.92	0.041	0.15
Lake Greeson Possum	937	162.5	0.48	86.0	1.22	0.19	0.030	0.03
Salem Area	938	1.90	0.80	2.1	20.74	1.40	0.018	0.04
Bathesda	939	2.85	0.80	4.0	46.36	6.44	0.080	<0.02
Mine Creek Area	940	1.24	0.46	2.6	58.90	1.70	0.320	<0.02
Rock	941	3.15	0.42	3.3	65.66	5.68	0.105	<0.02
West	942	0.93	0.49	<1.0	5.66	0.76	0.020	0.02
Pigeon Roost	943	2.00	0.70	8.2	12.64	2.35	0.068	0.19
Barite Pit	944	1.40	0.30	2.0	0.39	0.34	0.020	0.93
"Warm"	945	1.70	0.73	2.2	19.52	2.66	0.033	<0.02
Athens Area	946	2.85	0.78	2.0	0.78	0.47	0.010	0.02

Table 1-3 Con't

Name of Spring or Well(W)	Lab No.	Na ppm	K ppm	Li ppb	Ca ppm	Mg ppm	Sr ppm	Ba ppm
Umpire Area	947	2.70	0.62	1.6	1.37	0.64	0.010	<0.02
S. Cox	948	6.80	8.50	4.6	9.45	3.45	0.092	0.26
Cossatot	949	5.00	0.95	2.0	2.73	0.64	0.033	<0.02
Church	950	6.25	1.20	2.0	2.82	1.47	0.026	<0.02
Defore Well (W)	951	21.50	1.25	45.0	78.39	9.37	0.275	0.02
(No Name	952	6.50	1.30	2.6	2.62	1.93	0.020	0.03
Mena Park	953	6.70	0.78	2.6	3.68	1.88	0.020	<0.02

* Cored, plastic piping

Table 1-4

Chemical Analyses of Ouachita Spring Waters for Heavy Metals (all data in parts per billion)

e of Spring or Well(W)	Lab No.	Fe	Mn	Zn	Cu	Co	Ni	Pb	Hg	Sb
n (W)	501	4	20	1,480	14	<3	<3	<10	<0.1	<0.2
h	502	275	12	17	5	<3	<3	<10	<0.1	<0.2
ck	503	36	195	18	1	8	<3	<10	<0.1	<0.2
lier	504	<2	<5	6	1	<3	<3	<10	<0.1	0.2
do Valley	505	97	25	31	1	<3	<3	<10	<0.1	0.2
stal A	506	<2	<5	<2	1	<3	<3	<10	<0.1	0.2
t Brown	507	7	<5	25	7	<3	<3	<10	<0.1	0.3
g	508	22	10	2	3	<3	<3	<10	<0.1	0.25
en Wilhelmina S. Park	509	29	6	9	7	<3	<3	<10	<0.1	0.12
en Wilhelmina S. Park	510	85	8	17	6	<3	<3	<10	<0.1	0.12
ver World	511	472	35	26	85	8	8	18	<0.1	<0.2
rnathy	512	165	30	26	5	8	<3	<10	<0.1	0.2
ee Sisters	513	210	18	24	15	<3	3	<10	0.1	<0.2
Name)	514	6	17	17	8	<3	<3	<10	<0.1	<0.2
Name)	515	3	29	17	8	<3	<3	18	<0.1	<0.2
Name)	516	663	316	32	5	13	12	18	<0.1	<0.2
att	517	3620	1220	69	21	20	29	29	<0.1	0.2
Name)	518	43	25	16	9	<3	<3	13	<0.1	<0.2
Name)	519	3	5	5	5	<3	<3	10	<0.1	<0.2
geon Roost*(W)	520	323	272	10	3	13	8	33	0.72	<0.2
ipping	521	7	14	20	7	<3	<3	13	<0.1	<0.2
rawn	522	880	206	9	7	11	8	18	<0.1	<0.2
o Name)	523	15	4	10	14	<3	2	<5	<0.1	<0.2
o Name)	524	4632	664	15	4	19	17	8	0.2	<0.2
o Name)	525	47	24	14	3	3	7	<5	<0.1	<0.2
lham A	526	11	15	2	1	2	4	<5	0.47	<0.2
lham B	527	6	15	3	3	2	4	<5	0.30	<0.2
rd	528	3151	469	5	2	12	9	<5	2.10	<0.2
o Name)	529	27	20	11	6	7	4	<5	<0.1	<0.2
o Name)	530	11	2	20	2	2	4	<5	<0.1	<0.2
Claine A	531	1974	448	28	7	7	18	15	<0.1	<0.2
Claine B	532	135	9	26	8	2	9	<5	<0.1	<0.2
Claine C	533	1495	405	22	9	7	18	18	<0.1	<0.2
Claine D	534	198	62	23	5	8	10	<5	<0.1	<0.2
Jones	535	51	6	10	6	4	10	<5	<0.1	<0.2
es Valley	536	739	278	143	2	7	21	<5	<0.1	<0.2
ttermilk A	537	496	9	110	4	6	21	<5	<0.1	<0.2
ttermilk B	538	804	65	43	1	4	18	<5	<0.1	<0.2
o Name)	539	68	7	66	8	<2	12	<5	<0.1	<0.2
ellhanon	540	17	3	46	4	<2	9	11	0.16	<0.2
o Name)	541	19	9	49	6	<2	11	<5	<0.1	<0.2
o Name)	542	19	6	37	6	<2	9	<5	0.18	<0.2
ystal B	543	699	210	39	6	2	17	<5	0.1	<0.2
ogdams A	544	503	189	45	4	<2	15	5	1.86	<0.2
ogdams B	545	643	205	28	4	<2	15	10	<0.1	<0.2
ogdams C	546	760	210	27	4	5	17	7	0.29	<0.2

Table 1-4 Con't

Name of Spring or Well(W)	Lab No.	Fe	Mn	Zn	Cu	Co	Ni	Pb	Hg	Sb
Brogdams D	547	699	221	32	2	4	17	< 5	<0.1	<0.2
Brogdams E	548	661	296	13	2	6	16	10	<0.1	<0.2
Burrows	899	10	5	92	9	<3	8	11	0.72	<0.5
Lead Mine Road	900	33	5	137	4	2	4	<7	<0.1	<0.5
Lead Mine Road	901	2236	701	27	2	15	17	30	<0.1	<0.5
(No Name)	902	39	19	21	2	7	12	11	<0.1	<0.5
(No Name)	903	41	10	12	1	10	15	15	<0.1	<0.5
(No Name)	904	25	89	48	14	20	25	34	0.59	<0.5
Womack (W)	905	7	6	<5	1	10	15	23	0.51	<0.5
Womack	906	23	25	6	2	18	30	33	<0.1	<0.5
Lolla Bell (W)	907	2062	344	21	2	15	32	37	0.63	<0.5
(No Name)	908	10082	6	7	2	39	80	42	2.27	<0.5
(No Name)	909	146	23	6	4	4	7	17	1.48	<0.5
(No Name)	910	149	83	20	4	18	21	21	<0.1	<0.5
(No Name)	911	195	31	144	1	10	19	13	0.68	<0.5
(No Name)	912	5	1	<5	2	5	8	17	0.75	<0.5
Sulfur	913	31	7	<5	1	5	10	10	0.29	<0.2
Elliott	914	1347	32	5	4	13	17	14	0.76	<0.2
Caddo River	915	80	7	<5	4	8	12	18	0.28	<0.2
Artesian* Well(W)	916	5222	631	65	2	23	39	37	0.78	0.2
Artesian* Well(W)	917	1642	351	21	2	18	28	25	0.26	<0.2
(No Name)	918	49	10	<5	2	6	8	7	0.32	<0.2
(No Name)	919	49	42	<5	13	10	17	17	0.20	<0.5
(No Name)	920	15	22	<5	9	8	12	12	0.32	0.5
(No Name)	921	10	4	<5	3	5	10	12	1.02	<0.5
Chalybeate	922	43	77	19	10	7	20	21	0.65	-
Caddo Gap (W)	923	580	436	38	<1	11	17	21	0.75	-
Redland Mt.	924	226	345	9	<1	22	24	30	<0.2	-
Lolla Bell A	925	15	5	4	3	4	2	30	0.22	-
Lolla Bell B	926	43	10	16	5	15	32	42	0.44	-
Artesian Well (W)	927	85	86	29	3	15	24	46	0.87	-
Mineral	928	4218	345	16	3	11	21	30	0.65	-
Barite Pit	929	129	13	10	5	7	9	30	0.65	-
Murfreesboro Area	930	15	16	9	5	7	13	17	0.90	-
Murfreesboro Area	931	29	5	5	<1	7	9	34	0.65	-
Lake Greeson Area	932	1375	70	5	<1	15	28	59	<0.2	-
Dierks Area	933	175	14	16	5	11	17	34	<0.2	-
Cox Residence	934	43	16	24	<1	11	24	25	0.22	-
Dierks Area	935	29	10	10	3	11	24	25	0.65	-
L. Greeson, Sulfur	936	9930	370	11	<1	38	54	34	0.65	-
L. Greeson, Possum	937	57	8	8	5	15	20	25	1.10	-
Salem Area	938	287	24	16	3	22	36	30	0.65	-
Bethesda	939	301	743	11	2	30	28	24	0.22	-
Mine Creek	940	60	22	12	2	6	7	9	0.22	-
Rock	941	2	2	4	5	2	3	<5	<0.2	-
West	942	10	3	6	2	2	3	20	<0.2	-
Pigeon Roost	943	3306	800	28	3	31	39	29	0.30	-
Barite Pit	944	100	12	10	2	6	7	13	0.45	-
"Warm"	945	5	8	6	2	6	7	9	<0.2	-
Athens Area	946	13	6	4	2	2	7	18	<0.2	-

Table 1-4 Con't

Name of Spring or Well(W)	Lab No.	Fe	Mn	Zn	Cu	Co	Ni	Pb	Hg	Sb
Umpire Area	947	27	5	6	4	8	7	11	0.2	-
S. Cox	948	20	110	45	7	25	33	31	<0.2	-
Cossatot	949	17	4	6	2	11	7	13	<0.2	<0.5
Church	950	43	11	7	4	11	2	31	<0.2	<0.5
Defore (W)	951	48	283	111	3	34	33	33	<0.2	<0.5
(No Name)	952	18	14	13	2	11	5	22	<0.2	<0.5
Mena Park	953	10	11	8	2	9	7	13	<0.2	-

* Cored, plastic piping

Table 1-5

Median Values (and Ranges) of Various Measurements And Analyses for Areas I and II

Miscellaneous Measurements

	Water T_1^{o}C Surface	Water T^{o}C Subsurface*	pH Units	Specific Cond. µmhos per cm 25^{o}C	Total Alkalinity mg/l as $CaCO_3$
Area I	17(5-35)	40.0(7.1-91.2)	6.4(3.8-7.9)	107(14-385)	60(0-291)
Area II	16(8-25)	45.9(11.2-89.2)	5.8(4.1-8.7)	61(<5-563)	15(0-265)
(II/I)100 (%)	94	115	91	57	25

Anion Concentrations (ppm)

	NO_3 as N	NH_3 as N	PO_4 as P	SO_4	Cl	SiO_2
Area I	0.66(<0.01-5.5)	0.1(<0.01-1.52)	0.07(<0.01-0.54)	2.3(<0.3-32)	2.3(0.25-87)	10.3(3.2-34.9)
Area II	1.0(0.06-14.3)	0.20(0.02-152)	0.10(0.02-0.41)	3.2(0.3-55)	3.5(0.5-9.5)	12.1(3.8-37.1)
(II/I)100 (%)	152	200	143	139	152	117

*calculated from SiO_2 ranges

Table 1-5 (con't)

Alkali Metals Concentrations

	Na(ppm)	K(ppm)	Li(ppb)
Area I	1.8(0.95-152)	0.56(0.04-2.9)	2.5(<1-70)
Area II	3.9(0.85-162)	1.10(0.21-8.5)	2.3(<1-86)
(II/I)100 (%)	217	196	92

Alkaline Earth Metals Concentrations

	Ca(ppm)	Mg(ppm)	Sr(ppm)	Ba(ppm)
Area I	13.5(0.03-70)	1.9(0.15-14.9)	0.055(0.002-2.2)	<0.015(0.001-0.42)
Area II	2.7(0.6-78)	1.40(0.19-23.7)	0.03(<0.01-1.4)	0.04(0.01-0.92)
(II/I)100 (%)	20	74	55	>267

Base Metal Concentrations (ppb)

	Fe	Mn	Zn	Cu	Co	Ni	Pb
Area I	56(2-5220)	19(1-1220)	18(2-144)	4.0(1-85)	5(<2-31)	9(2-39)	10(1-37)
Area II	49(7-10082)	14(4-370)	9.5(2-48)	3.0(<1-14)	11(2-39)	20(2-54)	30(<10-59)
(II/I)100 (%)	87	74	53	75	220	222	300

Table 1-5 (con't)

Mercury and Antimony Concentrations (ppb)

	Hg	Sb*
Area I	<0.1(<0.1-2.1)	<0.2(<0.2-0.3)
Area II	0.2(<0.1-1.2)	<0.5(<0.2-0.5)
(II/I)100 (%)	>200	-

*limited number of samples

% Saturation

	% $BaSO_4$ Saturation		% $SrSO_4$ Saturation	
	Surface Temp.	Subsurface Temp.	Surface Temp.	Subsurface Temp.
Area I	2.0(0.16-96)	1.1(0.09-39)	0.0065(<0.0001-0.504)	0.01(0.0001-0.867)
Area II	8.0(0.46-97)	6.5(0.24-38)	0.0048(0.0004-1.97)	0.007(0.0005-3.38)
(II/I)100 (%)	400	591	44	70

Table I-1

Comparison of Ouachita Mountain Spring Water Ranges And Median Values with Limits for Drinking Water And with Ranges and Median Values for Wells from the Ouachita Mountains (Well Data from Albin and Stephens (1963))

	Limits	Springs Range	Springs Median	Wells Range
Temperature, ^oC	-	5-35	16.5	13.8-22.2
pH	6.5-9.2^{b*}	3.8-7.9	6.2	5.0-8.6
Specific cond. μ mhos/cm 25^oC	-	<5-563	85	34-1080
Total Alkalinity mg/l as $CaCO_3$	-	0-291	37	2-378
NO_3 as N ppm	10**	<0.01-14.3	0.9	0-68
NH_3 as N ppm	0.5^a	<0.01-1.52	0.15	-
PO_4 as P ppm	-	<0.01-0.54	0.08	-
SO_4 ppm	400^b	<0.3-32	3	0-221
Cl ppm	600^{b*}	0.25-87	2.9	2-288
SiO_2 ppm	-	3.2-31.9	11	5.1-25.0
Na ppm	-	0.85-162	2.85	1.6-167.0
K ppm	-	0.04-8.5	0.83	0.3-22.0
Li ppb	-	<1-86	2.4	-
Ca ppm	200^{b*}	0.03-78	16.2	1-131
Mg ppm	150^b	0.15-23.7	1.65	0.5-40.0
Sr ppm	-	<0.01-2.2	0.04	-
Ba ppm	1^a	0.001-0.92	0.024	-
Fe ppb	300^{a*}	2-10,082	53	-
Mn ppb	50^{a*}	1-1220	17	-
Zn ppb	15,000^{b*}	2-144	14	-
Cu ppb	1,000^{a*}	<1-85	4	-
Co ppb	-	<2-39	8	-
Ni ppb	-	2-54	15	-
Pb ppb	50^a	1-59	20	-
Hg ppb	2^a	<0.1-2.1	0.1	-
Sb ppb	-	<0.2-0.5	<0.3	-

* limit based solely on welfare
** EPA, 1976

[a] PHS, 1962
[b] WHO, 1971

Table I-2
Data on Sulfate and Carbonate Minerals of Ca, Sr and Ba

Mineral	Chemical Formula	Solubility Product (mo6)^2/l^2 at 25^{o}C	Reference
gypsum	$CaSO_4.2H_2O$	$1.49x10^{-4}=K_1$	Posnjak (1938)
celestite	$SrSO_4$	$1.37x10^{-7}=K_2$	Figure III-11
barite	$BaSO_4$	$1.25x10^{-10}=K_3$	Figure III-11
calcite	$CaCO_3$	$4.57x10^{-9}=K_4$	Garrels & Christ (1965)
strontianite	$SrCO_3$	$4.8x10^{-10}=K_5$	Helz & Holland (1965)
witherite	$BaCO_3$	$2.0x10^{-9}=K_6$	Garrels et al. (1960)

Equilibrium Equation for Two Solids	Equilibrium Activity Ratio (Moles/Mole)
$SrSO_4(C) + Ca^{++} + 2H_2O = CaSO_4.2H_2O(c) + Sr^{++}$	$a_{Sr^{++}}/a_{Ca^{++}} = K_2/K_1 = 0.92 \times 10^{-3}$
$BaSO_4(C) + Ca^{++} + 2H_2O = CaSO_4.2H_2O(c) + Ba^{++}$	$a_{Ba^{++}}/a_{Ca^{++}} = K_3/K_1 = 0.84 \times 10^{-6}$
$BaSO_4(C) + Sr^{++} = SrSO_4(c) + Ba^{++}$	$a_{Ba^{++}}/a_{Sr^{++}} = K_3/K_2 = 0.91 \times 10^{-3}$
$SrCO_3(C) + Ca^{++} = CaCO_3(c) + Sr^{++}$	$a_{Sr^{++}}/a_{Ca^{++}} = K_5/K_4 = 0.10$
$BaCO_3(C) + Ca^{++} = CaCO_3(c) + Ba^{++}$	$a_{Ba^{++}}/a_{Ca^{++}} = K_6/K_4 = 0.44$
$BaCO_3(C) + Sr^{++} = SrCO_3(c) + Ba^{++}$	$a_{Ba^{++}}/a_{Sr^{++}} = K_6/K_5 = 4.2$

Minerals in Equilibrium	Ionic Activity Ratio	Median Values Found For Activity Ratios*		Equilibrium Values* Activity Ratios
		Area I	Area II	
celestite=gypsum	$a_{Sr^{++}}/a_{Ca^{++}}$	$4.1x10^{-3}$	$11x10^{-3}$	$2.0x10^{-3}$
barite=gypsum	$a_{Ba^{++}}/a_{Ca^{++}}$	$1100x10^{-6}$	$15000x10^{-6}$	$2.9x10^{-6}$
barite=celestite	$a_{Ba^{++}}/a_{Sr^{++}}$	<0.27	1.3	$1.4x10^{-6}$
strontianite=calcite	$a_{Sr^{++}}/a_{Ca^{++}}$	0.0041	0.011	0.22
witherite=calcite	$a_{Ba^{++}}/a_{Ca^{++}}$	<0.0011	0.015	1.5
witherite=strontianite	$a_{Ba^{++}}/a_{Sr^{++}}$	<0.27	1.3	6.6

*units are ppm/ppm

Table II-1

Surface Temperature, Subsurface Temperature, Heat Flow and Geothermal Gradient

Sample #	Surface Temperature °C	SiO_2 ppm	Subsurface Temperature °C	Heat Flow w/m^2	Geothermal Gradient °C/km
501	15.0	7.7	31.7	27.6	17.5
502	5.0	3.2	7.1	-9.1	-5.8
503	15.0	18.3	60.9	70.6	44.9
504	16.5	12.2	46.1	49.2	31.3
505	15.0	7.7	31.7	27.6	17.5
506	18.0	12.2	46.1	49.2	31.3
507	13.0	13.7	50.2	55.2	35.1
508	13.0	7.7	31.7	27.6	17.5
509	10.0	10.3	40.6	40.8	26.0
510	9.0	6.6	26.7	20.2	12.8
511	16.0	10.2	40.3	40.4	25.7
512	16.0	8.9	36.0	34.1	21.7
513	16.0	19.4	63.2	74.0	47.1
514	18.0	10.2	40.3	40.4	25.7
515	17.0	9.6	38.5	37.8	24.0
516	21.0	12.0	45.6	48.4	30.8
517	17.0	12.0	45.6	48.4	30.8
518	15.0	10.6	41.7	42.5	27.0
519	18.0	9.5	37.9	36.9	23.5
520	17.0	13.5	49.7	54.5	34.7
521	17.0	9.6	38.5	37.8	24.0
522	18.0	9.5	37.9	36.9	23.5
523	22.0	12.0	45.6	48.4	30.8
524	15.5	15.5	54.5	61.6	39.2
525	15.0	9.7	38.8	38.2	24.3
526	17.0	16.8	57.5	66.1	42.1
527	17.5	16.8	57.5	66.1	42.1
528	15.5	16.2	56.1	64.1	40.7
529	17.5	9.2	37.0	35.5	22.6

Table II-1 (con't)

Sample #	Surface Temperature °C	SiO_2 ppm	Subsurface Temperature °C	Heat Flow w/m^2	Geothermal Gradient °C/km
530	15.0	9.2	37.0	35.5	22.6
531	17.5	10.1	40.0	40.0	25.4
532	18.0	9.7	38.8	38.2	24.3
533	17.5	10.1	40.0	40.0	25.4
534	15.5	7.0	28.7	23.1	14.7
535	16.0	7.5	30.8	26.3	16.7
536	18.0	9.2	37.0	35.5	22.6
537	15.0	8.3	33.8	30.7	19.5
538	19.0	8.5	34.6	32.0	20.4
539	17.0	7.5	30.8	26.3	16.7
540	18.0	7.2	29.6	24.5	15.6
541	16.0	8.8	35.8	33.7	21.4
542	16.0	8.5	34.6	32.0	20.4
543	20.0	9.7	38.8	38.2	24.3
544	18.0	10.1	40.0	40.0	25.4
545	20.0	9.7	38.8	38.2	24.3
546	21.0	10.1	40.0	40.0	25.4
547	20.0	10.4	41.1	41.7	26.5
548	22.0	10.4	41.1	41.7	26.5
899	17.0	10.8	42.2	43.3	27.6
900	18.0	9.3	37.3	36.0	22.9
901	18.0	9.1	36.7	35.0	22.3
902	20.0	10.5	41.4	42.1	26.8
903	18.0	11.6	44.6	46.9	29.8
904	18.0	8.7	35.4	33.1	21.1
905	20.0	9.9	39.4	39.1	24.9
906	20.0	5.4	21.0	11.7	7.4
907W	19.0	37.1	89.2	112.6	71.7
908	18.0	11.9	45.3	47.9	36.8
909	19.0	13.2	49.0	53.5	34.0
910	18.0	19.3	62.9	73.5	46.7

Table II-1 (con't)

Sample #	Surface Temperature ^{o}C	SiO_2 ppm	Subsurface Temperature ^{o}C	Heat Flow w/m^2	Geothermal Gradient $^{o}C/km$
911	16.0	11.6	44.6	46.9	29.8
912	16.5	9.3	37.3	36.0	22.9
913	17.0	14.0	50.9	56.2	35.8
914	20.0	18.2	60.7	70.3	44.7
915	35.0	17.2	58.3	67.3	42.8
916W	18.0	34.9	91.2	116.4	89.5
917	18.0	11.6	44.6	46.9	29.8
918	20.0	8.7	35.4	33.1	21.1
919	21.0	17.3	58.4	67.5	43.0
920	20.0	22.9	68.8	83.0	63.8
921	30.0	10.5	41.4	42.1	26.8
922	10.0	7.8	31.8	27.8	17.7
923W	22.0	32.0	82.9	103.3	65.7
924	25.0	18.5	60.4	71.3	45.3
925	12.0	10.5	41.3	41.9	26.7
926	12.0	9.9	39.5	39.3	31.1
927W	18.5	21.0	65.7	78.3	49.8
928	16.0	27.2	75.8	93.4	59.4
929	10.0	10.5	41.3	41.9	26.7
930	11.0	7.2	29.3	24.0	15.3
931	11.0	4.8	17.4	6.3	4.0
932	13.0	25.7	73.4	89.9	57.2
933	10.0	7.6	31.0	26.5	16.9
934	12.0	7.4	30.1	25.2	16.0
935	10.0	6.6	26.8	20.3	12.9
936	11.0	23.5	70.0	84.8	53.9
937	8.0	12.1	46.0	48.9	31.1
938	12.0	9.9	39.5	39.3	25.0
939	19.0	13.2	49.0	53.4	34.0
940	16.0	9.2	37.0	35.4	22.5
941	17.0	13.2	49.0	53.4	34.0
942	15.0	7.8	31.8	27.8	17.7

Table II-1 (con't)

Sample #	Surface Temperature °C	SiO_2 ppm	Subsurface Temperature °C	Heat Flow w/m^2	Geothermal Gradient °C/km
943	15.0	11.4	44.1	46.1	29.3
944	18.5	10.8	42.2	43.3	27.6
945	23.0	11.1	43.1	44.7	28.4
946	16.0	13.6	50.0	55.0	35.0
947	18.0	12.5	47.0	50.4	32.1
948	16.0	8.0	32.7	29.1	18.5
949	13.0	16.0	55.6	63.3	40.3
950	18.0	12.5	47.0	50.4	32.1
951W	16.0	29.0	78.3	97.2	61.8
952	14.0	12.8	48.0	51.9	33.0
953	12.8	12.8	48.0	51.9	33.0
Mean	16.8	11.5	44.3	46.4	35.7

Table II-2

Anomalous Springs Based on Surface and SiO_2 Geotemperatures

mple No.	Anomalous Surface Temperature °C	Anomalous SiO_2 Geotemperature °C
503	-	60.4
513	-	63.2
523	22.0	-
548	22.0	-
907W	-	89.2
910	-	62.9
914	-	60.7
915	35.0	-
916W	-	91.2
920	-	68.8
921	30.0	-
923W	22.0	82.9
924	25.0	60.4
927W	-	65.7
928	-	75.8
932	-	73.4
936	-	70.0
945	23.0	-
951W	-	78.3

Summary of Anomalous Measurements

Table III-1

rement	Area	Units	Median	Threshold*	Average Anomalous Value**	Sample Numbers of Anomalous Springs
	I	pH units	6.4	7.5	7.67	506,527,545,899
	I	pH units	-	4.4	4.10	913
	II	pH units	5.8	7.5	8.15	927,937
	II	pH units	-	4.4	4.16	904,906,948
fic conduc- at 25°C	I	µmhos/cm	107	320	364	503,526,527
fic conduc- at 25°C	II	µmhos/cm	61	500	563	937
alkalinity	I	Mg CaCO$_3$/L	60	290	291	501
	II	Mg CaCO$_3$/L	15	200	265	937
s N	I	ppm	0.66	3.1	7.4	922,939,945
	II	ppm	1.00	12.0	14.3	904
s N	I	ppm	0.10	0.51	0.95	520,526,913,930
	II	ppm	0.20	1.40	1.52	925,926
s P	I	ppm	0.07	0.24	0.36	517,911,913
	II	ppm	0.10	0.35	0.41	951
te	I	ppm	2.3	9.0	16.8	503,517,916,917
	II	ppm	3.2	20.0	42.2	927,951
ide	I	ppm	2.3	4.4	48	526,527,922,953
ide	II	ppm	3.5	6.8	8.7	904,948
	I	ppb	56	5000	5222	916
	II	ppb	49	580	6399	908,928,932,937
	I	ppb	19	900	1220	517
	II	ppb	14	220	353	924,928,936,
	I	ppb	18	100	134	536,537,900,911
	II	ppb	9.5	33	46	904,948
	I	ppb	4.0	11	34	511,513,517,523
	II	ppb	3.0	7	12	904,919,920
	I	ppb	5	20	27	916,938,939,943
	II	ppb	11	32	38	908,936
	I	ppb	9	28	36	517,916,938,943
	II	ppb	20	37	54	936
	I	ppb	<0.1	<0.3	2.0	528,544
	II	ppb	0.2	0.6	1.1	909,910,937
	I	ppb	10	31	35	520,916
	II	ppb	30	42	59	932
	I	ppb	<15	320	420	520
	II	ppb	40	320	915	929,944
	I	ppb	55	380	987	501W,526,527,911,91
	II	ppb	30	150	857	927W,951W
	I	ppb	2.5	18	46	501,520,526,527
	II	ppb	2.3	54	72	927,937
	I	ppm	0.56	1.35	2.0	506,520W,922
	II	ppm	1.10	6.0	8.5	948

95% frequency value from cumulative frequency curve (Lepeltier, 1969), except Hg=1 ppb
Anomalous values are those exceeding threshold

Anomalous Springs

AREA I

Table III-2

Spring No.	Measurement (Value) for Which Spring is Anomalous
501W	Alkalinity(291), Sr(501 ppb), Li(21 ppb)
503	Specific conductance(324), SO_4(32 ppm), SiO_2, subsurface T(60.4°C)
506	pH(7.6), K(1.7 ppm)
511	Cu(85 ppb)
513	Cu(15 ppb), SiO_2, subsurface T(62.2°C)
517	PO_4(0.54 ppm), SO_4(12 ppm), Mn(1220 ppb), Cu(21 ppb), Ni(29 ppb)
520W	NH_3(0.64 ppm), Pb(33 ppb), Li(23 ppb), Ba(420 ppb), K(1.4 ppm)
523	Cu(14 ppb), surface T(22°C)
526	Specific conductance(353), NH_3(0.54 ppm), Cl(86 ppm), Sr(838 ppb), Li(70 ppb)
527	pH(7.6), specific conductance(385), Cl(87 ppm), Sr(802 ppb), Li(70 ppb)
528	Hg(2.1 ppb)
536	Zn(143 ppb)
537	Zn(110 ppb)
544	Hg(1.9 ppb)
545	pH(7.6)
899	pH(7.9)
900	Zn (137 ppb)
911	PO_4(0.28 ppm), Zn(144 ppb), Sr(500 ppb)
913	NH_3(1.08 ppm), PO_4(0.25 ppm), Sr(2200 ppb), pH(4.1)
916W	SO_4(13.1 ppm), Fe(5222 ppb), Co(23 ppb), Ni(39 ppb), Pb(37 ppb), SiO_2, subsurface T(91.2°C)
917	SO_4(10.2 ppm)
922	NO_3(12 ppm), Cl(13 ppm), K(2.9 ppm)
930	NH_3(1.52 ppm)
938	Co(22 ppb), Ni(36 ppb)
939	NO_3(4.8 ppm), Co(30 ppb)
943	Co(31 ppb), Ni(39 ppb)
945	NO_3(5.5 ppm), surface T(23°C)
953	Cl(6 ppm)

(anomalous springs) = 28, % anomalous = $(\frac{28}{71})100 = 39$

(springs) = 71

(anomalous springs), cations only = 21, % " = $(\frac{21}{71})100 = 30$

Anomalous Springs

AREA II

Table III-3

Spring No.	Measurement (Value) for Which Spring is Anomalous
904	pH(4.1 units), NO_3(14.3 ppm), Cl(9.5 ppm), Zn(48 ppb), Cu(14 ppb)
906	pH(4.3 units)
908	Fe(10082 ppb), Co(39 ppb)
909	Hg(1.1 ppb)
910	Hg(1.2 ppb), SiO_2, subsurface T(62.9^{o}C)
919	Cu(13 ppb),
920	Cu(9 ppb), SiO_2, subsurface T(68.8^{o}C)
924	Mn(345 ppb), SiO_2, surface T(25^{o}C), subsurface T(60.4^{o}C)
925	NH_3(1.52 ppm)
926	NH_3(1.52 ppm)
927W	pH(7.6 units), SO_4(29.5 ppm), Sr(1440 ppb), Li(58 ppb), SiO_2, subsurface T(65.7^{o}C)
928	Fe(4218 ppb), Mn(345 ppb), SiO_2, subsurface T(75.8^{o}C)
929	Ba(910 ppb)
932	Fe(1375 ppb), Pb(59 ppb), SiO_2, subsurface T(73.4^{o}C)
936	Mn(370 ppb), Co(38 ppb), Ni(54 ppb), SiO_2, subsurface T(70.0^{o}C)
937	pH(8.7 units), specific conductance(563 μmhos), alkalinity (265 mg/L $CaCO_3$) Fe(9930 ppb), Li(86 ppb), Hg(1.1 ppb)
944	Ba(920 ppb)
948	pH(4.1 units), Cl(8.0 ppm), Zn(45 ppb), K(8.5 ppm)
951W	PO_4(0.41 ppm), SO_4(55 ppm), Sr(275 ppb), SiO_2, subsurface T(78.3^{o}C)

(anomalous springs) = 19, % anomalous = $(\frac{19}{31})100 = 61$

(anomalous springs), cations only = 16, % anomalous = $(\frac{16}{31})100 = 52$

Table III-4

Location and Date of Collection of Spring Samples

Sample No.	Name	Location	Area	County	Topo Quad	Date
501**	Iron	NE¼, SW¼, sec. 6, T1N, R9W	I	Garland	Nimrod	3/2/78
502	Iron	NE¼, SW¼, sec. 6, T1N, R19W	I	Garland	Nimrod	" "
503	Black	SW¼, SE¼, sec. 19, T3S, R25W	I	Montgomery	Glenwood	3/3/78
504	Collier	SE¼, NW¼, sec. 17, T3S, R24W	I	Montgomery	Glenwood*	" "
505	Caddo Valley	SW¼, SW¼, sec. 25, T3S, R27W	I	Montgomery	Athens*	" "
506	Crystal A	SE¼, SW¼, sec. 28, T2S, R22W	I	Garland	Crystal Spring	" "
507	Goat Brown	NW¼, NW¼, sec. 22, T3S, R31W	I	Polk	Cove	3/6/78
508	Bogg	NW¼, NW¼, sec. 16, T5S, R32W	II	Polk	Cove*	" "
509	Queen Wilhelmina	SE¼, NE¼, sec. 11, T1S, R32W	I	Polk	Rich Mtn.	3/7/78
510	Queen Wilhelmina	SE¼, SE¼, sec. 11, T1S, R32W	I	Polk	Rich Mtn.	" "
511	Silver World	NE¼, SW¼, sec. 14, T3S, R29W	I	Polk	Umpire	" "
512	Abernathy	NW¼, SW¼, sec. 24, T3S, R28W	I	Polk	Athens*	" "
513	Three Sisters	NW¼, NW¼, sec. 29, T1S, R20W	I	Garland	Mtn. Pine	4/8/78
514	(No Name)	NE¼, SW¼, sec. 16, T3S, R22W	I	Garland	Percy	" "
515	(No Name)	NE¼, SW¼, sec. 16, T3S, R22W	I	Garland	Percy	" "
516	(No Name)	NE¼, SW¼, sec. 16, T3S, R22W	I	Garland	Percy	" "
517	Wyatt	SW¼, NE¼, sec. 22, T3S, R23W	I	Montgomery	Bonnerdale*	" "
518	(No Name)	NE¼, NW¼, sec. 24, T4S, R24W	I	Montgomery	Glenwood	4/9/78
519	(No Name)	SW¼, SW¼, sec. 20, T4S, R23W	I	Montgomery	Amity	" "
520***,****	Pigeon Roost (W)	SW¼, SW¼, sec. 20, T4S, R23W	I	Montgomery	Amity	" "
521	Dripping	SE¼, NW¼, sec. 11, T5S, R25W	I	Pike	Glenwood*	" "
522	Strawn	SE¼, NW¼, sec. 18, T4S, R24W	I	Montgomery	Glenwood*	" "
523	(No Name)	SE¼, NE¼, sec. 16, T1S, R28W	I	Polk	Oden	5/16/78
524	(No Name)	SE¼, SE¼, sec. 26, T4S, R32W	I	Polk	Cove	" "

Location and Date of Collection of Spring Samples (con't)

Sample No.	Name	Location	Area	County	Topo Quad	Date
525	(No Name)	SW¼, SW¼, sec. 3, T2S, R32W	I	Polk	Cove*	5/17/78
526	Gilham A	SW¼, NW¼, sec. 22, T4S, R30W	I	Polk	Umpire*	" "
527	Gilham B	SW¼, NW¼, sec. 22, T4S, R30W	I	Polk	Umpire*	" "
528	Bard	SW¼, NE¼, sec. 20, T4S, R28W	I	Polk	Umpire	" "
529	(No Name)	NW¼, NW¼, sec. 27, T4S, R27W	I	Montgomery	Athens	" "
530	(No Name)	NW¼, SW¼, sec. 22, T4S, R27W	I	Montgomery	Athens	" "
531	McClaine A	SW¼, NE¼, sec. 18, T4S, R24W	I	Montgomery	Glenwood	5/18/78
532	McClaine B	SW¼, NE¼, sec. 18, T4S, R24W	I	Montgomery	Glenwood	" "
533	McClaine C	SW¼, NE¼, sec. 18, T4S, R24W	I	Montgomery	Glenwood	" "
534	McClaine D	SW¼, NE¼, sec. 18, T4S, R24W	I	Montgomery	Glenwood	" "
535	W. Jones	NE¼, SE¼, sec. 18, T4S, R24W	I	Montgomery	Glenwood	" "
536	Jones Valley	NE¼, SE¼, sec. 18, T4S, R24W	I	Montgomery	Glenwood	" "
537	Buttermilk A	NW¼, NE¼, sec. 6, T4S, R24W	I	Montgomery	Glenwood	" "
538	Buttermilk B	NW¼, NE¼, sec. 6, T4S, R24W	I	Montgomery	Glenwood	" "
539	(No Name)	NW¼, NE¼, sec. 6, T4S, R24W	I	Montgomery	Glenwood	" "
540	McEllhanan	SW¼, SW¼, sec. 7, T4S, R24W	I	Montgomery	Glenwood	" "
541	(No Name)	NW¼, NW¼, sec. 18, T4S, R24W	I	Montgomery	Glenwood	" "
542	(No Name)	NW¼, NW¼, sec. 18, T4S, R24W	I	Montgomery	Glenwood	" "
543	Crystal B	SE¼, NE¼, sec. 34, T2S, R22W	I	Garland	Crystal Spring	5/19/78
544	Brogdams A	SW¼, NE¼, sec. 34, T2S, R22W	I	Garland	Crystal Spring	" "
545	Brogdams B	SW¼, NE¼, sec. 34, T2S, R22W	I	Garland	Crystal Spring	" "
546	Brogdams C	SW¼, NE¼, sec. 34, T2S, R22W	I	Garland	Crystal Spring	" "

Location and Date of Collection of Spring Samples (con't)

Sample No.	Name	Location	Area	County	Topo Quad	Date
547	Brogdams D	SW¼, NE¼, sec. 34, T2S, R22W	I	Garland	Crystal Spring	5/19/78
548	Brogdams E	SW¼, NE¼, sec. 34, T2S, R22W	I	Garland	Crystal Spring	" "
899	Burrows	SE¼, SE¼, sec. 6, T5S, R22W	I	Clark	Amity	7/13/78
900	Lead Mine Road	SW¼, SW¼, sec. 30, T4S, R21W	I	Hot Spring	Point Cedar	" "
901	Lead Mine Road	SW¼, SW¼, sec. 30, T4S, R21W	I	Hot Spring	Point Cedar	" "
902	(No Name)	SE¼, NW¼, sec. 31, T4S, R21W	I	Hot Spring	Point Cedar*	" "
903	" "	SW¼, NW¼, sec. 36, T4S, R21W	I	Hot Spring	Point Cedar	" "
904	" "	SE¼, NE¼, sec. 35, T7S, R25W	II	Pike	Murfreesboro*	7/14/78
905**	Womack	NW¼, SW¼, sec. 25, T7S, R25W	II	Pike	Delight	" "
906	Womack	SE¼, SW¼, sec. 25, T7S, R25W	II	Pike	Delight	" "
907**	Lolla Bell	NW¼, NE¼, sec. 3, T7S, R25W	II	Pike	Narrows Dam	" "
908	(No Name)	NW¼, SE¼, sec. 26, T6S, R24W	II	Pike	Murfreesboro NE	" "
909	" "	SE¼, SW¼, sec. 32, T6S, R24W	II	Pike	Murfreesboro NE	" "
910	" "	SE¼, SE¼, sec. 31, T7S, R25W	I	Pike	Murfreesboro	7/15/78
911	" "	SE¼, SE¼, sec. 20, T3S, R26W	I	Montgomery	Athens	" "
912	" "	SW¼, NE¼, sec. 33, T3S, R26W	I	Montgomery	Athens	" "
913	Sulfur	SW¼, SW¼, sec. 10, T3S, R27W	I	Montgomery	Athens	" "
914	Elliott	NE¼, SE¼, sec. 21, T2S, R29W	I	Polk	Board Camp	7/18/78
915	Caddo River	NW¼, NE¼, sec. 19, T4S, R24W	I	Montgomery	Glenwood	" "
916***,****	Artesian Well	SE¼, SW¼, sec. 19, T4S, R26W	I	Montgomery	Athens	" "
917***,****	Artesian Well	SW¼, NE¼, sec. 19, T4S, R26W	I	Montgomery	Athens	" "
918	(No Name)	NE¼, NE¼, sec. 28, T4S, R26W	I	Montgomery	Athens	" "
919	(No Name)	SW¼, NW¼, sec. 16, T6S, R27W	II	Pike	Newhope	" "

Location and Date of Collection of Spring Samples (con't)

Sample No.	Name	Location	Area	County	Topo Quad	Date
920	(No Name)	SE¼, NE¼, sec. 20, T7S, R27W	II	Howard	Newhope	7/18/78
921	(No Name)	SW¼, NW¼, sec. 26, T4S, R25W	I	Montgomery	Glenwood	" "
922	Chalybeate	NE¼, SE¼, sec. 20, T4N, R24W	I	Yell	Gravelly	3/3/79
923	Caddo Gap Well	SE¼, NW¼, sec. 26, T4S, R25W	I	Montgomery	Glenwood	" "
924	Redland Mtn.	SW¼, NW¼, sec. 12, T5S, R26W	I	Pike	Glenwood	3/4/79
925	Lolla Bell A	NW¼, NE¼, sec. 3, T7S, R25W	II	Pike	Narrows Dam	" "
926	" " B	SW¼, NE¼, sec. 3, T7S, R25W	II	Pike	Narrows Dam	" "
927**,****	Artesian Well	SE¼, NE¼, sec. 3, T10S, R27W	II	Howard	Nashville	" "
928	Mineral	SW¼, NE¼, sec. 19, T10S, R27W	II	Howard	Mineral Springs S	" "
929	Barite Pit	NE¼, NE¼, sec. 24, T7S, R28W	II	Howard	Newhope	" "
930	Murfreesboro Area	NE¼, NE¼, sec. 4, T8S, R25W	II	Pike	Murfreesboro	" "
931	Murfreesboro Area	NE¼, SE¼, sec. 10, T7S, R25W	II	Pike	Narrows Dam	3/5/79
932	Lake Greeson Area	NE¼, NW¼, sec. 24, T6S, R27W	II	Pike	Center Pt. NE	" "
933	Dierks Area	NE¼, NW¼, sec. 4, T8S, R29W	II	Sevier	Dierks	" "
934	Cox Residence	SE¼, SW¼, sec. 33, T7S, R29W	II	Sevier	Dierks	" "
935	Dierks Area	SW¼, NE¼, sec. 34, T7S, R29W	II	Howard	Dierks	" "
936	L. Greeson, Sulfur	SW¼, NW¼, sec. 34, T6S, R26W	II	Pike	Center Pt. NE	3/6/79
937	L. Greeson, Possum	NW¼, NW¼, sec. 34, T6S, R26W	II	Pike	Center Pt. NE	" "
938	Salem Area	NE¼, NE¼, sec. 7, T5S, R24W	I	Pike	Glenwood	" "
939	Bethesda	NW¼, SE¼, sec. 31, T2S, R30W	I	Polk	Mena	5/15/79
940	Mine Creek	SW¼, NW¼, sec. 14, T3S, R28W	I	Polk	Athens	" "
941	Rock	SW¼, SE¼, sec. 25, T2S, R27W	I	Montgomery	Oden*	" "
942	West	SE¼, NE¼, sec. 2, T2S, R25W	I	Montgomery	Mt. Ida*	" "
943	Pigeon Roost	SW¼, SW¼, sec. 20, T4S, R23W	I	Montgomery	Amity	5/16/79
944	Barite Pit	NE¼, NE¼, sec. 24, T7S, R28W	II	Howard	Newhope	" "

Location and Date of Collection of Spring Samples (con't)

Sample No.	Name	Location	Area	County	Topo Quad	Date
945	"Warm"	SW¼, SE¼, sec. 8, T4S, R27W	I	Montgomery	Athens	5/17/79
946	Athens Area	SW¼, SE¼, sec. 16, T5S, R28W	II	Howard	Athens	" "
947	Umpire Area	SW¼, SW¼, sec. 13, T5S, R30W	II	Howard	Umpire	" "
948	S. Cox	SW¼, SW¼, sec. 33, T7S, R29W	II	Sevier	Dierks	" "
949	Cossatot	NW¼, NE¼, sec. 19, T7S, R30W	II	Sevier	Gillham Dam	" "
950	Church	NW¼, SW¼, sec. 16, T7S, R31W	II	Sevier	Gillham*	" "
951	Defore Well	NE¼, SW¼, sec. 20, T7S, R31W	II	Sevier	Gillham	5/18/79
952	(No Name)	SE¼, NE¼, sec. 6, T7S, R31W	II	Sevier	Gillham*	" "
953	Mena Park	NE¼, NW¼, sec. 18, T2S, R30W	I	Polk	Mena	" "

* spring is shown on map

** well with metal pipe

*** well with plastic pipe

**** artesian well

NOTE: 944 and 929 are duplicate collections of the same site.

Spring Water Surface and Subsurface Temperatures And Corresponding % Saturations of the Waters with $BaSO_4$ and $SrSO_4$

Table III-5

	Water Temperature (°C)		% $BaSO_4$ Saturation[c]		% $SrSO_4$ Saturation[d]	
Area	Surface[a] (T_1)	Subsurface[b] (T_2)	Surface	Subsurface	Surface	Subsurface
I	15.0	31.7	0.51	0.30	0.0077	0.0089
I	5.0	7.1	<0.47	<0.38	0.0001	0.0001
I	15.0	60.9	<14.4	<5.38	0.504	0.867
I	16.5	46.1	1.37	0.67	0.0014	0.0022
I	15.0	31.7	<0.80	<0.47	0.0097	0.0113
I	18.0	46.1	<0.50	<0.25	0.0035	0.0052
I	13.0	50.2	<0.76	<0.28	0.0020	0.0032
II	13.0	31.7	<1.4	<0.73	0.0072	0.0086
I	10.0	40.6	<2.5	<0.93	0.0024	0.0034
I	9.0	26.7	1.33	0.59	0.0004	0.0005
I	16.0	40.3	<2.60	<1.31	0.0311	0.0401
I	16.0	36.0	<1.10	<0.61	0.0152	0.0185
I	16.0	63.2	<3.40	<1.31	0.0303	0.0531
I	18.0	40.3	<0.62	<0.34	<0.0001	<0.0002
I	17.0	38.5	<0.92	<0.50	<0.0001	<0.0001
I	21.0	45.6	<1.95	<1.11	0.0069	0.0097
I	17.0	45.6	<8.0	<3.90	<0.0016	<0.0024
I	15.0	41.7	<0.46	<0.22	0.0002	0.0003
I	18.0	37.9	16.5	9.41	0.0733	0.0210
I	17.0	49.7	52.8	24.3	0.0424	0.0652
I	17.0	38.5	<1.3	<0.71	0.0011	0.0014
I	18.0	37.9	<1.8	<0.97	0.0469	0.0565
I	22.0	45.6	<0.32	<0.19	<0.0002	<0.0004
I	15.5	54.5	<0.21	<0.08	<0.0002	<0.0004
I	15.0	38.8	<2.0	<0.99	0.0063	0.0081
I	17.0	57.5	2.71	1.14	0.0111	0.0180
I	17.5	57.5	<2.60	<1.12	<0.0102	<0.0166
I	15.5	56.1	<3.8	<1.5	0.0517	0.0857
I	17.5	37.0	<0.19	<0.11	<0.0002	<0.0004

III-5 (con't)

	Water Temperature (^{o}C)		% $BaSO_4$ Saturation[c]		% $SrSO_4$ Saturation[d]	
Area	Surface[a] (T_1)	Subsurface[b] (T_2)	Surface	Subsurface	Surface	Subsurface
I	15.0	37.0	<1.83	<0.95	0.0032	0.0040
I	17.5	40.0	2.16	1.18	0.0327	0.0409
I	18.0	38.8	1.90	1.07	0.0150	0.0185
I	17.5	40.0	<2.20	<1.21	0.0390	0.0487
I	15.5	28.7	2.96	1.87	0.0025	0.0028
I	16.0	30.8	<0.20	<0.12	0.0007	0.0008
I	18.0	37.0	<2.76	<1.61	0.0592	0.0706
I	15.0	33.8	1.57	0.87	0.0026	0.0032
I	19.0	34.6	<3.17	<2.05	0.0563	0.0644
I	17.0	30.8	1.65	1.06	0.0025	0.0028
I	18.0	29.6	<0.20	<0.14	0.0003	0.0003
I	16.0	35.8	0.86	0.48	0.0003	0.0003
I	16.0	34.6	0.16	0.09	0.0001	0.0003
I	20.0	38.8	<3.47	<2.16	0.0354	0.0419
I	18.0	40.0	<0.99	<0.55	0.0169	0.0209
I	20.0	38.8	<0.98	<0.61	0.0107	0.0126
I	21.0	40.0	<4.40	<2.75	0.0417	0.0493
I	20.0	41.1	<2.65	<1.58	0.0240	0.0293
I	22.0	41.1	<2.94	<1.86	0.0325	0.0385
I	17.0	42.2	<0.41	<0.21	<0.0015	<0.0022
I	18.0	37.3	1.29	0.74	0.0002	0.0003
I	18.0	36.7	0.66	0.39	0.0066	0.0078
I	20.0	41.4	1.70	1.01	0.0002	0.0002
I	18.0	44.6	0.49	0.25	0.0026	0.0039
II	18.0	35.4	35.0	21.0	0.0131	0.0155
II	20.0	39.4	2.27	1.39	0.0222	0.0266
II	20.0	21.0	6.66	6.48	0.0019	0.0019
II	19.0	89.2	68.7	25.2	0.0314	0.0647
II	18.0	45.3	8.00	3.80	0.0005	0.0008
II	19.0	49.0	3.67	1.85	0.0004	0.0006
II	18.0	62.9	63.8	26.2	0.0094	0.0164
I	16.0	44.6	13.4	6.35	0.1170	0.1730

III-5 (con't)

	Water Temperature (^{o}C)		% $BaSO_4$ Saturation[c]		% $SrSO_4$ Saturation[d]	
Area	Surface[a] (T_1)	Subsurface[b] (T_2)	Surface	Subsurface	Surface	Subsurface
I	16.5	37.3	4.09	2.23	0.0367	0.0451
I	17.0	50.9	4.52	2.05	0.1520	0.2360
I	20.0	60.7	0.36	0.17	0.0003	0.0005
I	35.0	58.3	0.60	0.42	0.0021	0.0031
I	18.0	91.2	96.0	34.7	0.0207	0.0480
I	18.0	44.6	51.6	26.3	0.0237	0.0349
I	20.0	35.4	11.3	7.46	0.0055	0.0063
II	21.0	58.4	1.10	0.54	0.0022	0.0036
II	20.0	68.8	0.37	0.20	0.0016	0.0024
I	30.0	41.4	<0.96	<0.77	0.0171	0.0205
I	10.0	31.8	54.2	23.8	0.0196	0.0245
I	22.0	82.9	22.4	9.46	0.0264	0.0529
II	25.0	60.4	5.90	3.17	0.0343	0.0511
II	12.0	41.3	9.29	3.77	0.0057	0.0080
II	12.0	39.5	17.8	7.34	0.0049	0.0067
II	18.5	65.7	92.0	37.8	1.97	3.38
II	16.0	75.8	3.93	1.36	0.0186	0.0456
II	10.0	41.3	45.1	16.5	0.0011	0.0015
I	11.0	29.3	23.3	11.3	0.0036	0.0043
II	11.0	17.4	16.4	11.6	0.0036	0.0043
II	13.0	73.4	96.7	28.7	0.0128	0.0261
II	10.0	31.0	16.8	7.54	0.0023	0.0028
II	12.0	30.1	13.1	6.64	0.0079	0.0094
II	10.0	26.8	8.41	4.20	0.0025	0.0029
II	11.0	70.0	50.8	13.8	0.0092	0.0187
II	8.0	46.0	7.50	2.09	0.0045	0.0075
I	12.0	39.5	23.6	9.73	0.0081	0.0110
I	19.0	48.8	<1.96	<1.00	0.0096	0.0141
I	16.0	36.9	<2.73	<1.48	0.0444	0.0532
I	17.0	49.0	<3.60	<1.69	0.0211	0.0318
I	15.0	31.8	1.91	1.10	0.0017	0.0020
I	15.0	44.1	86.0	39.3	0.0280	0.0424

III-5 Con't

	Water Temperature (°C)		% $BaSO_4$ Saturation[c]		% $SrSO_4$ Saturation[d]	
Area	Surface[a] (T_1)	Subsurface[b] (T_2)	Surface	Subsurface	Surface	Subsurface
II	18.5	42.2	63.10	34.3	0.0015	0.0022
I	23.0	43.1	<2.30	<1.46	0.0056	0.0073
II	16.0	50.0	3.71	1.63	<0.0018	<0.0030
II	18.0	47.0	<0.68	<0.34	0.0004	0.0006
II	16.0	32.7	15.20	9.00	0.0057	0.0065
II	13.0	55.6	<2.50	<0.86	0.0033	0.0059
II	18.0	47.0	<3.20	<1.59	0.0047	0.0070
II	16.0	78.3	43.5	14.8	0.606	1.22
II	14.0	48.0	2.22	0.90	0.0016	0.0018
I	16.0	48.0	<11.1	<5.00	0.0110	0.0171

asured in flowing spring at surface

lculated from $T\ {}^{o}C = 1315/\left[5.205 - \log_{10}(\text{ppm } SiO_2)\right] - 273.15$

a $\cdot\ a_{SO_4}/(\text{solubility product})_{T_1} \times 100$

r $\cdot\ a_{SO_4}/(\text{solubility product})_{T_2} \times 100$ where a = activity = activity
efficient x concentrations (molality)

FIGURES

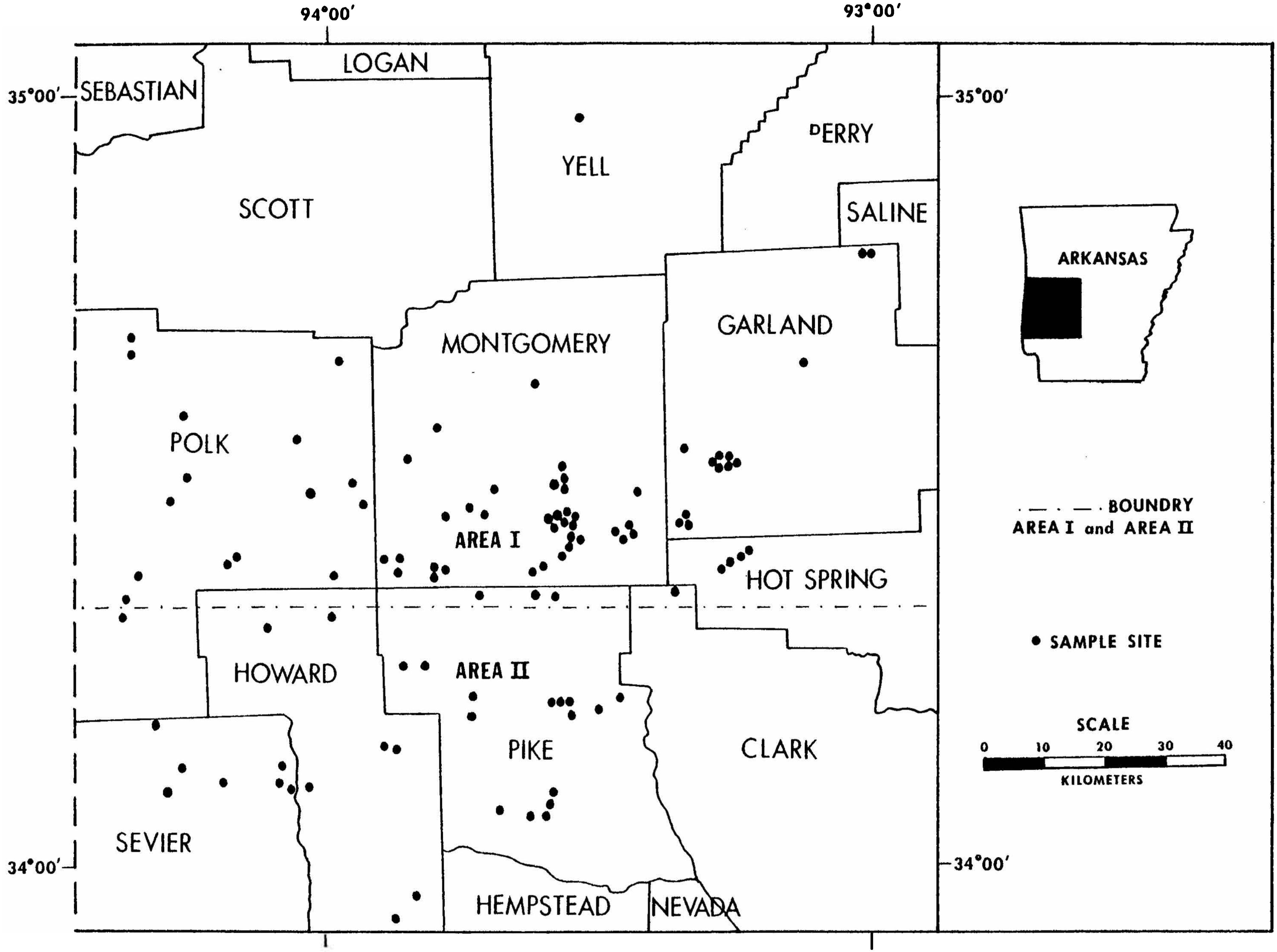

94°00′
93°00′
35°00′
35°00′
34°00′
34°00′
SEBASTIAN
LOGAN
SCOTT
YELL
PERRY
SALINE
GARLAND
MONTGOMERY
POLK
AREA I
HOT SPRING
HOWARD
AREA II
PIKE
CLARK
SEVIER
HEMPSTEAD
NEVADA
ARKANSAS
BOUNDRY
AREA I and AREA II
SAMPLE SITE
SCALE
0
10
20
30
40
KILOMETERS

Figure 1-1

Location Map of Study Area and Spring Sites

SYSTEM	SERIES	FORMATION	MEMBER	THICKNESS (METERS)	LITHOLOGY
QUATERNARY		ALLUVIUM			SILT, SAND, AND GRAVEL ALONG STREAM CHANNELS.
		TERRACE DEPOSITS			GRAVEL, SAND, AND SILT OCCURING ALONG MAJOR STREAMS.
CRETACEOUS		TRINITY FORMATION			GRAVEL, SILT, CLAY, SILTSTONE, AND SANDSTONE WITH SOME BARITE IN WESTERN PART OF ITS OUTCROP.
PENNSYLVANIAN	ATOKAN	ATOKA	UPPER MIDDLE LOWER	6000+	SHALE, LIGHT GRAY, SILTY, MICACEOUS, AND FLAKY WITH INTERBEDDED FINE TO COARSE-GRAINED, MICACEOUS SANDSTONE WITH VERY ABUNDANT SOLE MARKINGS. THIN SILICEOUS SHALES NEAR BASE AND IN LOWER PART OF FORMATION.
	MORROWAN	JOHNS VALLEY SHALE		500	SHALE, LIGHT GRAY TO TAN, DARK GRAY NEAR BASE, AND THIN BEDS OF SANDSTONE AND LIMESTONE. LARGE ERRATIC MASSES OF LIMESTONE OR SHALE ARE FOUND NEAR THE BASE OF THE FORMATION, AND EXOTIC BOULDERS, PEBBLES, AND GRANULES OCCUR AT NUMEROUS HORIZONS.
		JACKFORK SANDSTONE		2300	SANDSTONE, MEDIUM TO COARSE GRAINED, HARD, WITH INTERBEDDED SHALE. SOLE MARKINGS ARE ABUNDANT IN THE SANDSTONES. FOUR BEDS OF SILICEOUS SHALE AND ONE BED OF MAROON TO GREEN SHALE ARE IDENTIFIABLE OVER LONG DISTANCES AND FORM MARKER BEDS.
MISSISSIPPIAN	CHESTERIAN	STANLEY GROUP	CHICKASAW CREEK	4000	SHALE, DARK COLORED, MOSTLY GRAY, INTERBEDDED WITH DARK GRAY ARGILLACEOUS SILTSTONE AND VERY POORLY SORTED FINE- TO VERY FINE-GRAINED ARGILLACEOUS CHLORITIC SANDSTONE. BEDS OF SILICEOUS SHALE ARE IDENTIFIABLE OVER LONG DISTANCES IN SEVERAL HORIZONS. CONE-IN-CONE CONCRETIONS ARE ABUNDANT AT PLACES.
	MERAMECIAN		HATTON TUFF	0-30	FELSIC VITRIC TUFF.
			HOT SPRINGS SANDSTONE	0-20	SANDSTONE, HARD, QUARTZOSE, FINE TO VERY FINE GRAINED, SMALL AMOUNTS OF INTERBEDDED SHALE AND LOCALLY CONGLOMERATIC NEAR BASE. CROPS OUT ONLY IN RELATIVELY SMALL AREA NEAR HOT SPRINGS.
	OSAGEAN KINDERHOOKIAN	ARKANSAS NOVACULITE	UPPER	310	GREEN, BROWN, AND GRAY RADIOLARIAN CHERT AND RADIOLARIAN SHALE.
DEVONIAN	UPPER AND MIDDLE		UPPER MIDDLE		RED AND GREEN RADIOLARIAN SHALE SILICEOUS SHALE RADIOLARIAN CHERT AND BITUMINOUS CHERT.
			LOWER MIDDLE		LIGHT GRAY TO BLACK BITUMINOUS SPORE-BEARING CHERT AND BLACK PAPERY BITUMINOUS SHALE.
			LOWER		WHITE TO GREEN MASSIVE SPICULITIC CHERT AND GREEN LAMINATED SILICEOUS SHALE.
SILURIAN	NIAGARAN	MISSOURI MOUNTAIN SHALE		100	SHALE, HARD, GREEN SILICEOUS, SANDY IN PART. THIN BEDS OF FINELY LAMINATED CHERT AND QUARTZOSE SANDSTONE AND LOCAL LENSES OF SANDY CHERT CONGLOMERATE.
	ALEXANDRIAN	BLAYLOCK SANDSTONE		500	SANDSTONE, GRAY TO GREEN, THIN BEDDED, FINE GRAINED, WITH INTERBEDDED SHALEY MICACEOUS SILTSTONE AND DARK FISSILE SHALES. VEINS OF QUARTZ AND SMOKY QUARTZ ARE ABUNDANT. FORMATION PRESENT ONLY IN PART OF BROKEN BOW-BENTON UPLIFT.
MIDDLE AND UPPER ORDOVICIAN	CINCINNATIAN	POLK CREEK SHALE		58	SHALE, SOFT, BROWN, PLATY IN MOST OF FORMATION; HARD, BLACK, BITUMINOUS, AND SILICEOUS NEAR BASE. ABUNDANT GRAPTOLITES. THIN STREAKS OF QUARTZITIC SANDSTONE AND OOLITIC LIMESTONE.
	TRENTONIAN	BIG FORK CHERT	UPPER	260	BLACK, NONCALCAREOUS, BITUMINOUS CHERT AND BLACK BITUMINOUS PAPERY SHALE.
			LOWER		GRAY TO BROWN CALCAREOUS CHERT, SILICEOUS LIMESTONE, CLASTIC LIMESTONE AND CHERTY SHALE.
LOWER ORDOVICIAN	BLACKRIVERIAN CHAZYAN	WOMBLE SHALE		1100	SHALE, BLACK TO GREEN, WITH THIN INTERBEDS OF QUARTZOZE SANDSTONE AND LIMESTONE. SOME SILICEOUS BITUMINOUS SHALE NEAR CONTACT WITH BIGFORK CHERT.
	CANADIAN	BLAKELY SANDSTONE		130	SHALE, BLACK TO GREEN, INTERBEDDED WITH FINE TO MEDIUM GRAINED QUARTZOSE SANDSTONE. SOME VEINS OF SMOKY QUARTZ.
		MAZARN SHALE		1000	SHALE, BLACK TO GREEN, BANDED, CLAYEY, FISSILE, WITH THIN LAYERS OF GREEN SANDSTONE AND BLUISH-BLACK LIMESTONE. VEINS OF QUARTZ AND CALCITE.
		CRYSTAL MOUNTAIN SANDSTONE		280	SANDSTONE, MASSIVE, LIGHT GRAY, CALCAREOUS TO QUARTZITIC. MANY QUARTZ VEINS AND CRYSTALS.
		COLLIER SHALE		330	SHALE, BLACK, GRAPHITIC, AND DARK-COLORED SILICEOUS LIMESTONE. SOME DENSE BLACK CHERT.

Figure 1-2. Stratigraphic column for study Area I. After Vogelpohl (1977).

Figure 1-2

Stratigraphic Column for Study Area

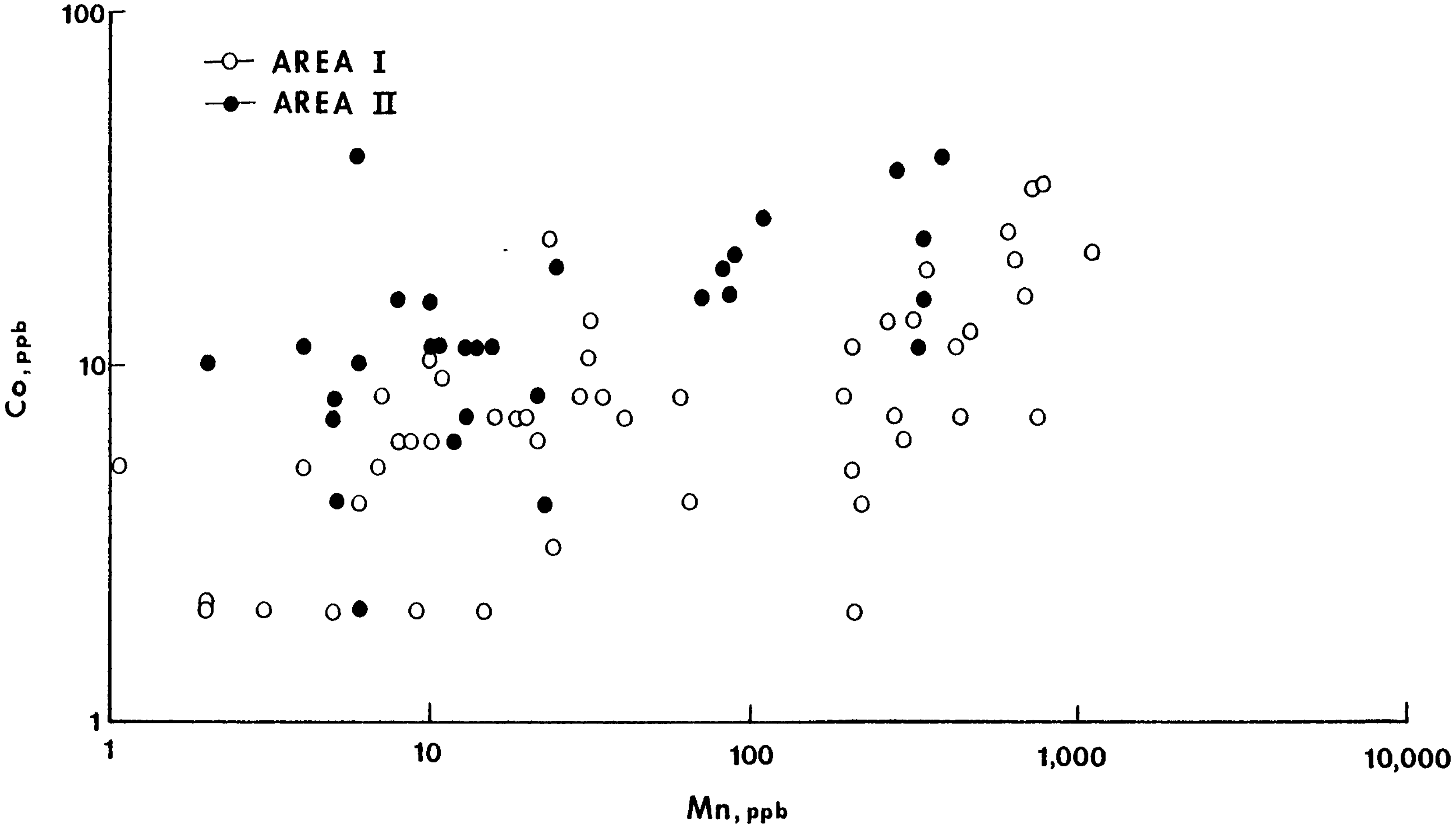

○ AREA I
● AREA II
Co, ppb
100
10
1
Mn, ppb
1
10
100
1,000
10,000

Figure I-1

Correlation Plot for Co vs Mn, Areas I and II

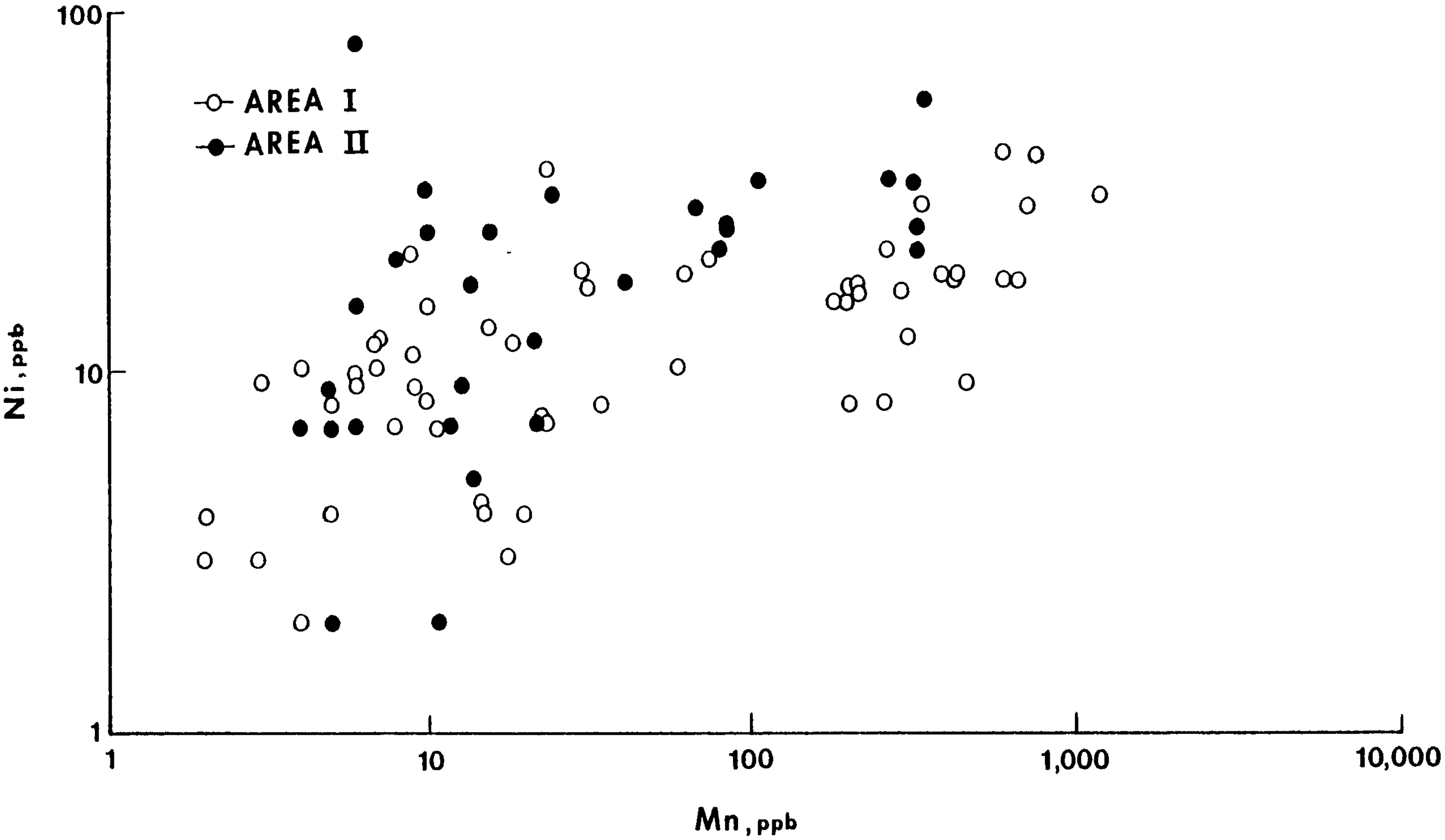

AREA I
AREA II
100
10
1
Ni, ppb
1
10
100
1,000
10,000
Mn, ppb

Figure I-2

Correlation Plot for Ni vs Mn, Areas I and II

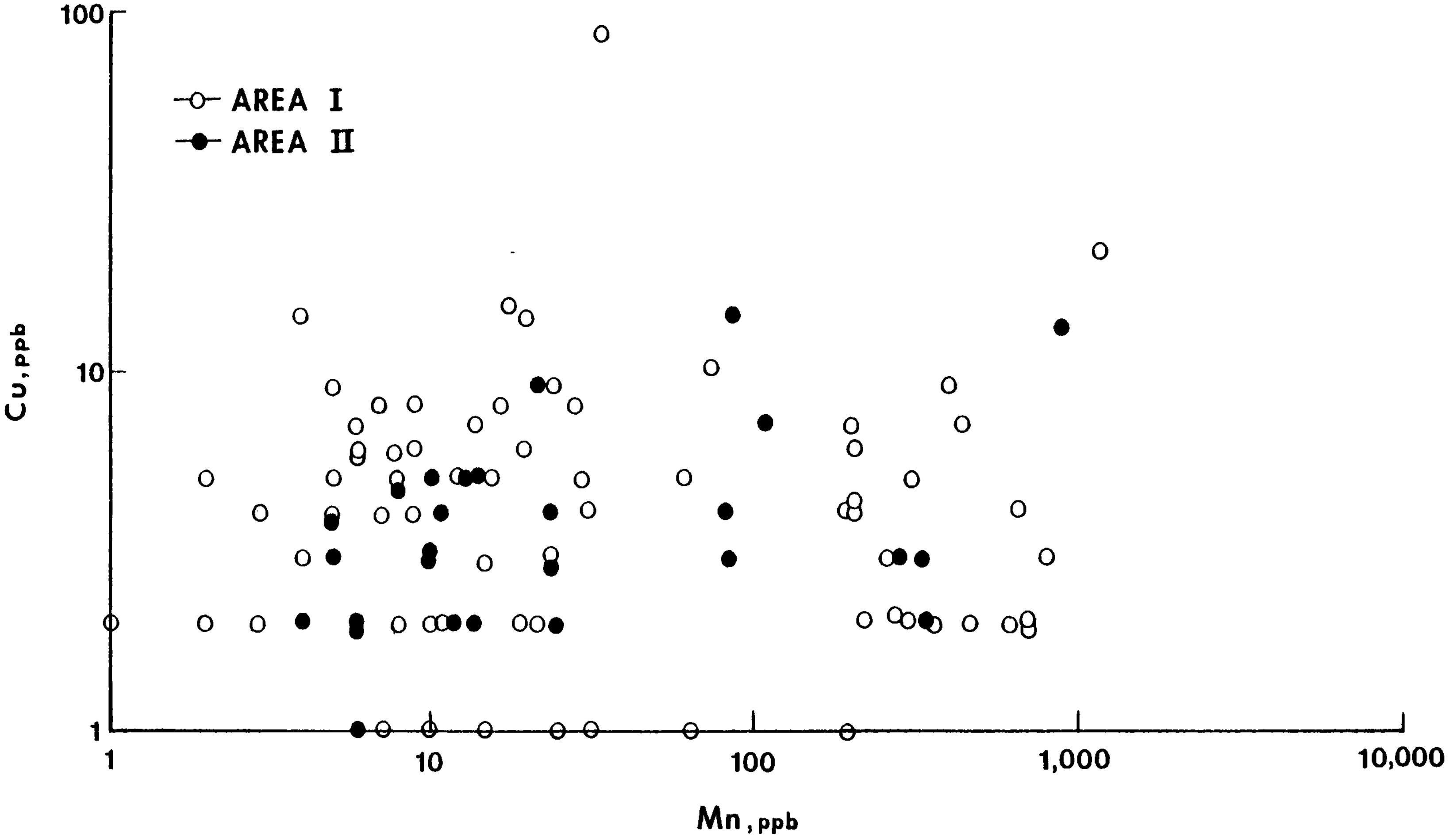
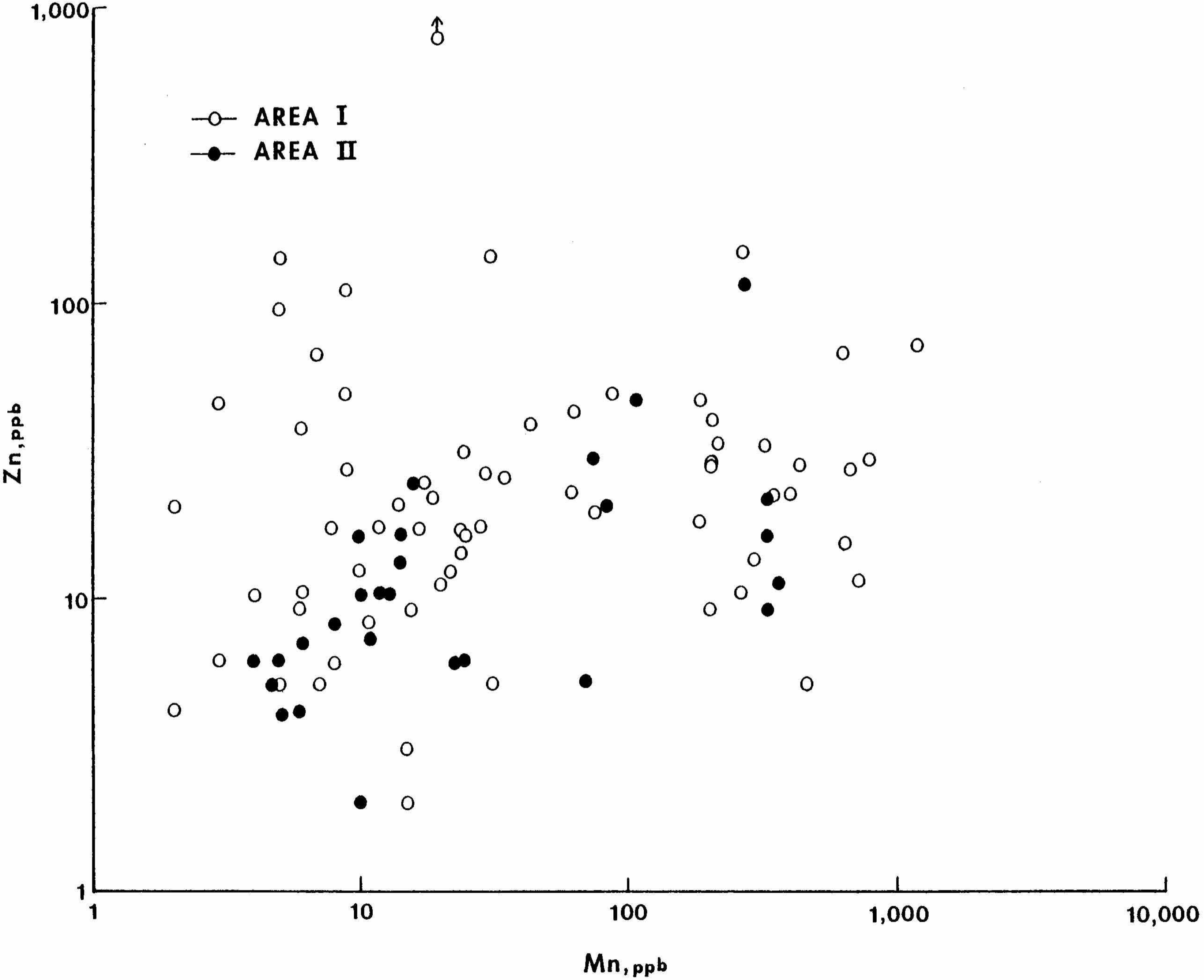

100
10
1
Cu, ppb
AREA I
AREA II
1
10
100
1,000
10,000
Mn, ppb

Figure I-3

Correlation Plot for Cu vs Mn, Areas I and II



AREA I
AREA II
1,000
100
10
1
Zn, ppb
1
10
100
1,000
10,000
Mn, ppb

Figure I-4

Correlation Plot for Zn vs Mn, Areas I and II

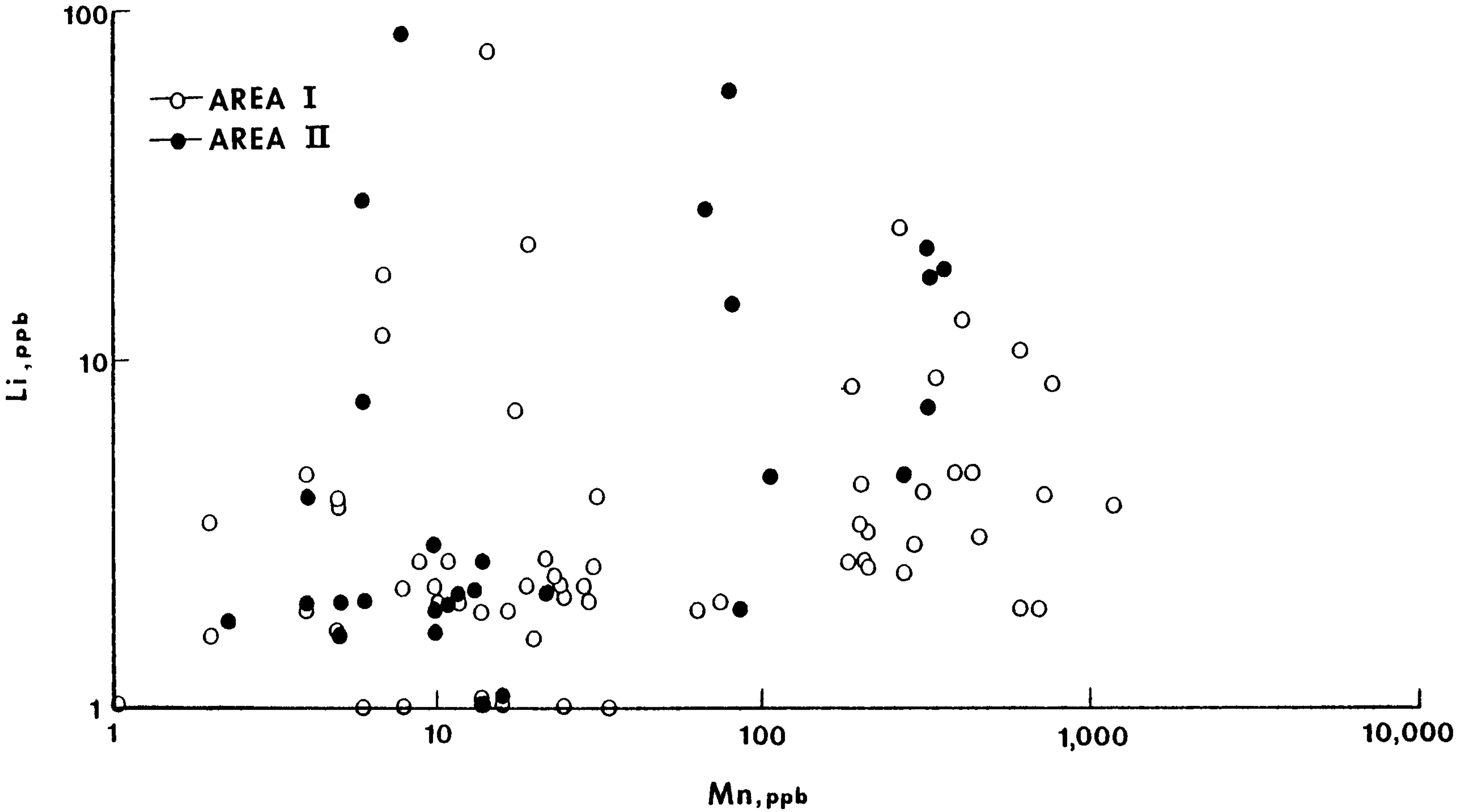

AREA I
AREA II
Li, ppb
100
10
1
1
10
100
1,000
10,000
Mn, ppb

Figure I-5

Correlation Plot for Li vs Mn, Areas I and II

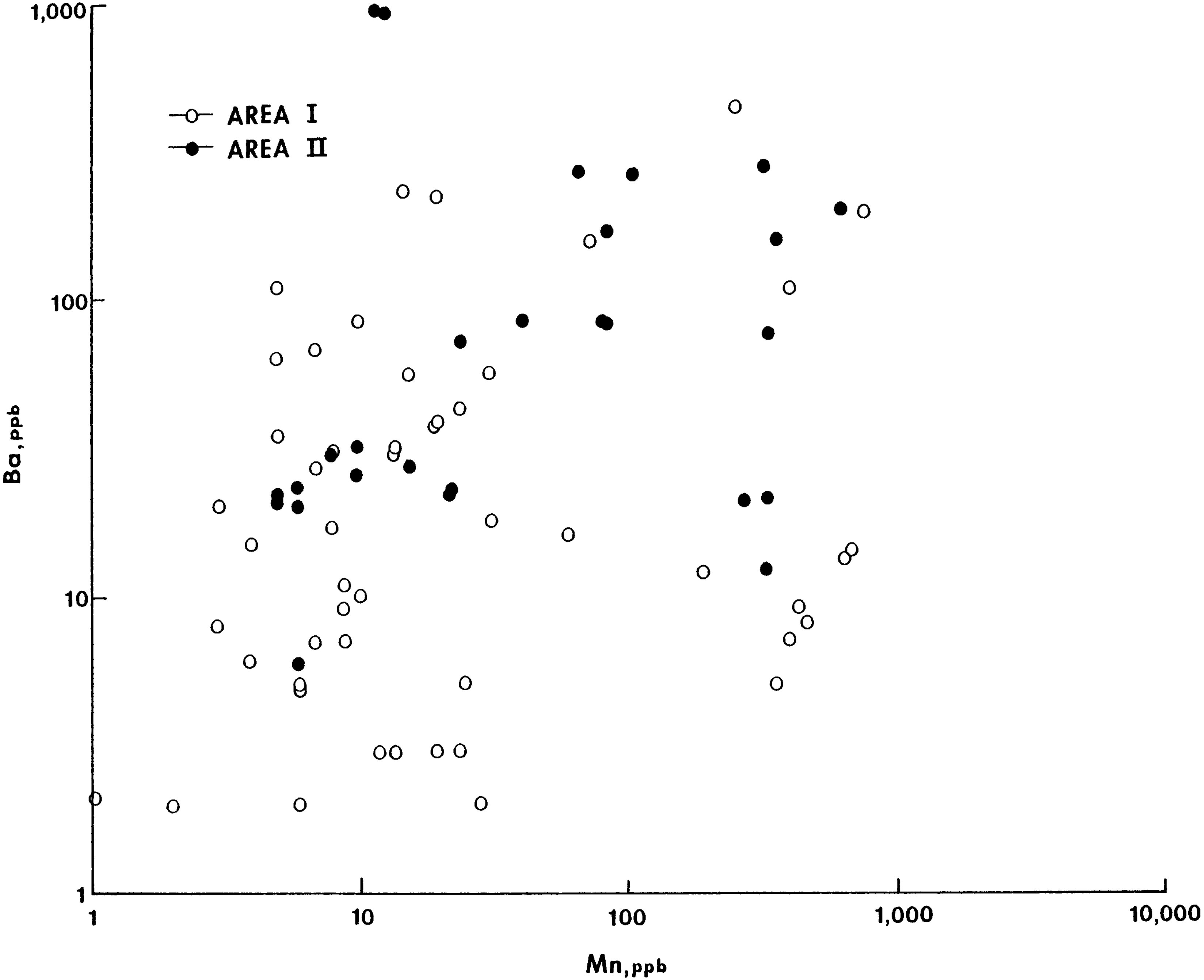

AREA I
AREA II
Ba, ppb
1,000
100
10
1
Mn, ppb
1
10
100
1,000
10,000

Figure I-6

Correlation Plot for Ba vs Mn, Areas I and II

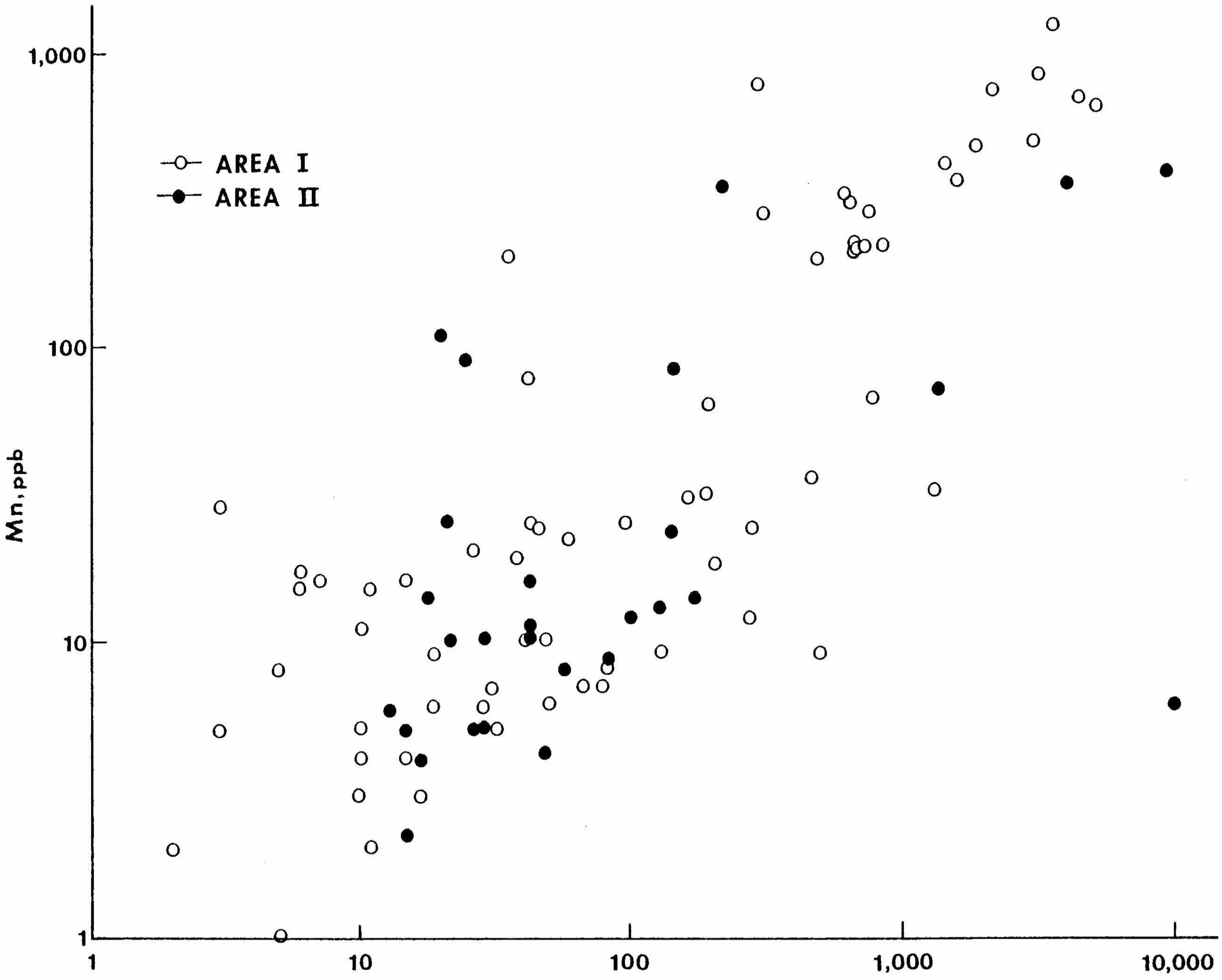
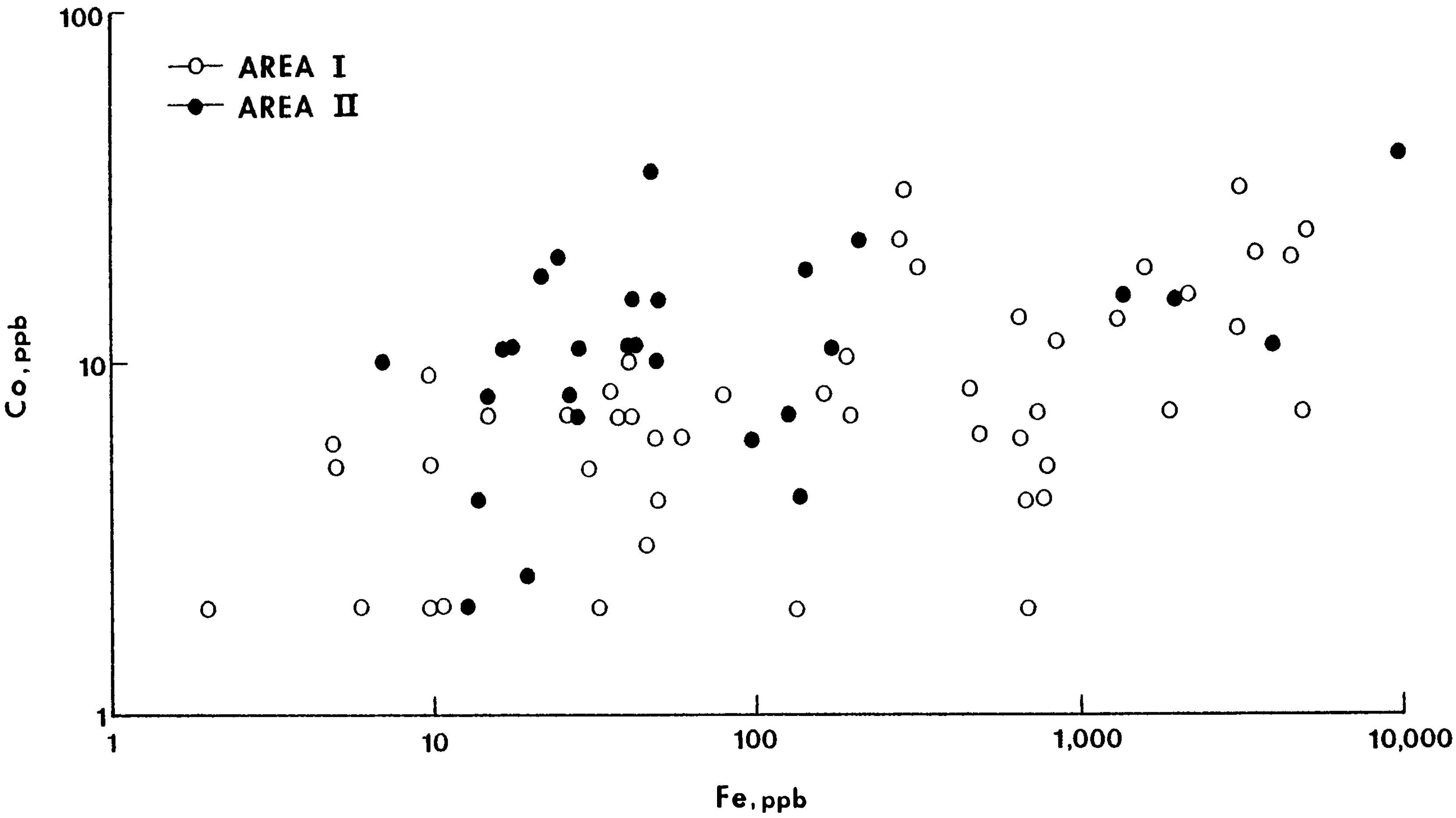

AREA I
AREA II
1,000
100
10
1
Mn, ppb
1
10
100
1,000
10,000

Figure I-7

Correlation Plot for Mn vs Fe, Areas I and II



AREA I
AREA II
Co, ppb
100
10
1
1
10
100
1,000
10,000
Fe, ppb

Figure I-8

Correlation Plot for Co vs Fe, Areas I and II

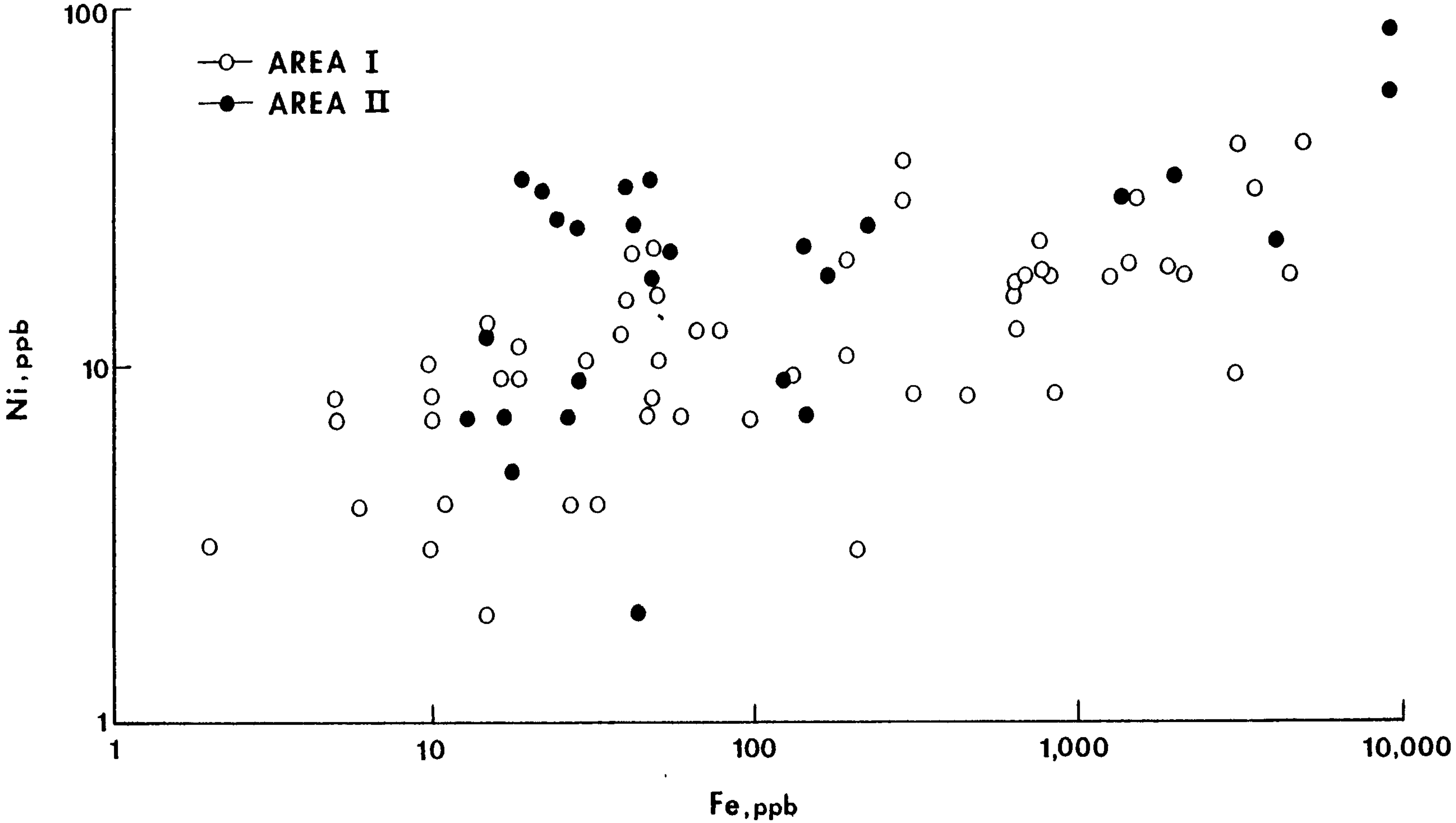

AREA I
AREA II
Ni, ppb
100
10
1
Fe, ppb
1
10
100
1,000
10,000

Figure I-9

Correlation Plot for Ni vs Fe, Areas I and II

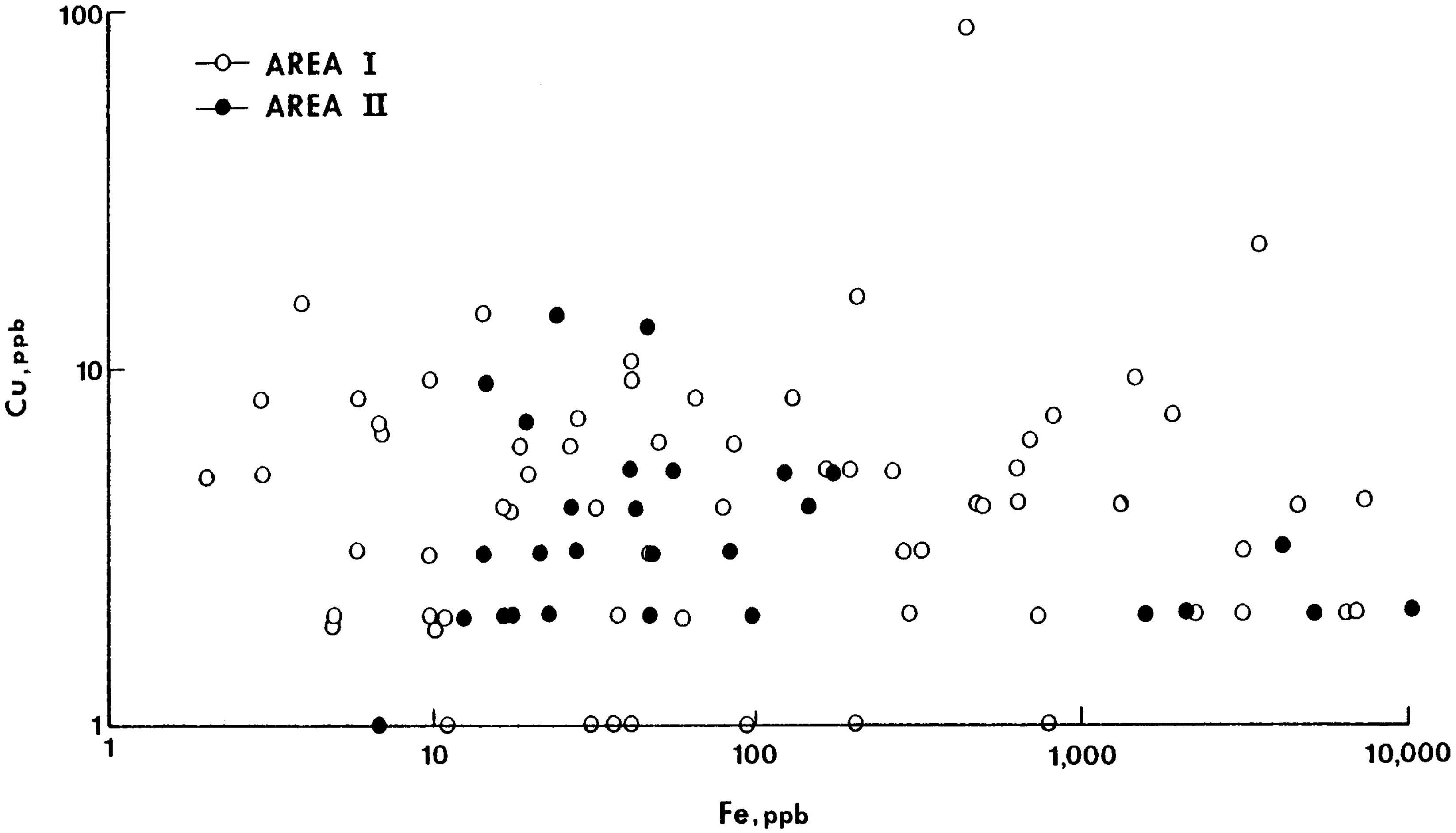

100
10
1
Cu, ppb
1
10
100
1,000
10,000
Fe, ppb
AREA I
AREA II

Figure I-10

Correlation Plot for Cu vs Fe, Areas I and II

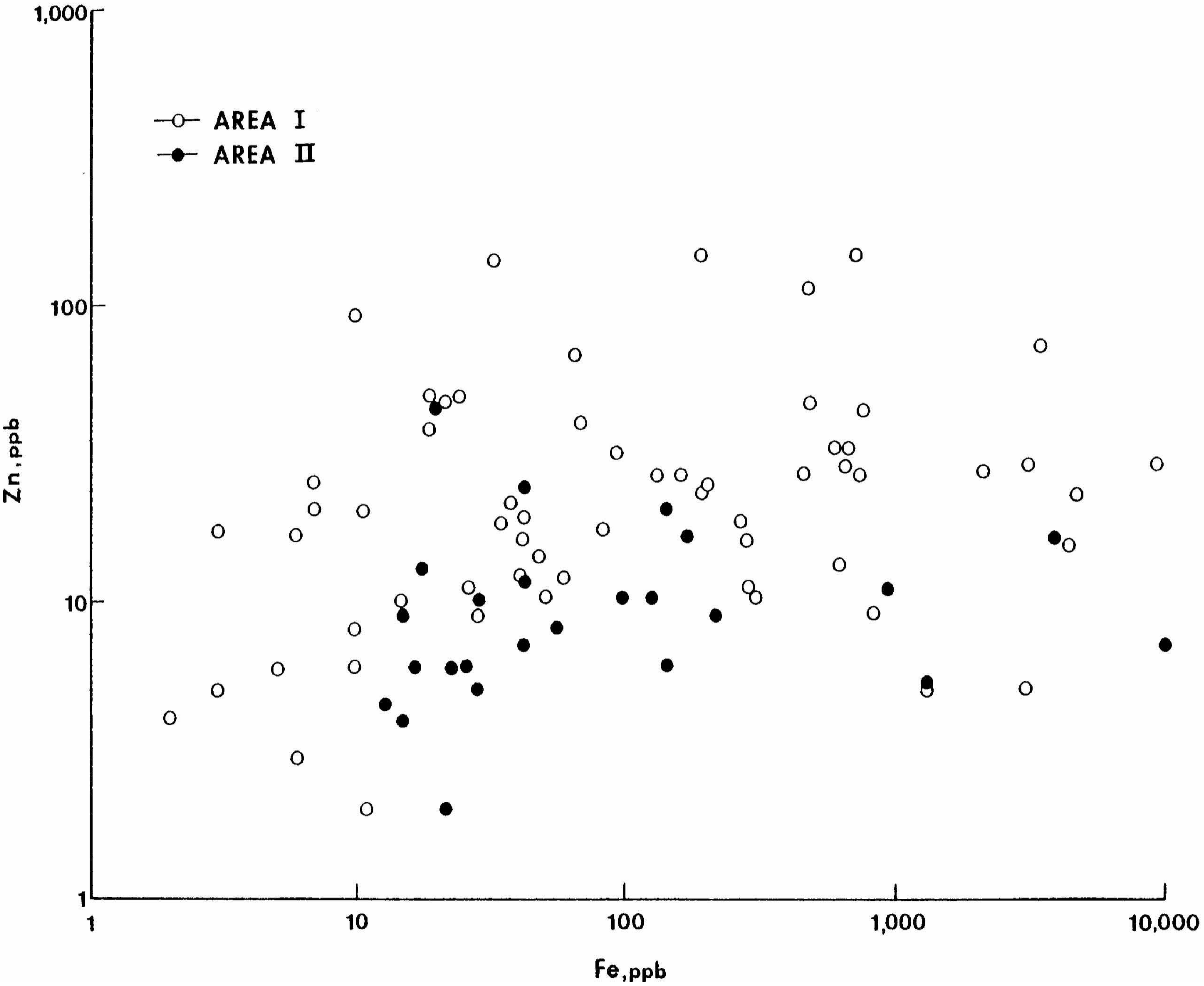

○ AREA I
● AREA II
Zn, ppb
1,000
100
10
1
Fe, ppb
1
10
100
1,000
10,000

Figure I-11

Correlation Plot for Zn vs Fe, Areas I and II

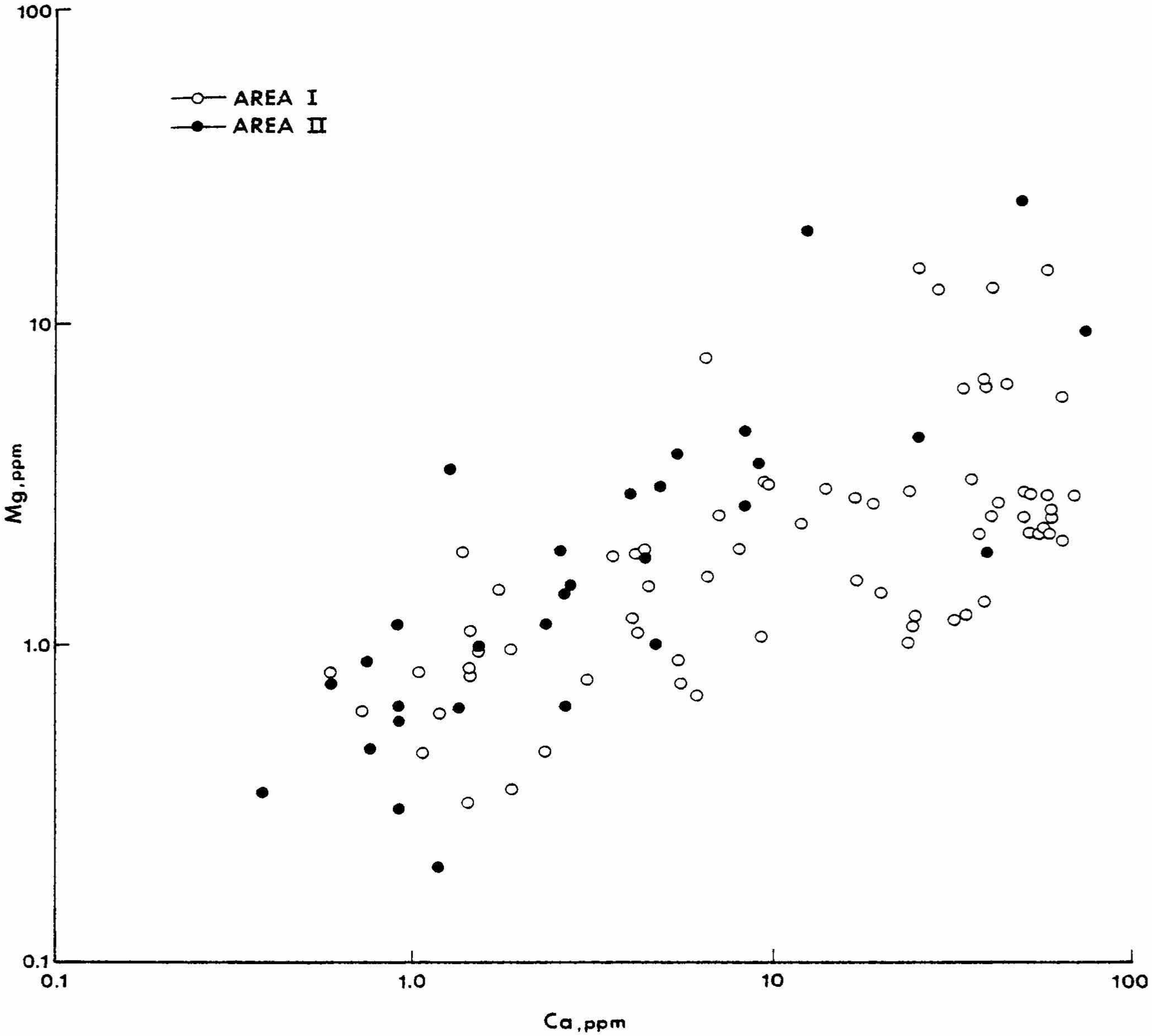
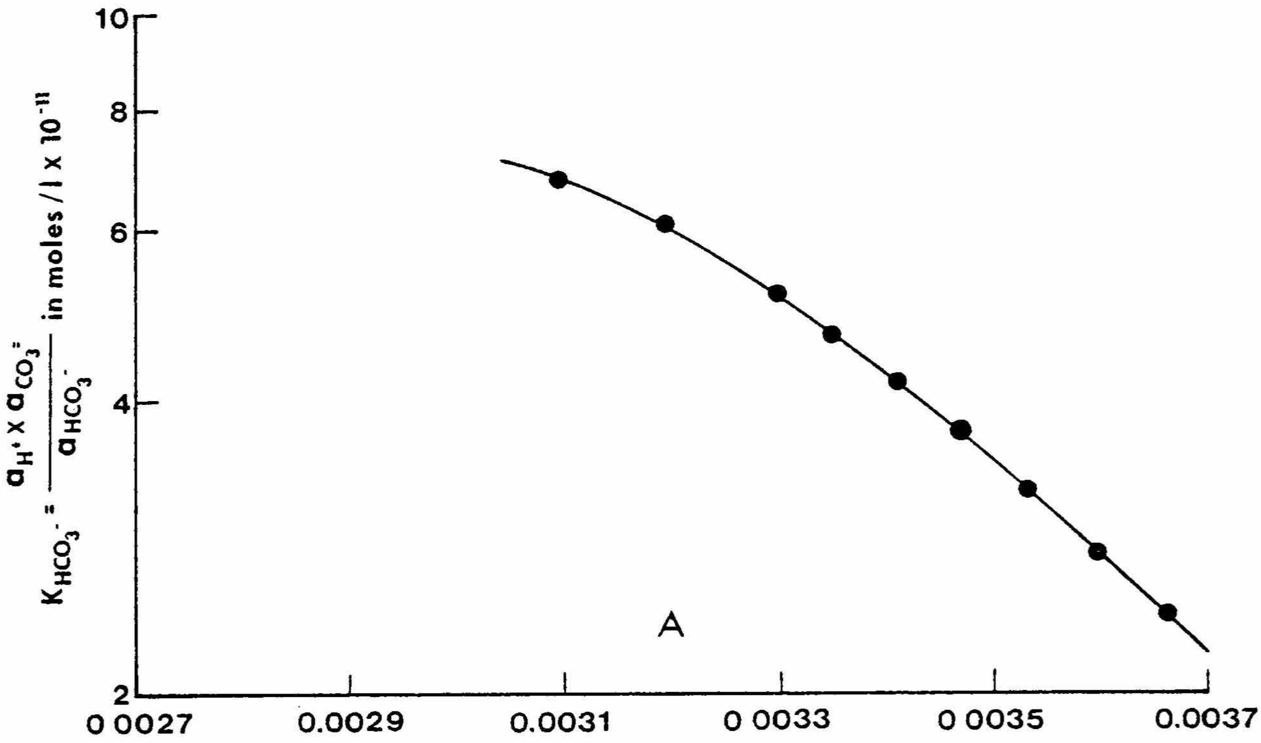
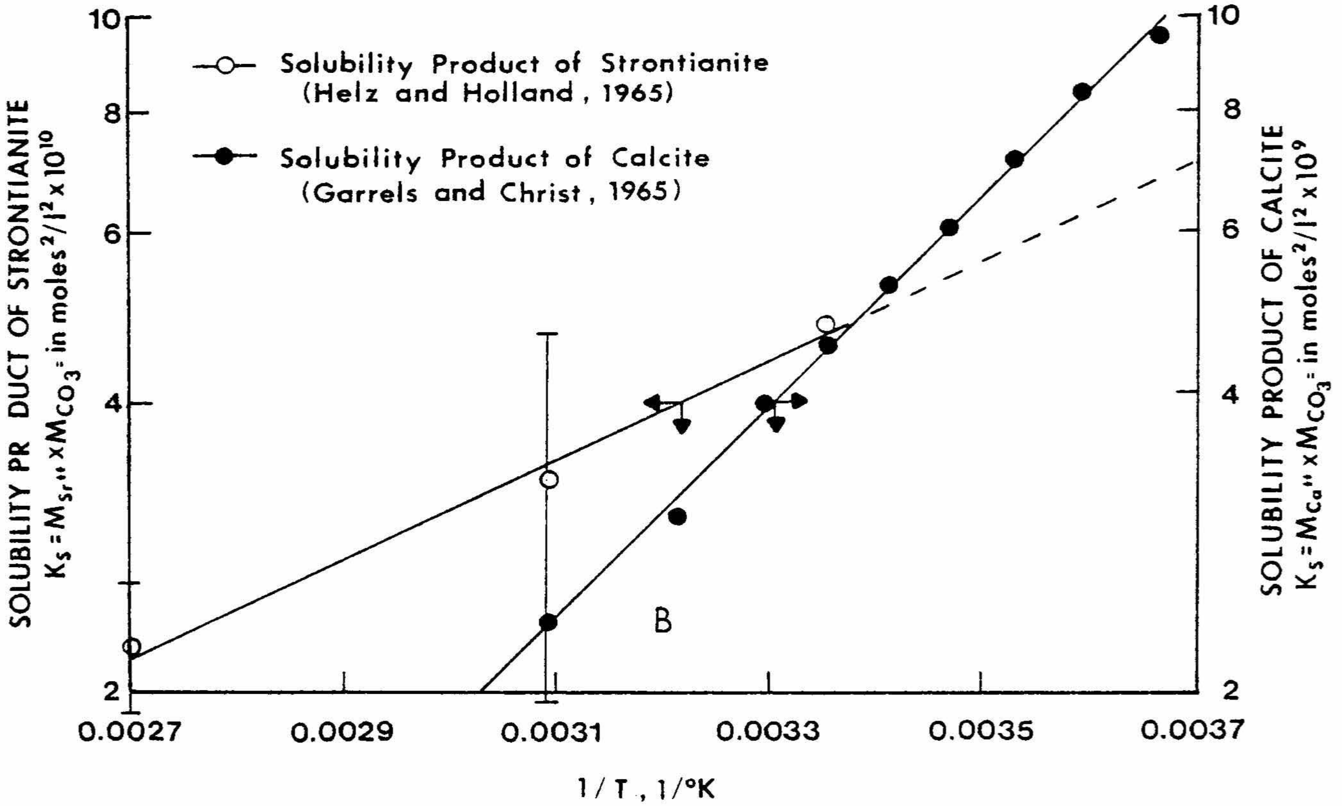

100
10
1.0
0.1
Mg, ppm
AREA I
AREA II
0.1
1.0
10
100
Ca, ppm

Figure I-12

Correlation Plot for Mg vs Ca, Areas I and II



$K_{HCO_3^-} = \frac{a_{H^+} \times a_{CO_3^=}}{a_{HCO_3^-}}$ in moles / l x 10^{-11}
10
8
6
4
2
A
0 0027
0.0029
0.0031
0 0033
0 0035
0.0037



Solubility Product of Strontianite (Helz and Holland, 1965)
Solubility Product of Calcite (Garrels and Christ, 1965)
SOLUBILITY PR DUCT OF STRONTIANITE
$K_S = M_{Sr^{++}} \times M_{CO_3^=}$ in moles^2/l^2 x 10^{10}
SOLUBILITY PRODUCT OF CALCITE
$K_S = M_{Ca^{++}} \times M_{CO_3^=}$ in moles^2/l^2 x 10^{9}
10
8
6
4
2
B
0.0027
0.0029
0.0031
0.0033
0.0035
0.0037
1 / T , 1/°K

Figure I-13A

Equilibrium Constant for HCO_3^- vs T

Figure I-13B

Solubility Product of Calcite ($CaCO_3$) and Strontianite ($SrCO_3$) vs T

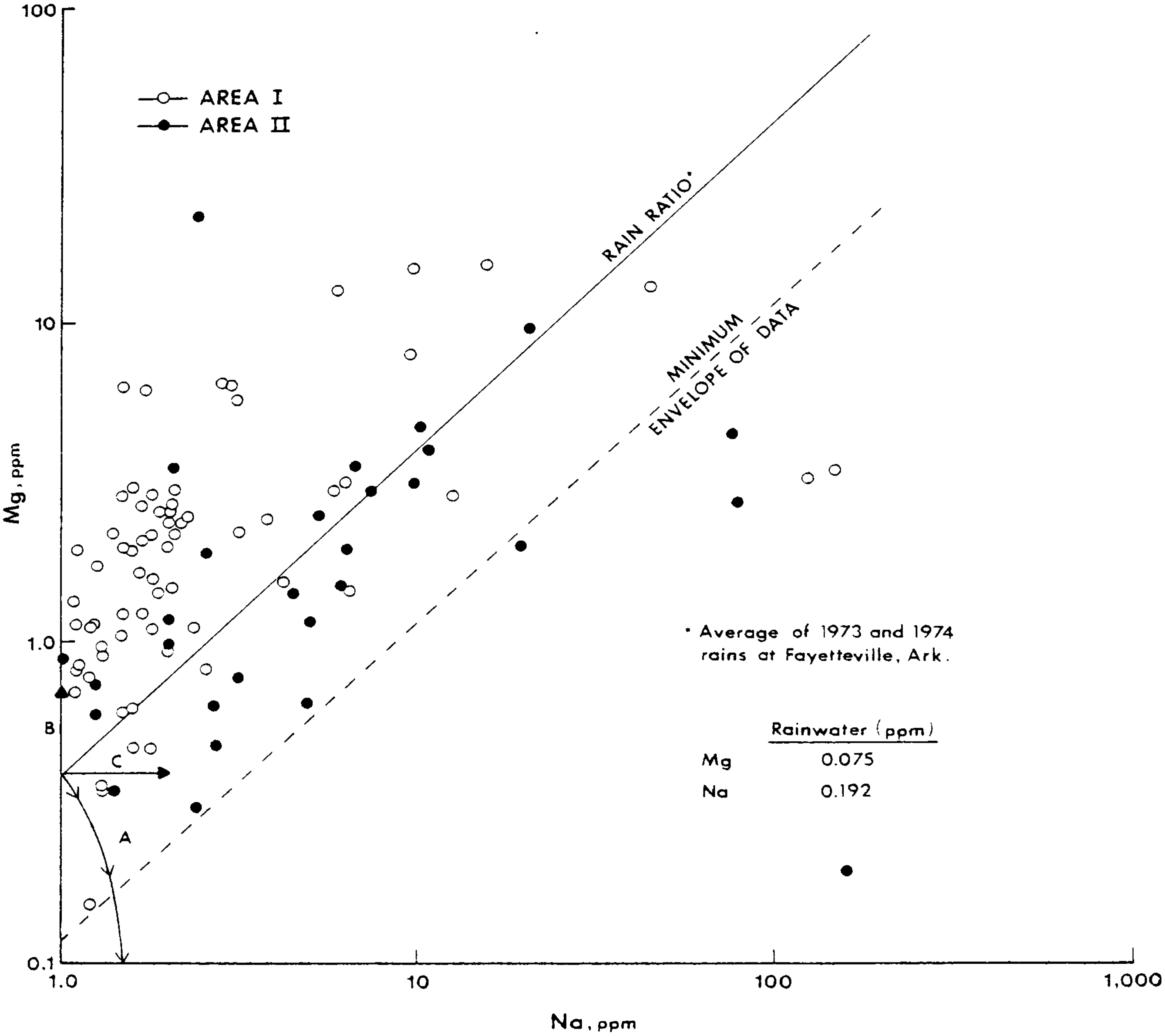
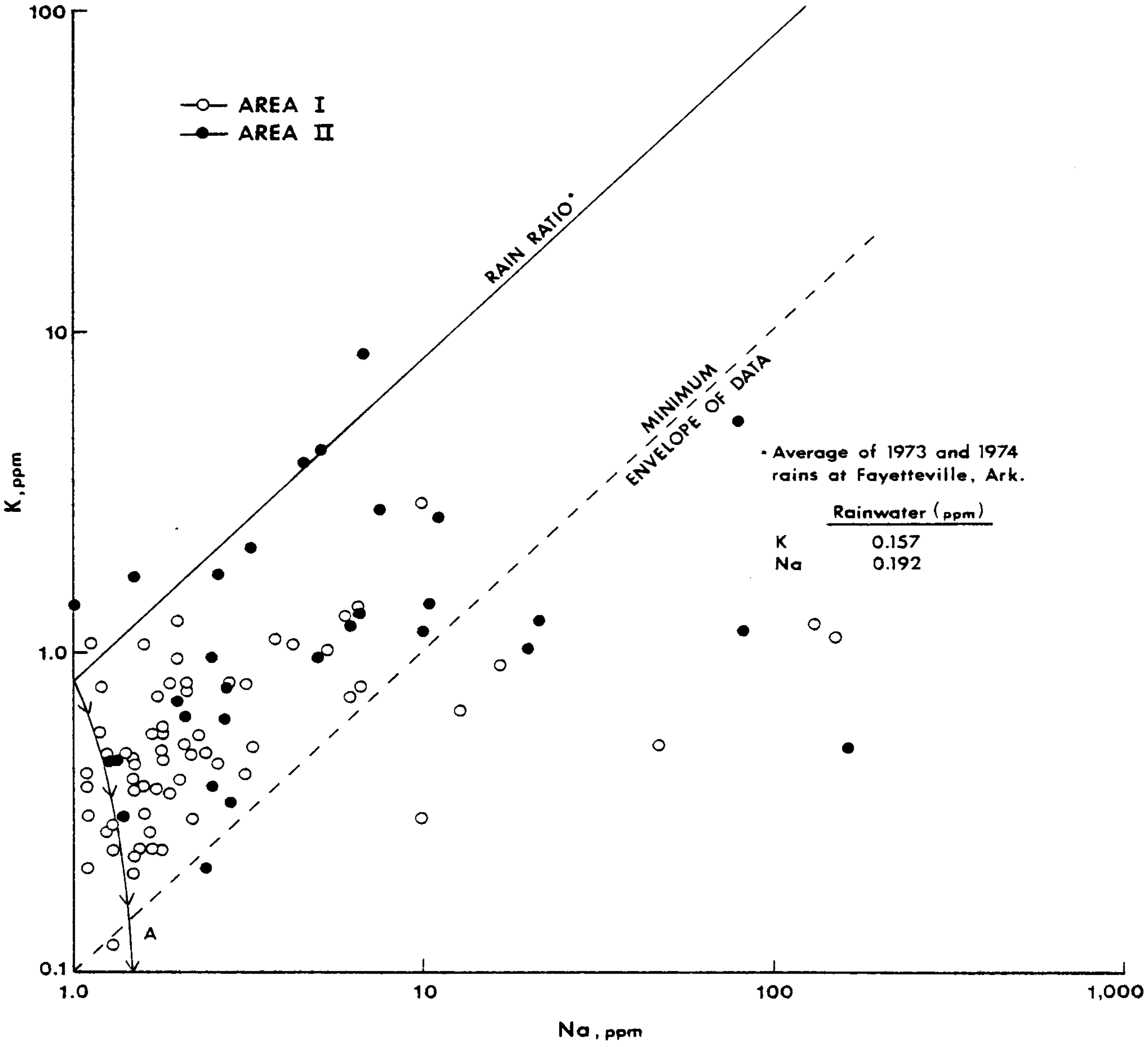

100
10
1.0
0.1
Mg, ppm
1.0
10
100
1,000
Na, ppm
AREA I
AREA II
RAIN RATIO*
MINIMUM ENVELOPE OF DATA
A
B
C
* Average of 1973 and 1974 rains at Fayetteville, Ark.
Rainwater (ppm)
Mg 0.075
Na 0.192

Figure I-14

Concentration of Mg vs Concentration of Na for Areas I and II



* Average of 1973 and 1974 rains at Fayetteville, Ark.

	Rainwater (ppm)
K	0.157
Na	0.192

Figure I-15

Concentration of K vs Concentration of Na for Areas I and II

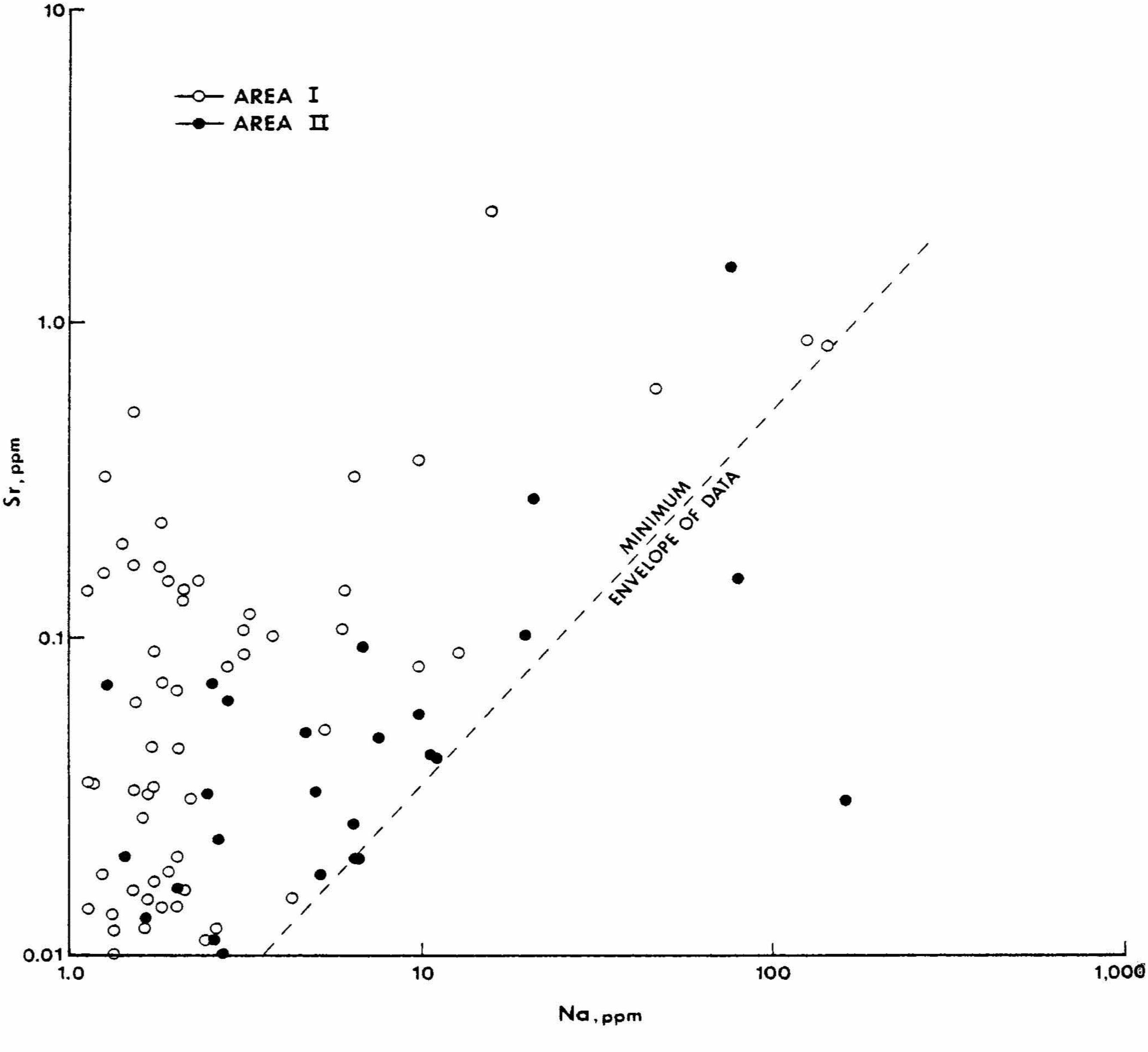

10
1.0
0.1
0.01
Sr, ppm
AREA I
AREA II
MINIMUM
ENVELOPE OF DATA
1.0
10
100
1,000
Na, ppm

Figure I-16

Concentration of Sr vs Concentration of Na for Areas I and II

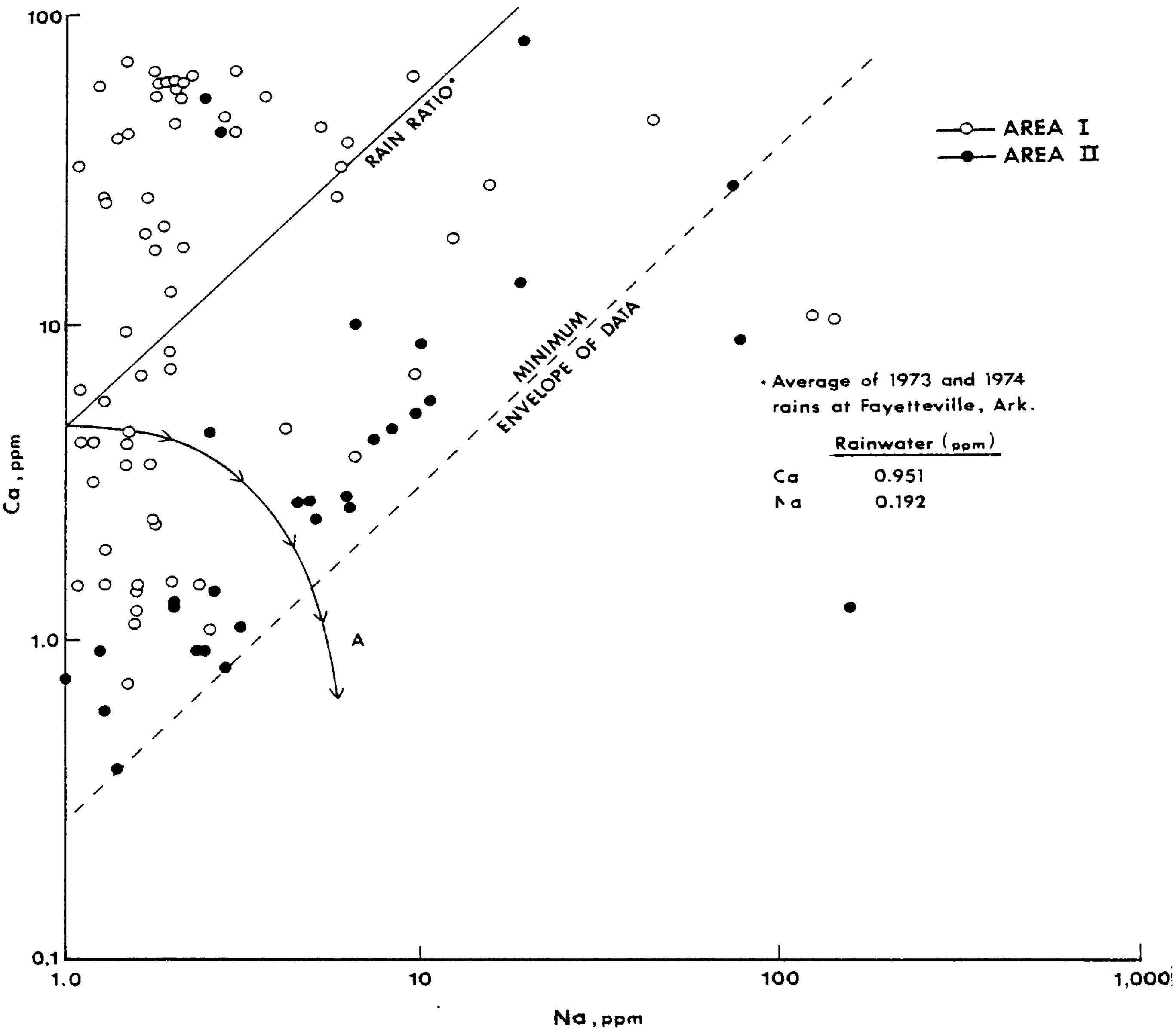

100
10
1.0
0.1
Ca, ppm
1.0
10
100
1,000
Na, ppm
RAIN RATIO*
MINIMUM ENVELOPE OF DATA
A
AREA I
AREA II
* Average of 1973 and 1974 rains at Fayetteville, Ark.
Rainwater (ppm)
Ca 0.951
Na 0.192

Figure I-17

Concentration of Ca vs Concentration of Na for Areas I and II

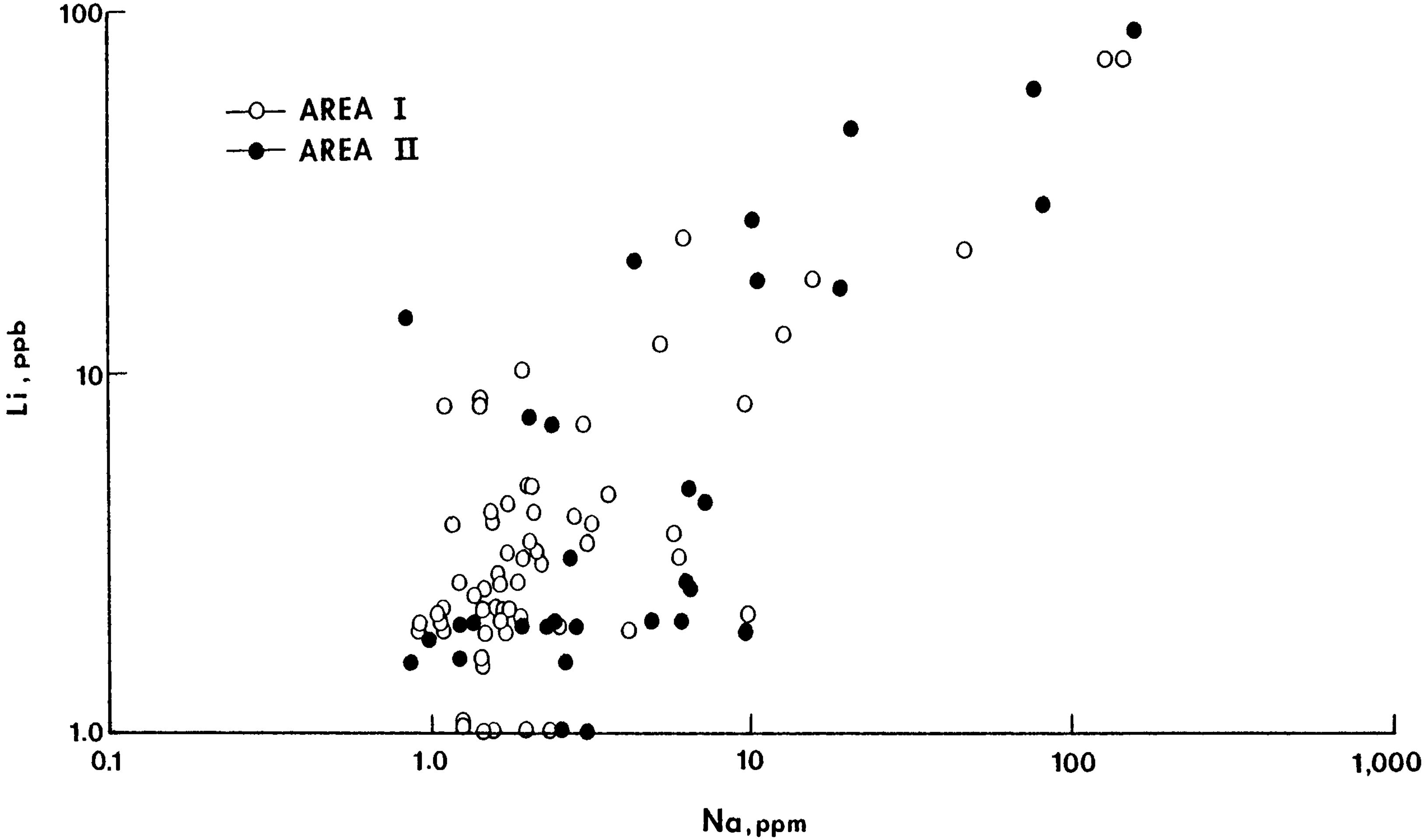

100
10
1.0
Li , ppb
0.1
1.0
10
100
1,000
Na , ppm
○ AREA I
● AREA II

Figure I-18

Concentration of Li vs Concentration of Na for Areas I and II

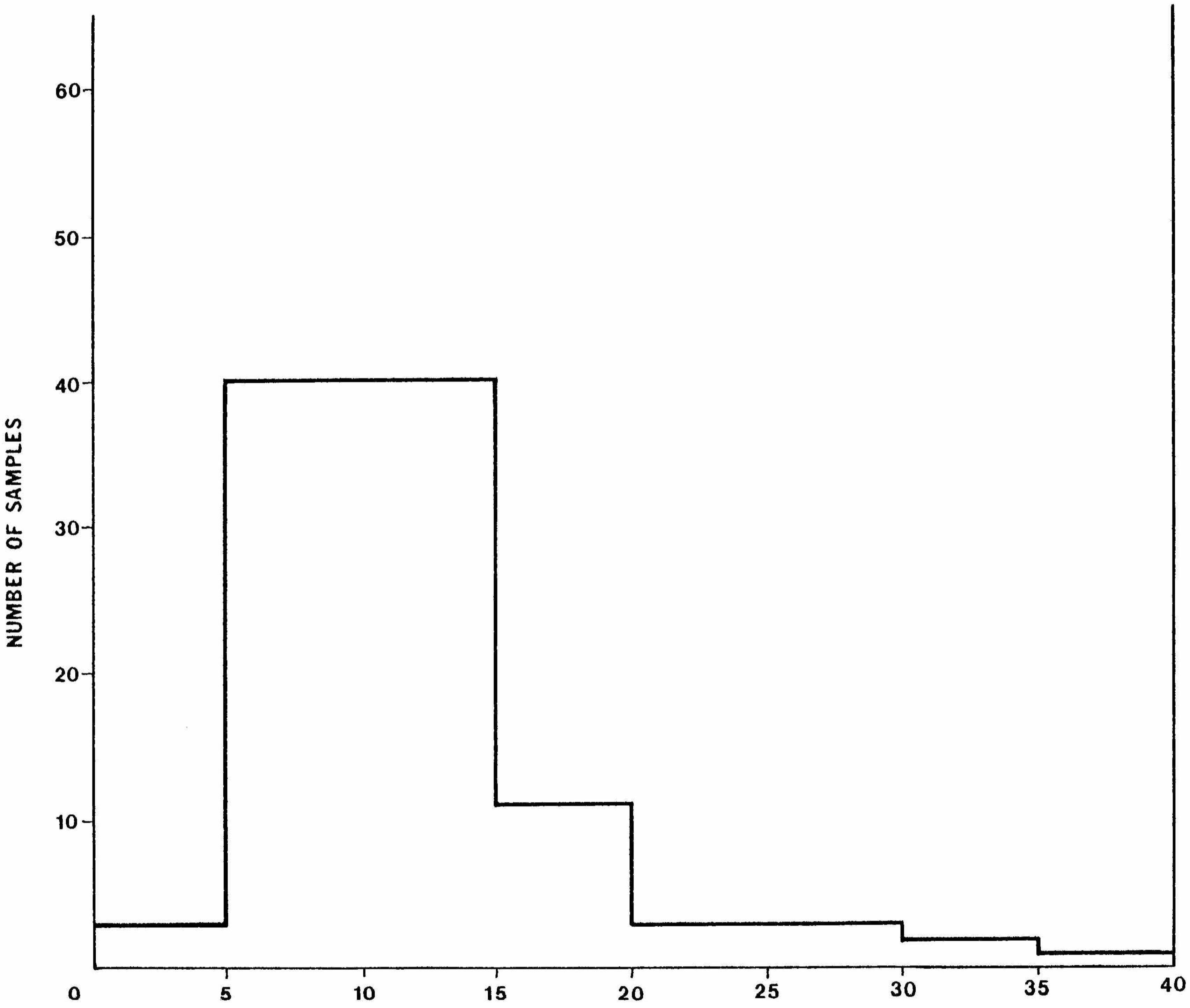

60
50
40
30
20
10
NUMBER OF SAMPLES
0
5
10
15
20
25
30
35
40

Figure II-1

Histogram of Silica Concentration in Spring Waters
of Areas I and II Combined

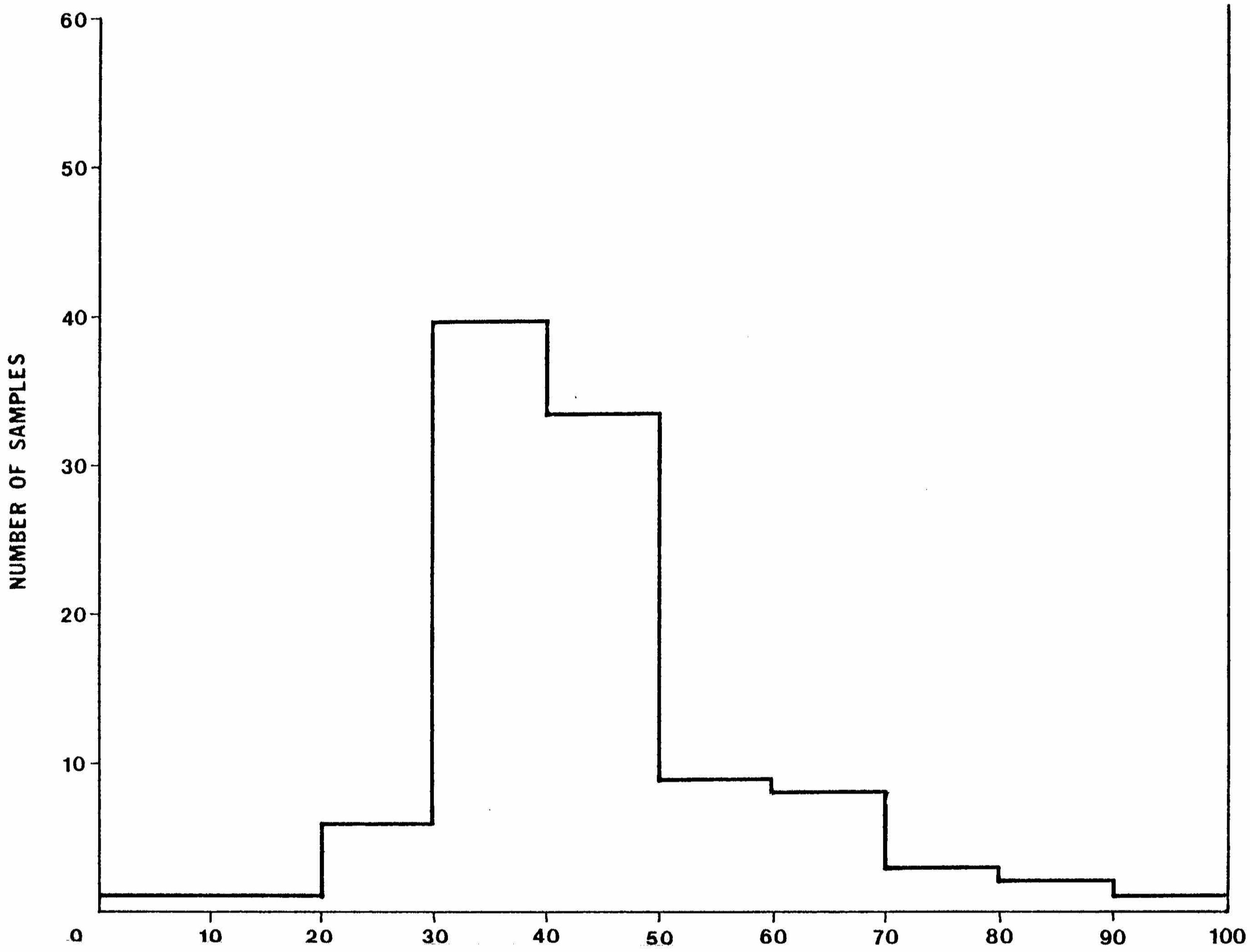

NUMBER OF SAMPLES
60
50
40
30
20
10
0
10
20
30
40
50
60
70
80
90
100

Figure II-2

Histogram of Silica Geotemperatures of Spring Waters for Areas I and II Combined

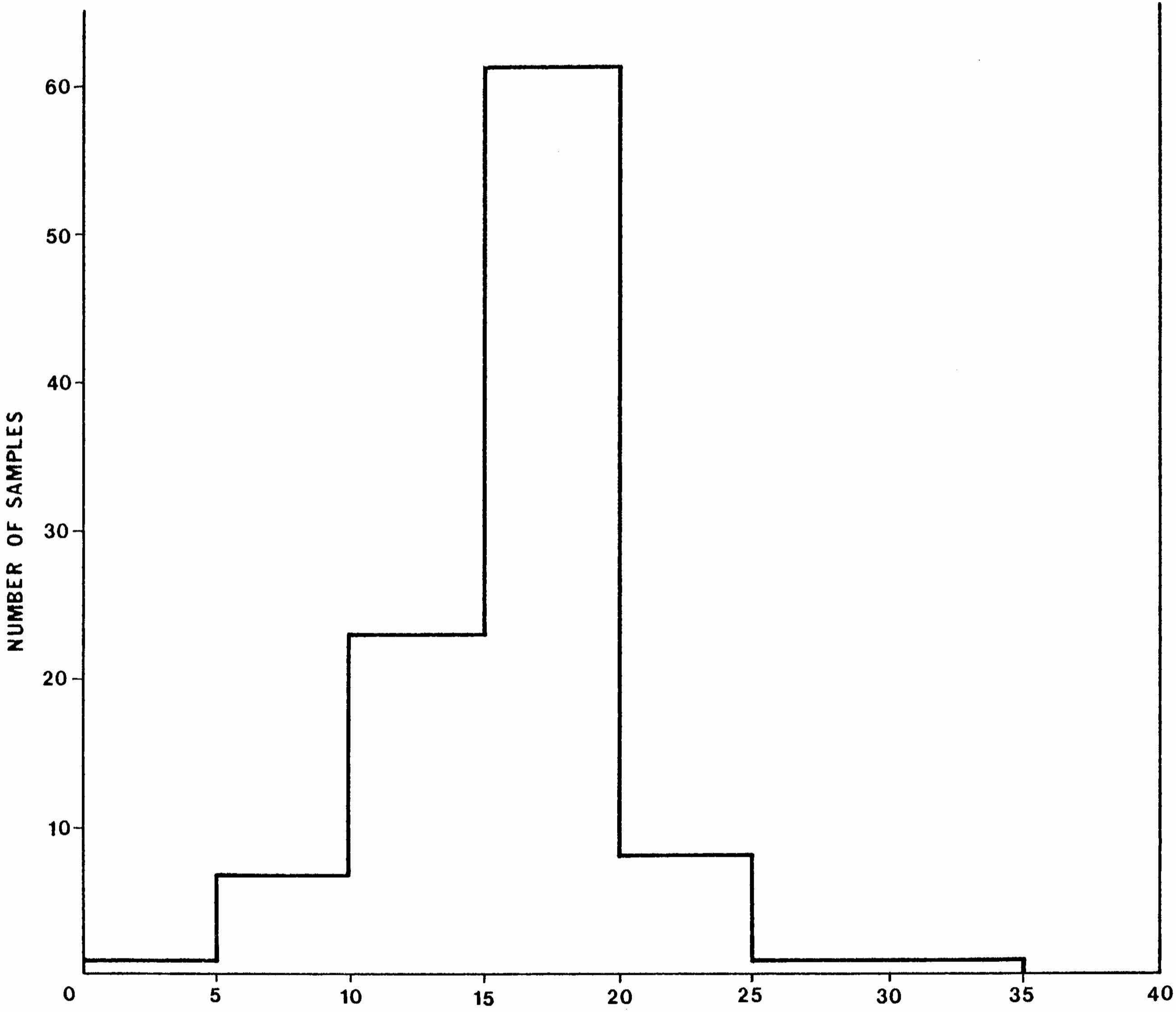

NUMBER OF SAMPLES
60
50
40
30
20
10
0
5
10
15
20
25
30
35
40

Figure II-3

Histogram of Surface Temperatures of Spring
Waters for Areas I and II Combined

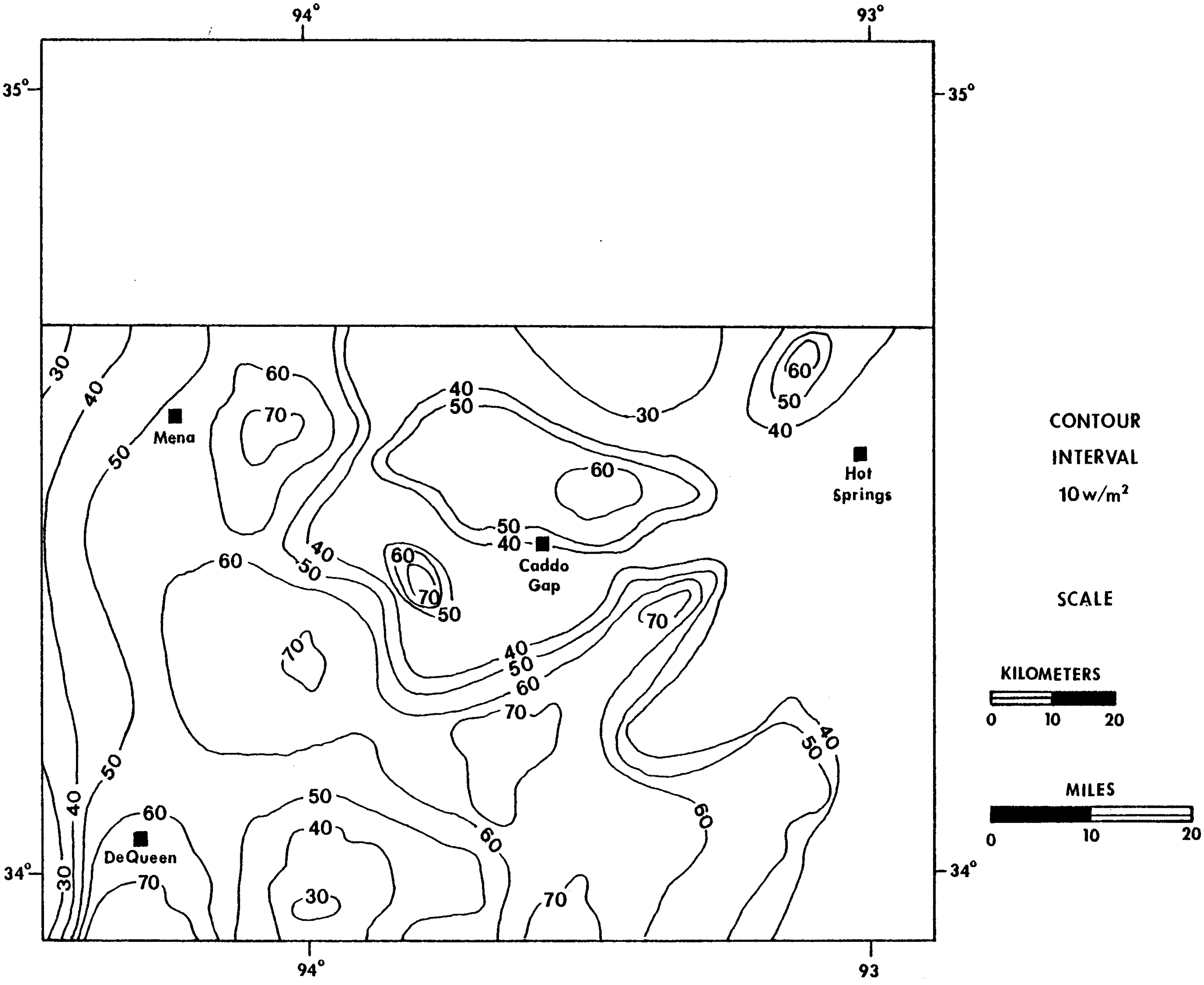

94°
93°
35°
35°
34°
34°
94°
93
Mena
Hot Springs
Caddo Gap
DeQueen
30
40
50
60
70
CONTOUR INTERVAL 10 w/m²
SCALE
KILOMETERS
0
10
20
MILES
0
10
20

Figure II-4

Contour Map of Heat Flow

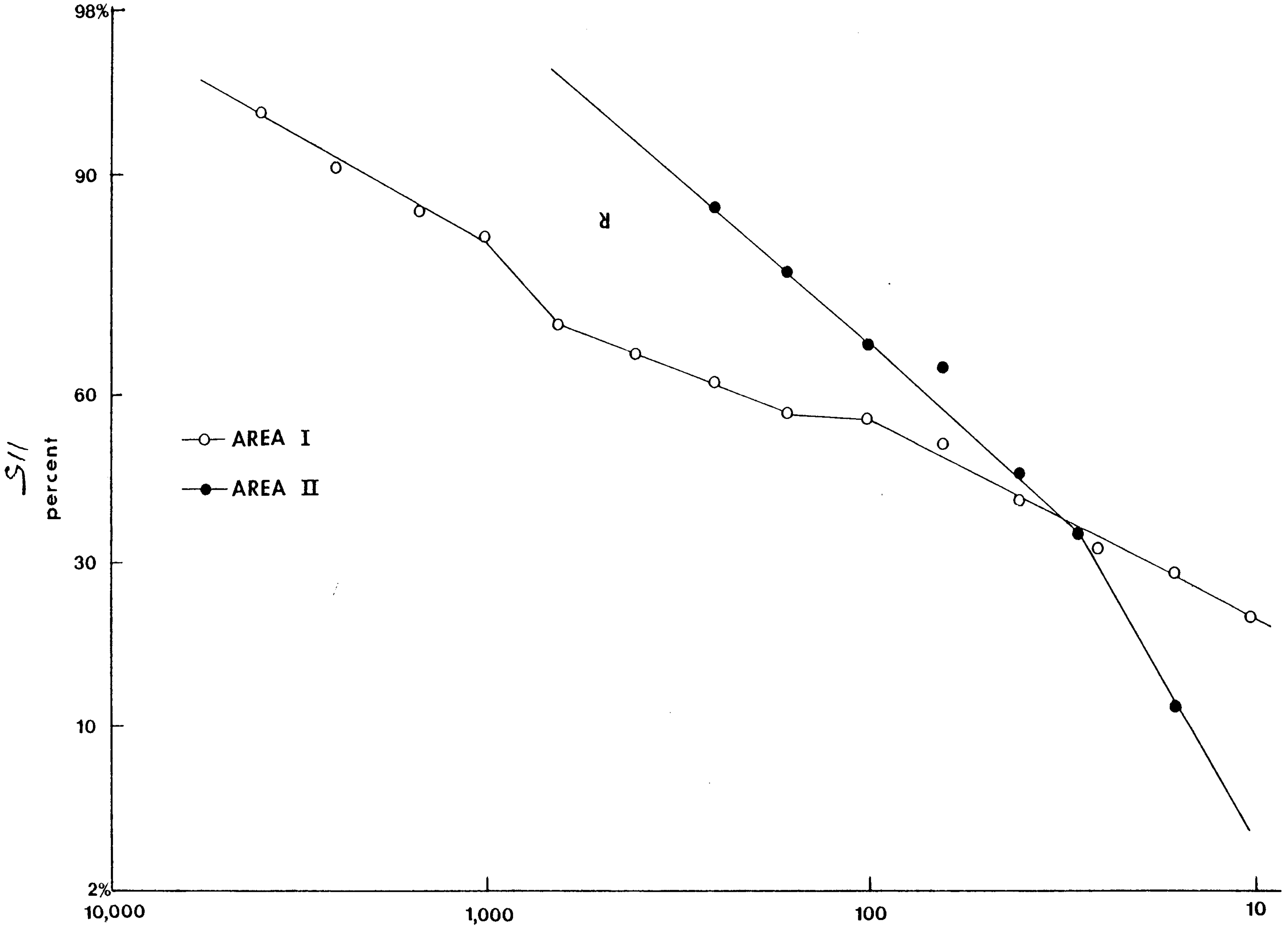

98%
90
60
30
10
2%
S//
percent
AREA I
AREA II
10,000
1,000
100
10

Figure III-1

Cumulative Frequency Curve for Fe, Areas I and II

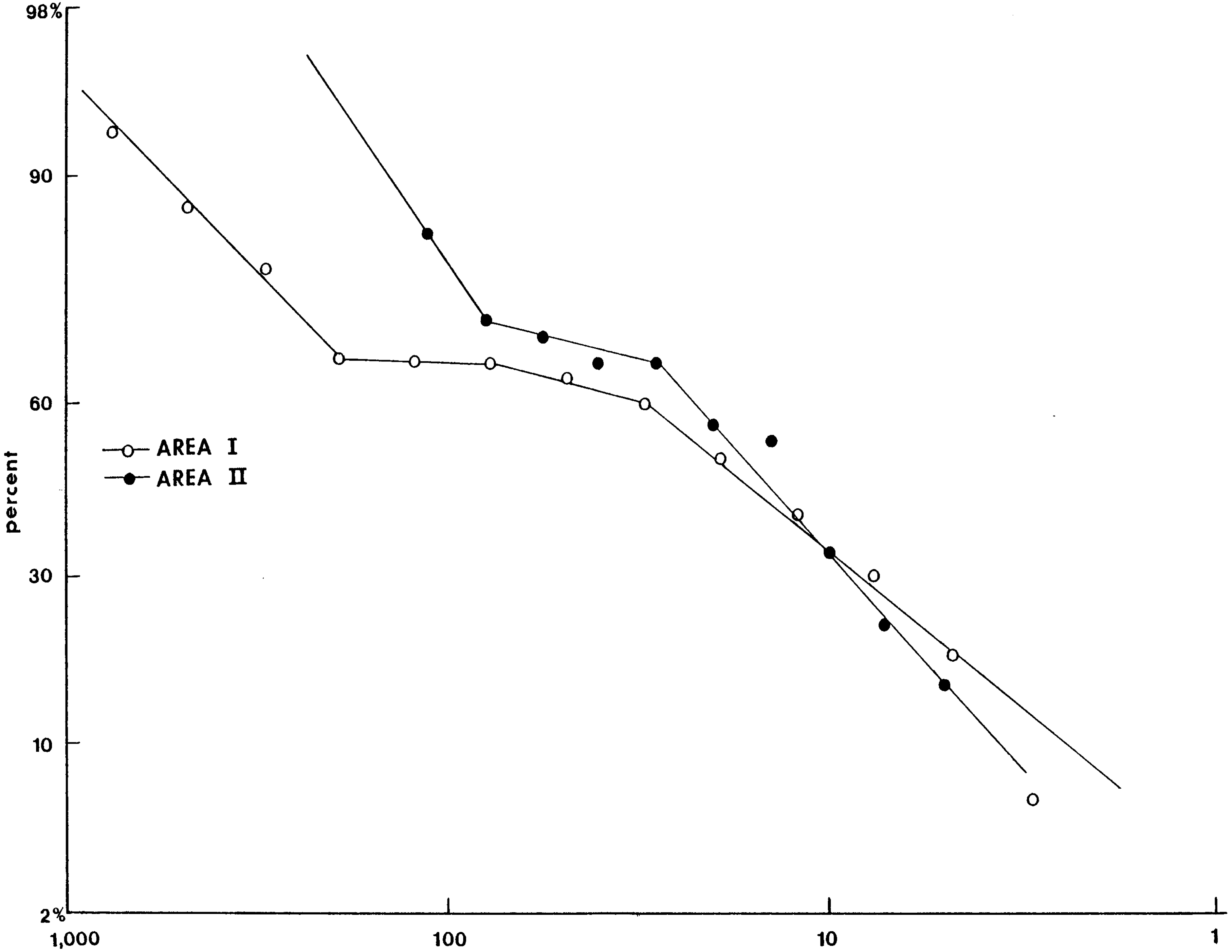

98%
90
60
30
10
2%
percent
AREA I
AREA II
1,000
100
10
1

Figure III-2

Cumulative Frequency Curve for Mn, Areas I and II

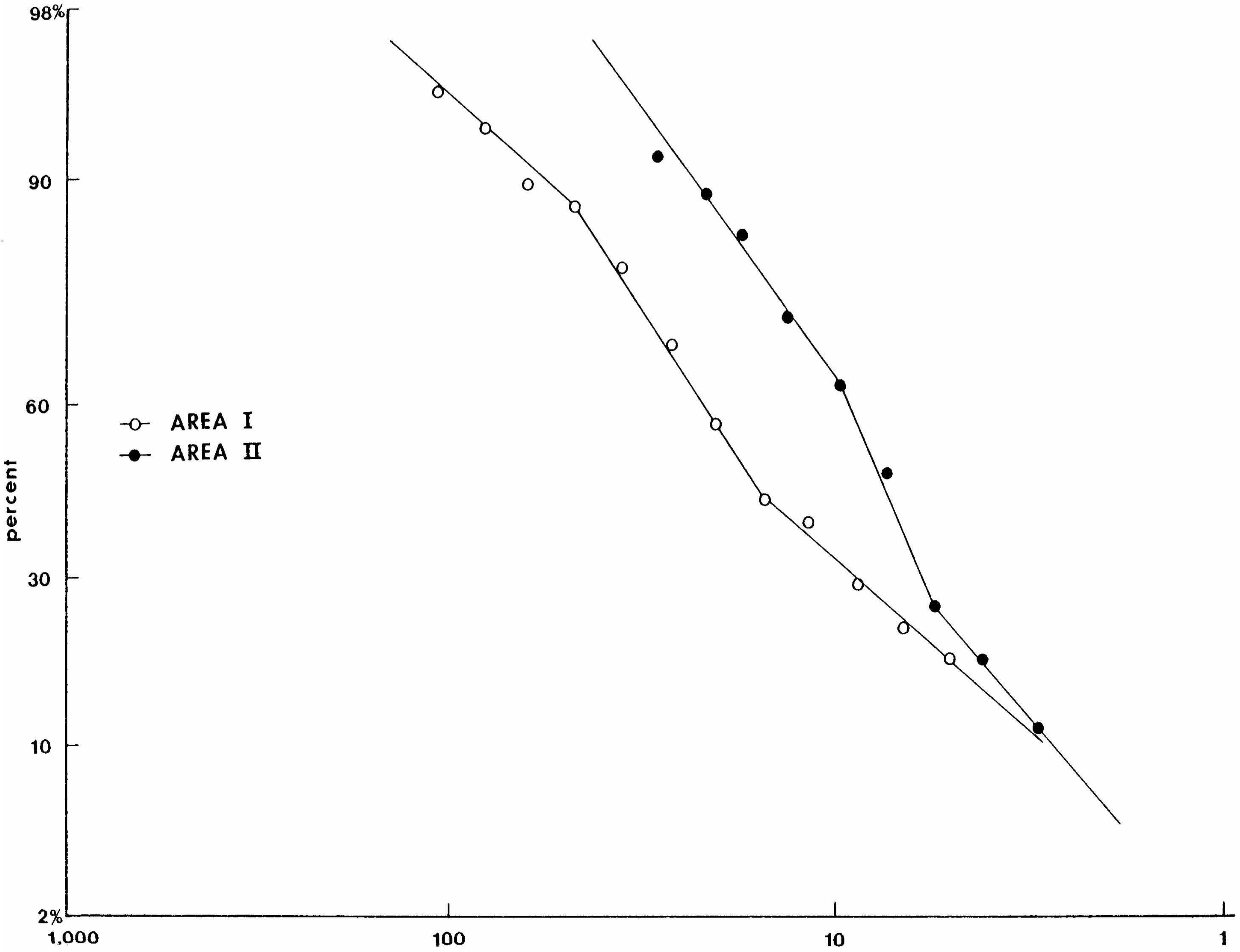

98%
90
60
30
10
2%
percent
1,000
100
10
1
AREA I
AREA II

Figure III-3

Cumulative Frequency Curve for Zn, Areas I and II

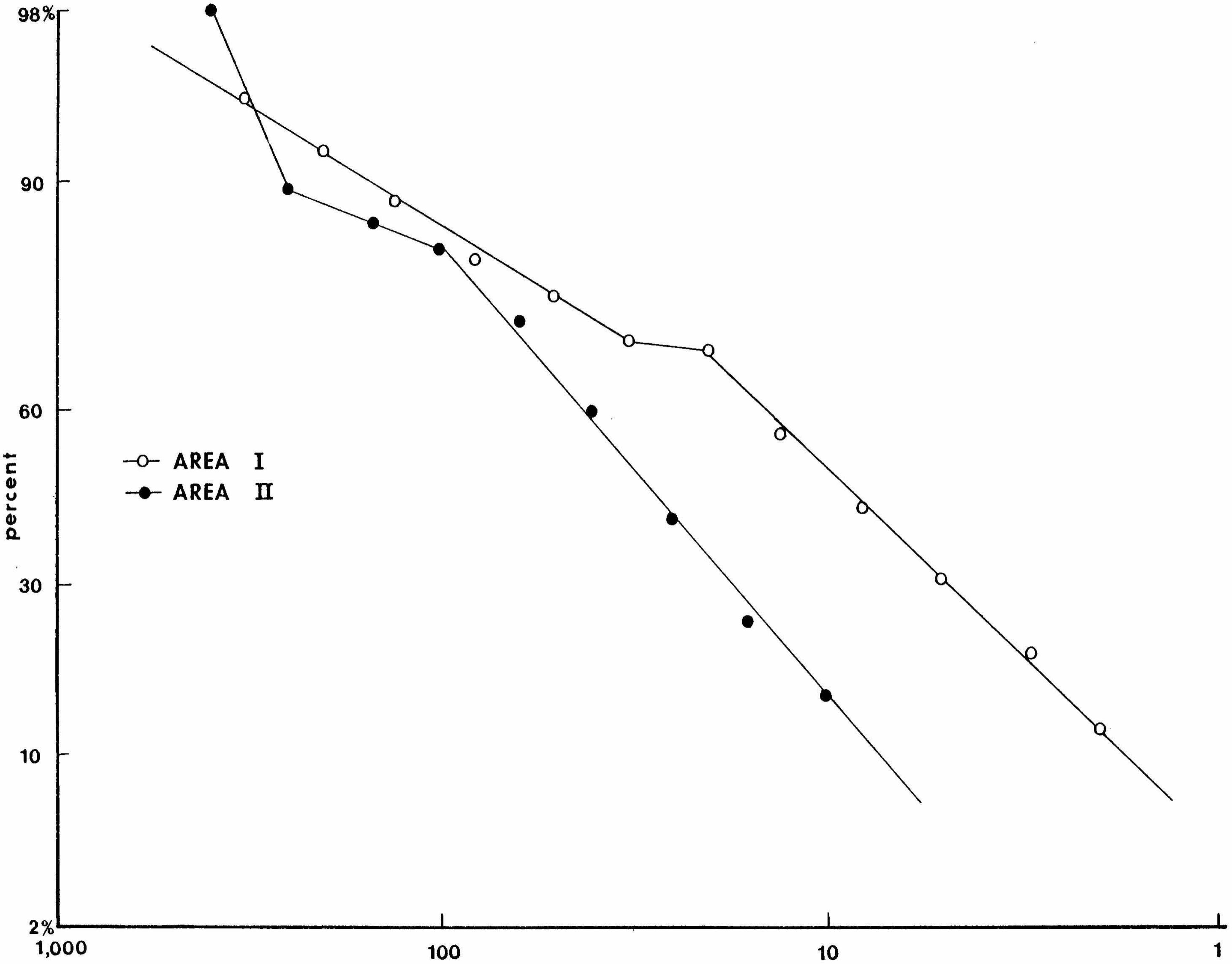

98%
90
60
30
10
2%
percent
AREA I
AREA II
1,000
100
10
1

Figure III-4

Cumulative Frequency Curve for Ba, Areas I and II

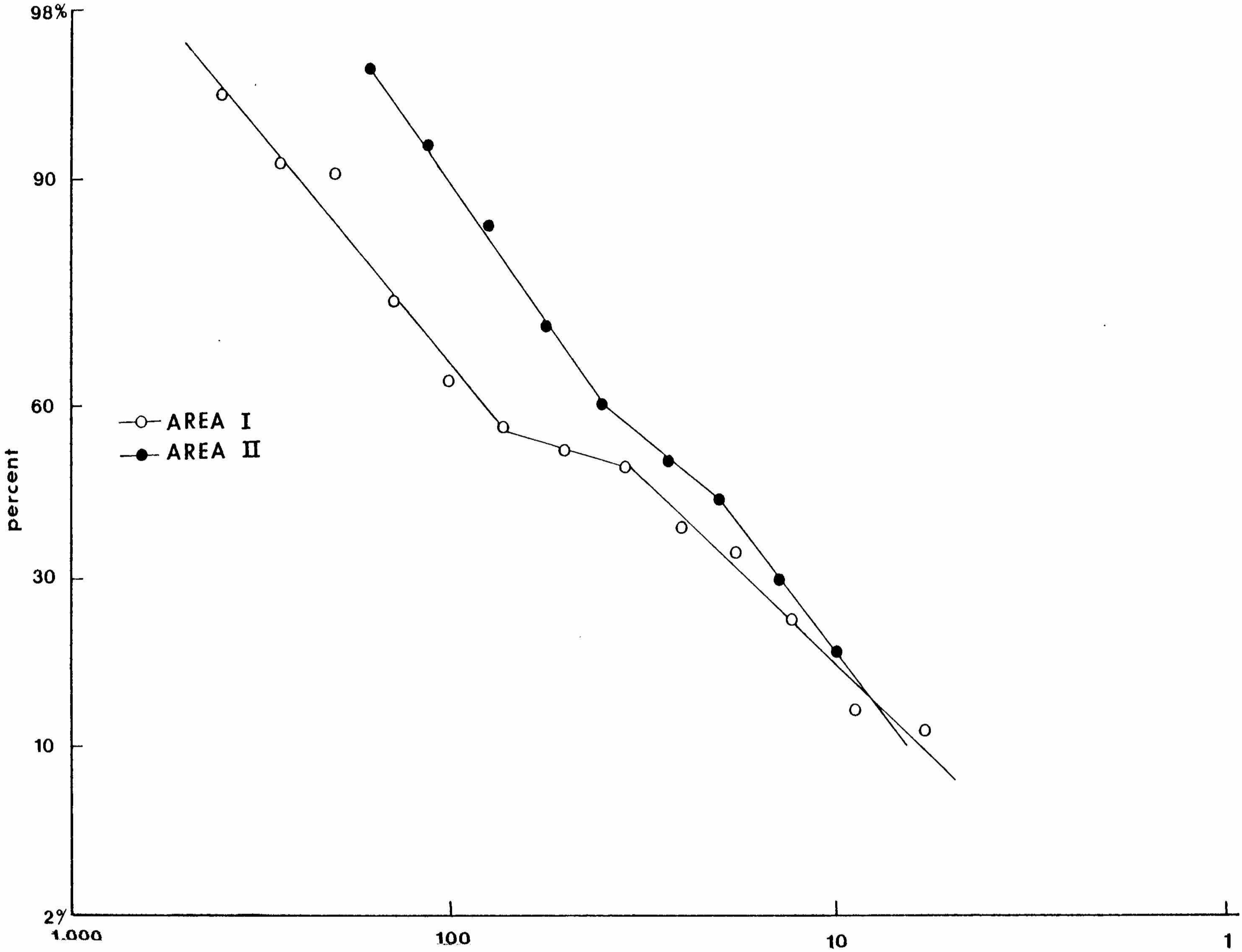

98%
90
60
30
10
2%
percent
1.000
100
10
1
AREA I
AREA II

Figure III-5

Cumulative Frequency Curve for Sr, Areas I and II

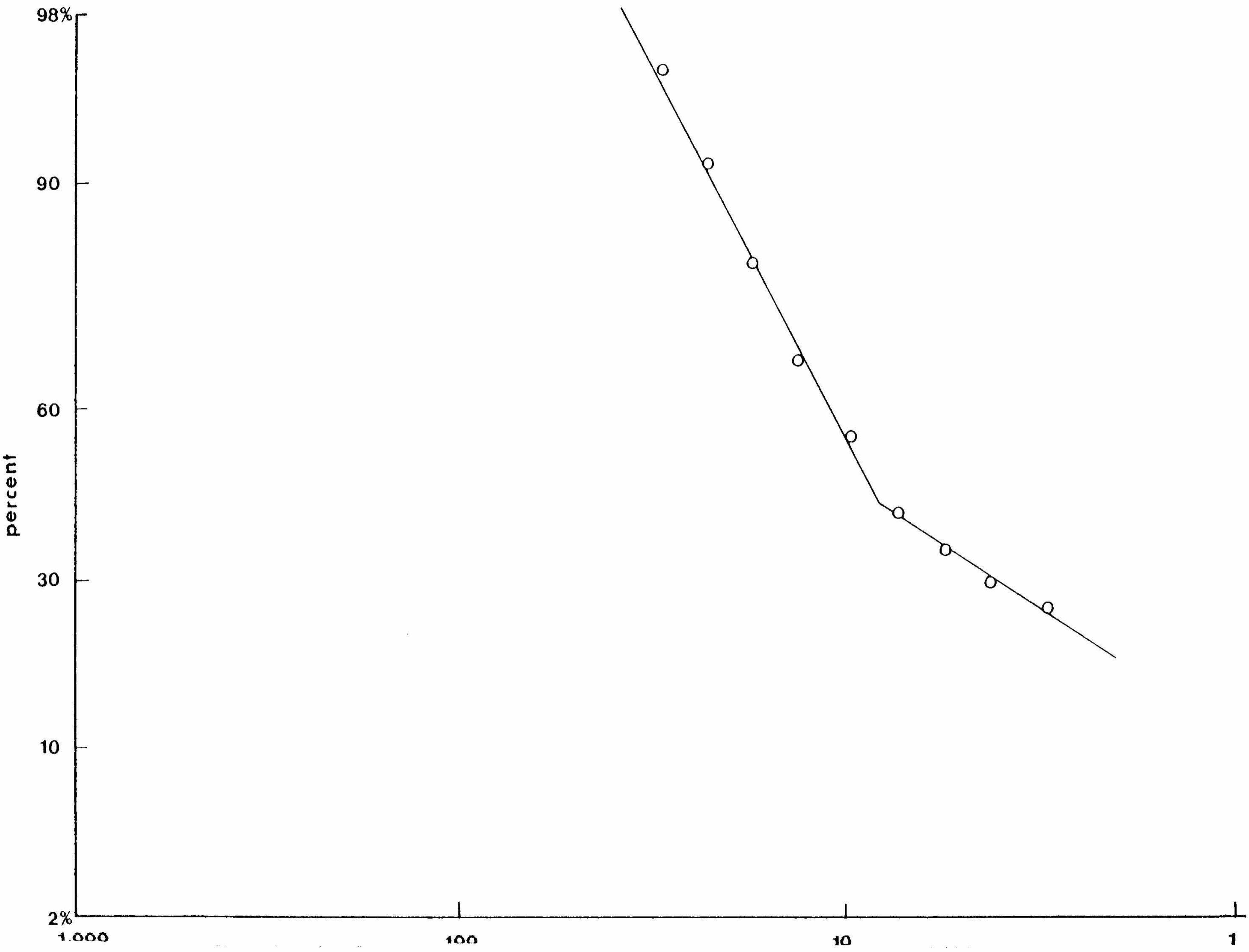

98%
90
60
30
10
2%
percent
1,000
100
10
1

Figure III-6

Cumulative Frequency Curve for Ni, Area I

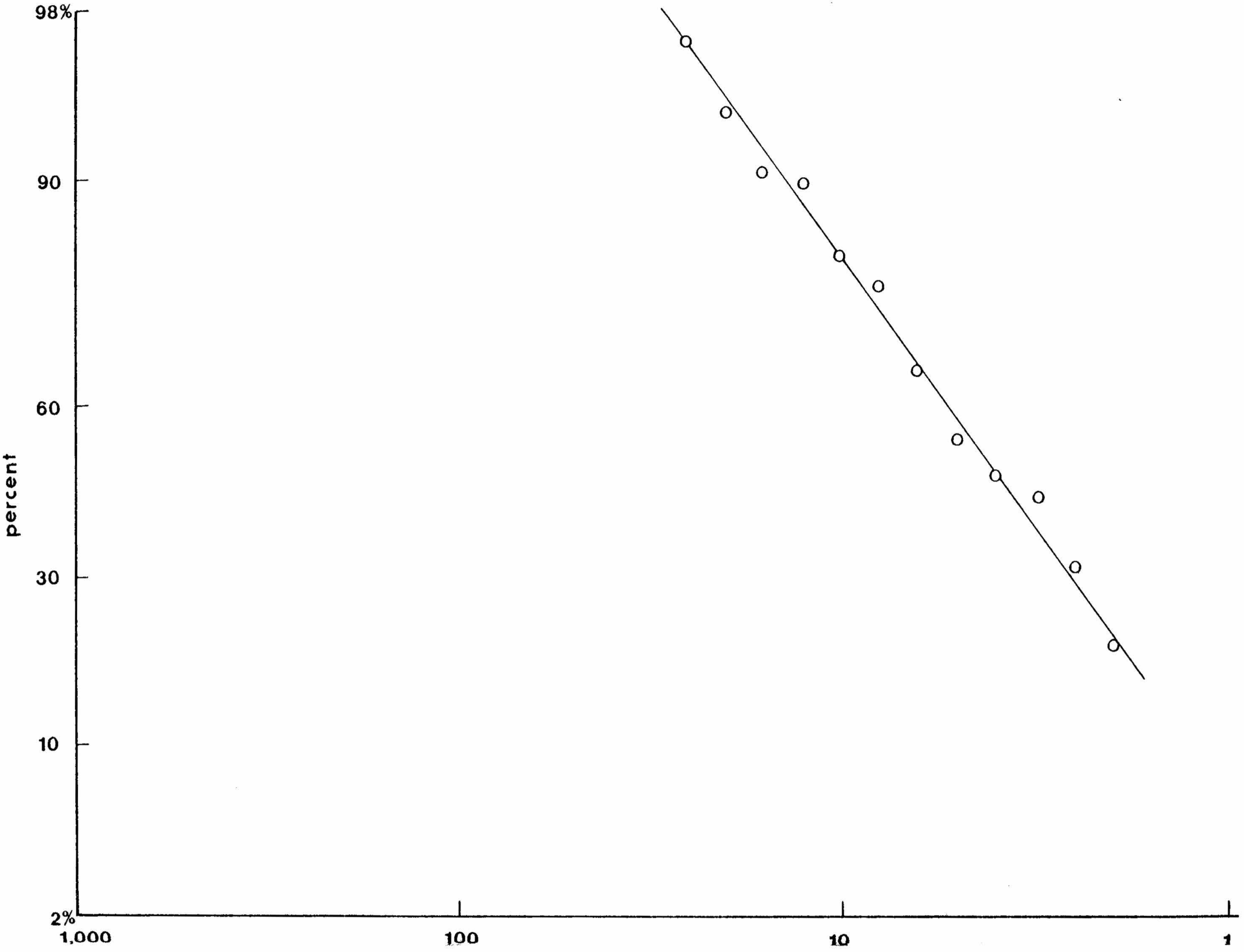

98%
90
60
30
10
2%
percent
1,000
100
10
1

Figure III-7

Cumulative Frequency Curve for Co, Area I

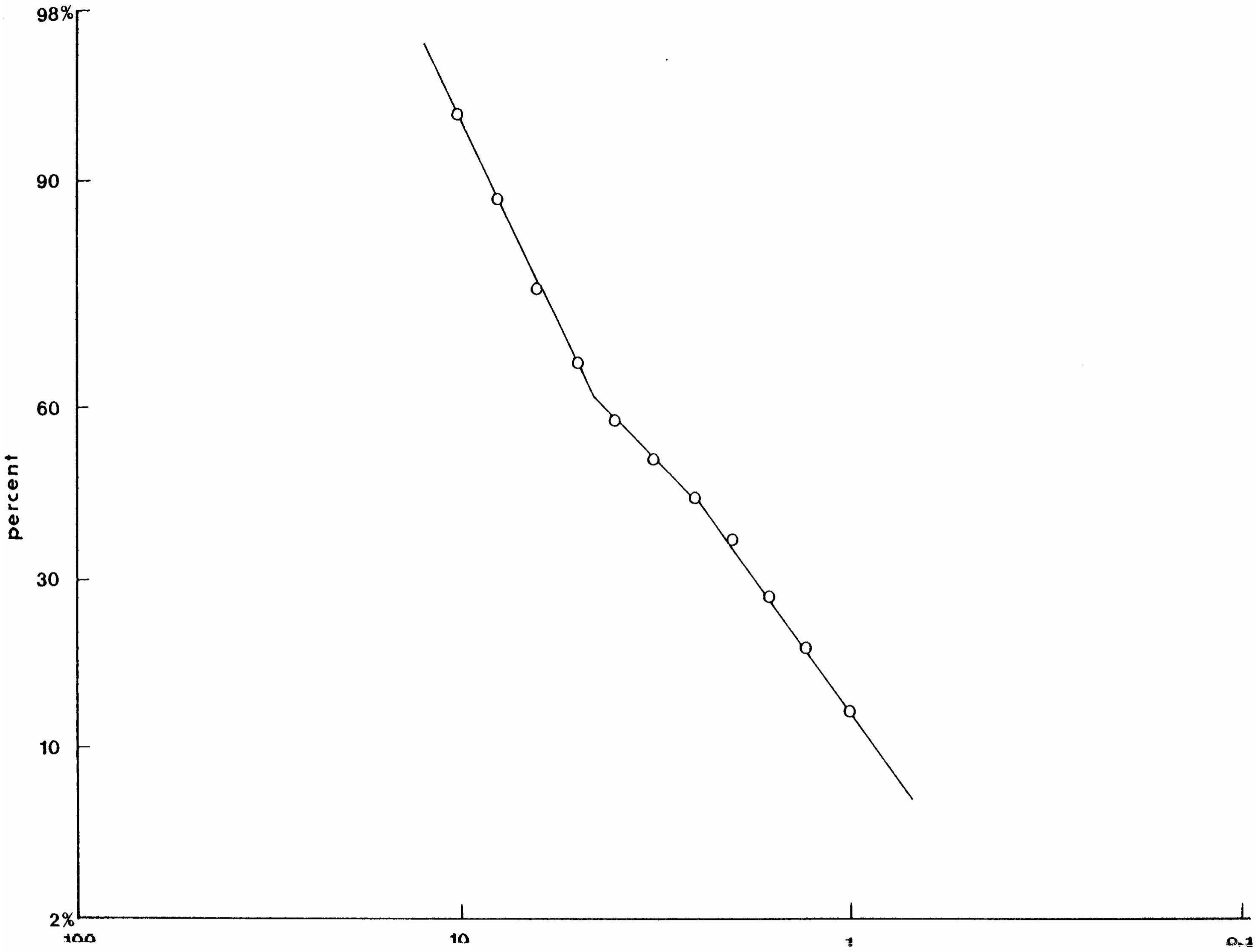

98%
90
60
30
10
2%
percent
100
10
1
0.1

Figure III-8

Cumulative Frequency Curve for Cu, Area I

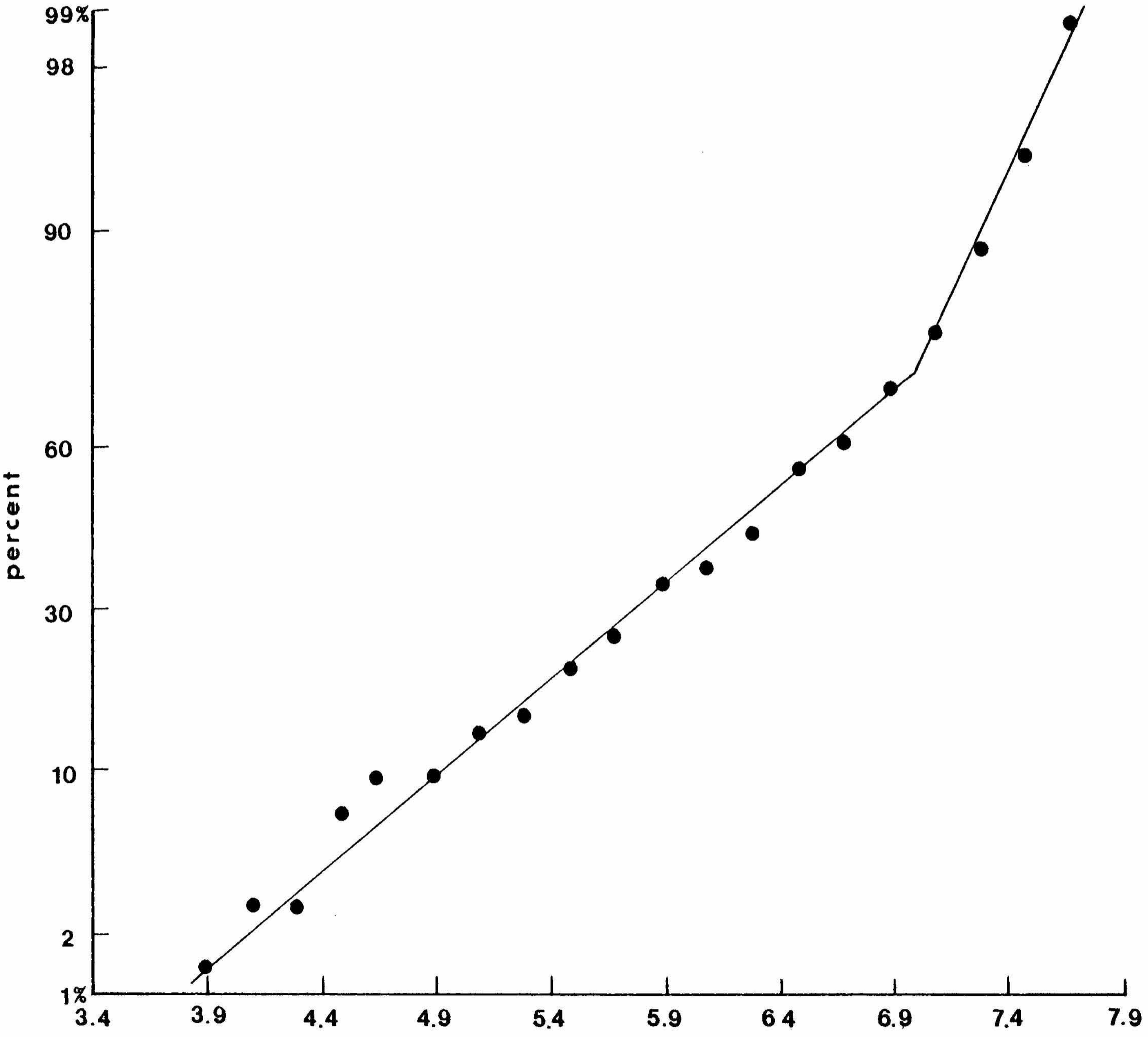

99%
98
90
60
30
10
2
1%
percent
3.4
3.9
4.4
4.9
5.4
5.9
6 4
6.9
7.4
7.9

Figure III-9

Cumulative Frequency Curve for pH, Area I

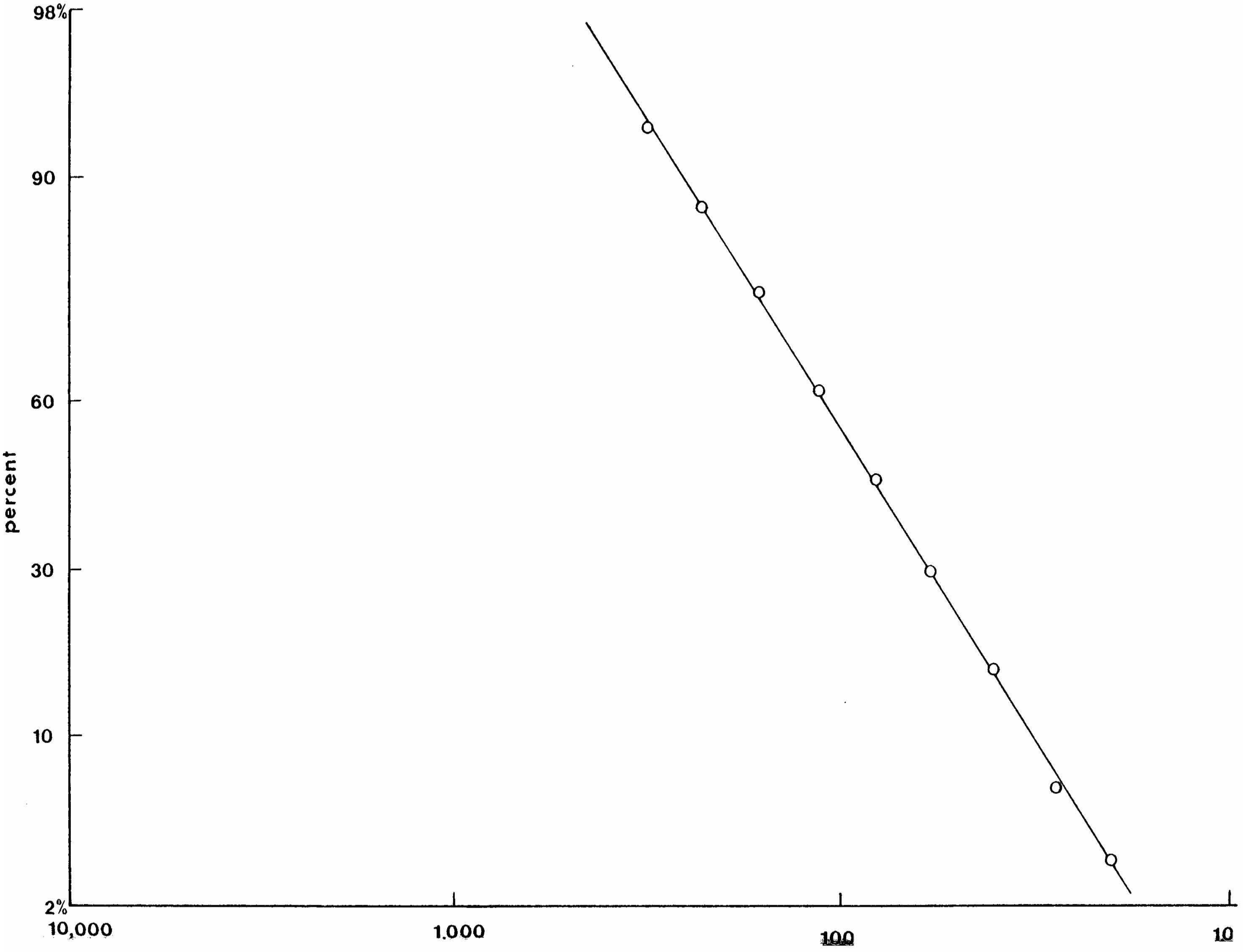

98%
90
60
30
10
2%
percent
10,000
1,000
100
10

Figure III-10

Cumulative Frequency Curve for PO_4, Area II

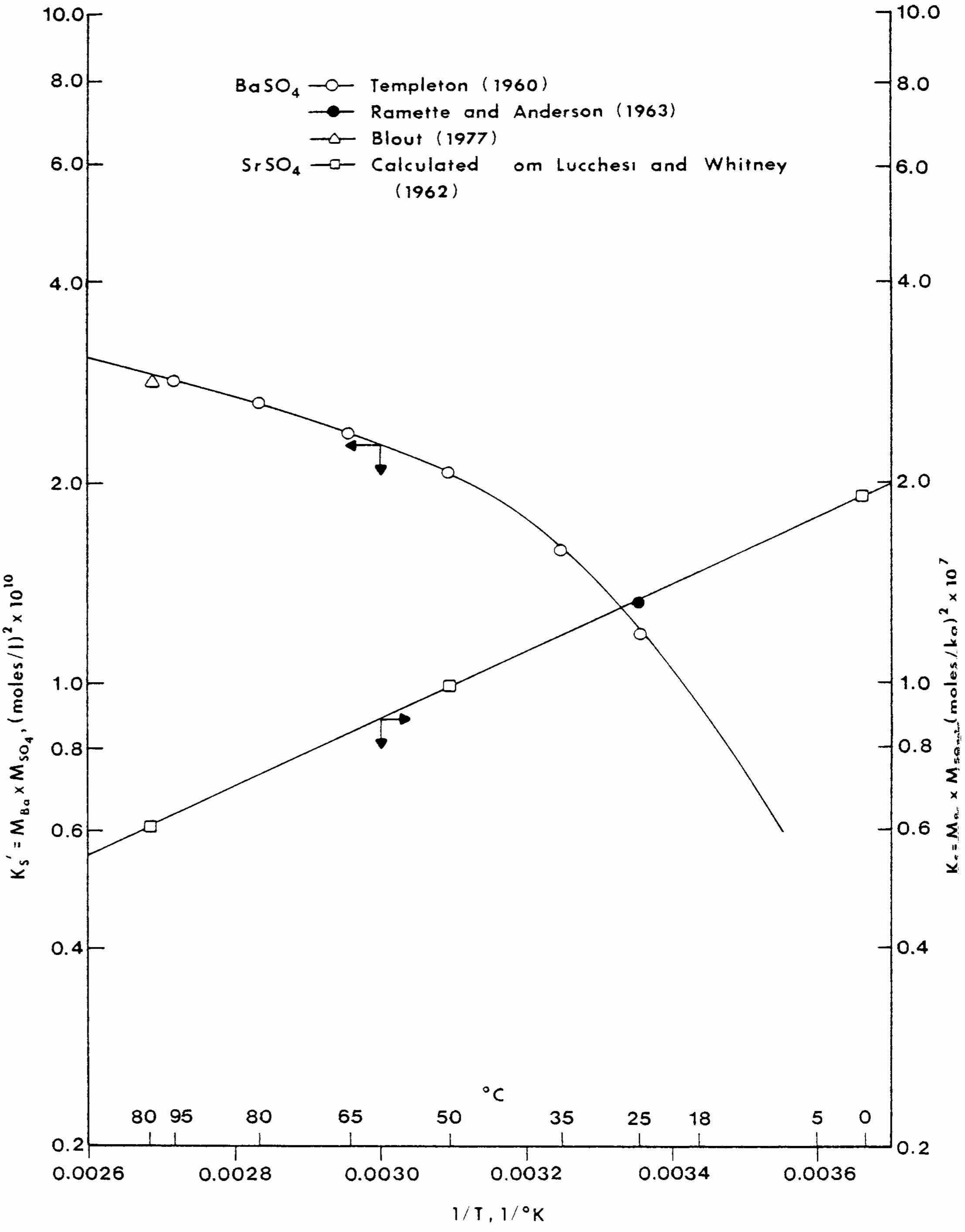

BaSO4 —○— Templeton (1960)
—●— Ramette and Anderson (1963)
—△— Blout (1977)
SrSO4 —□— Calculated om Lucchesi and Whitney (1962)
$K_S' = M_{Ba} \times M_{SO_4}, (\text{moles/l})^2 \times 10^{10}$
$K_s = M_{Ba} \times M_{SO_4}, (\text{moles/kg})^2 \times 10^7$
10.0
8.0
6.0
4.0
2.0
1.0
0.8
0.6
0.4
0.2
°C
80
95
80
65
50
35
25
18
5
0
0.0026
0.0028
0.0030
0.0032
0.0034
0.0036
1/T, 1/°K

Figure III-11

Solubility Product of Barite ($BaSO_4$) and Celestite ($SrSO_4$) vs Temperature

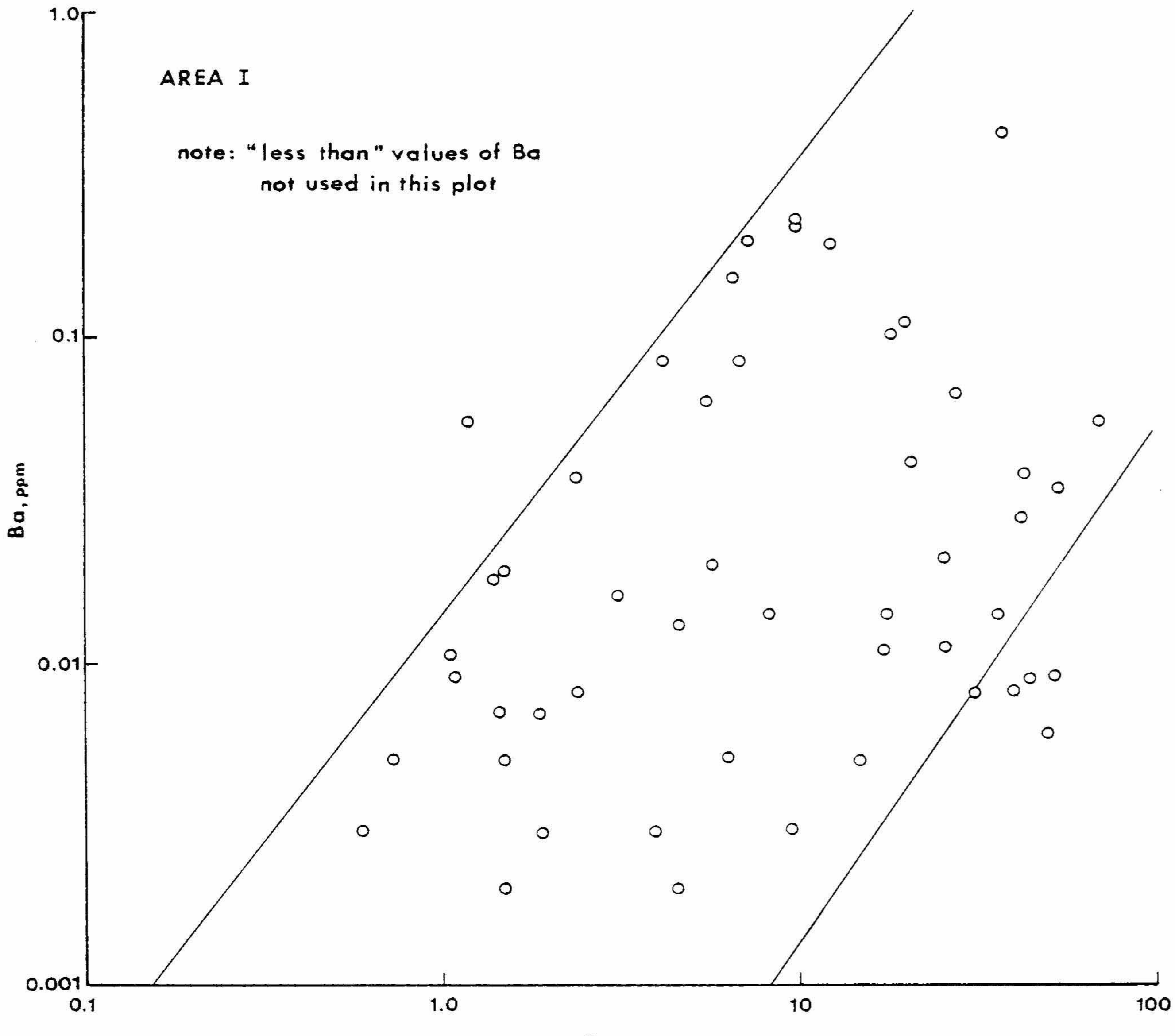

AREA I
note: "less than" values of Ba not used in this plot
Ba, ppm
Ca, ppm
1.0
0.1
0.01
0.001
0.1
1.0
10
100

Figure III-12

Ba^{++} Concentration vs Ca^{++} Concentration For Ouachita Spring Waters of Area I

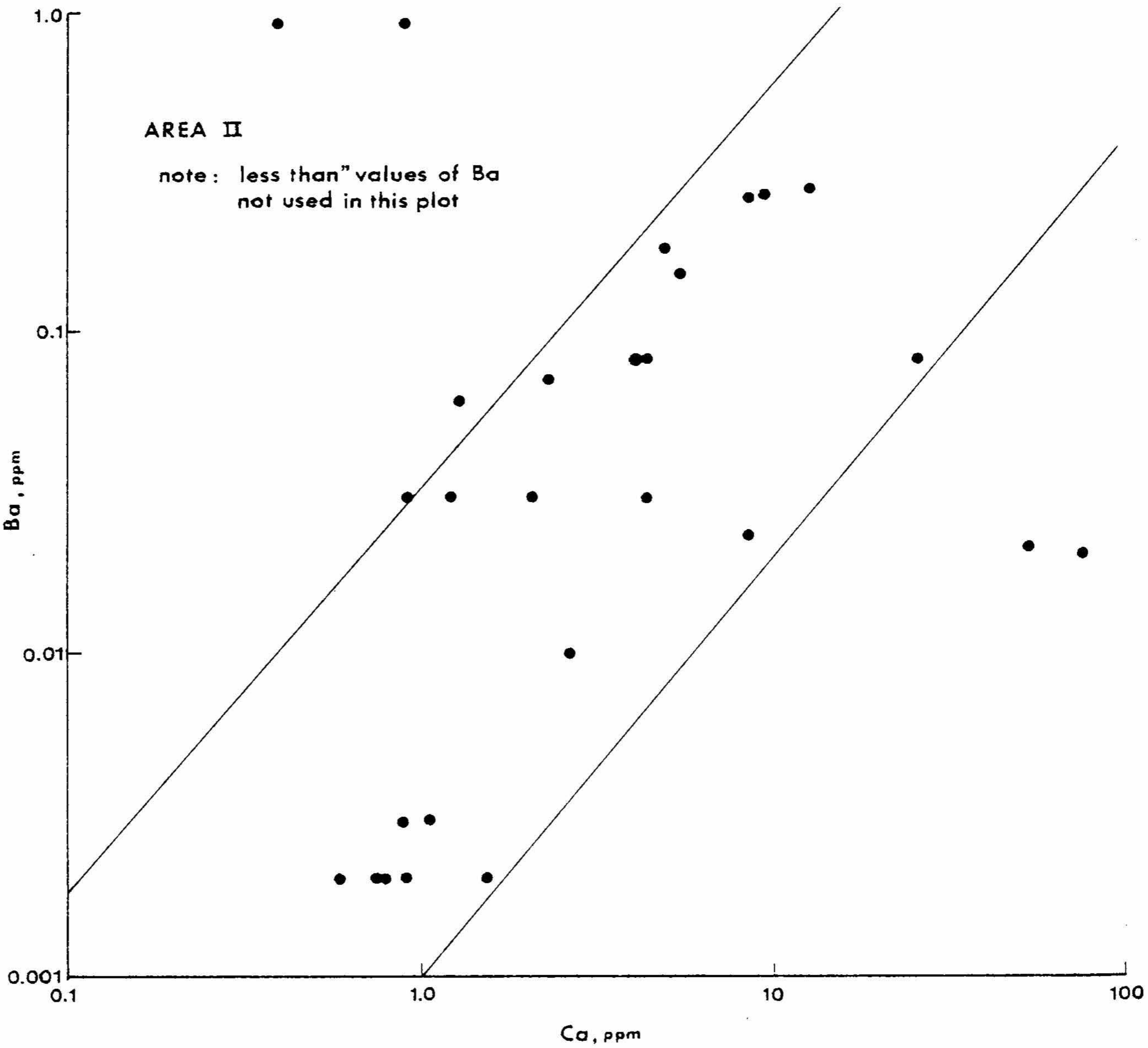

1.0
0.1
0.01
0.001
Ba, ppm
AREA II
note: less than" values of Ba not used in this plot
0.1
1.0
10
100
Ca, ppm

Figure III-13

Ba^{++} Concentration vs Ca^{++} Concentration
For Ouachita Spring Waters of Area II

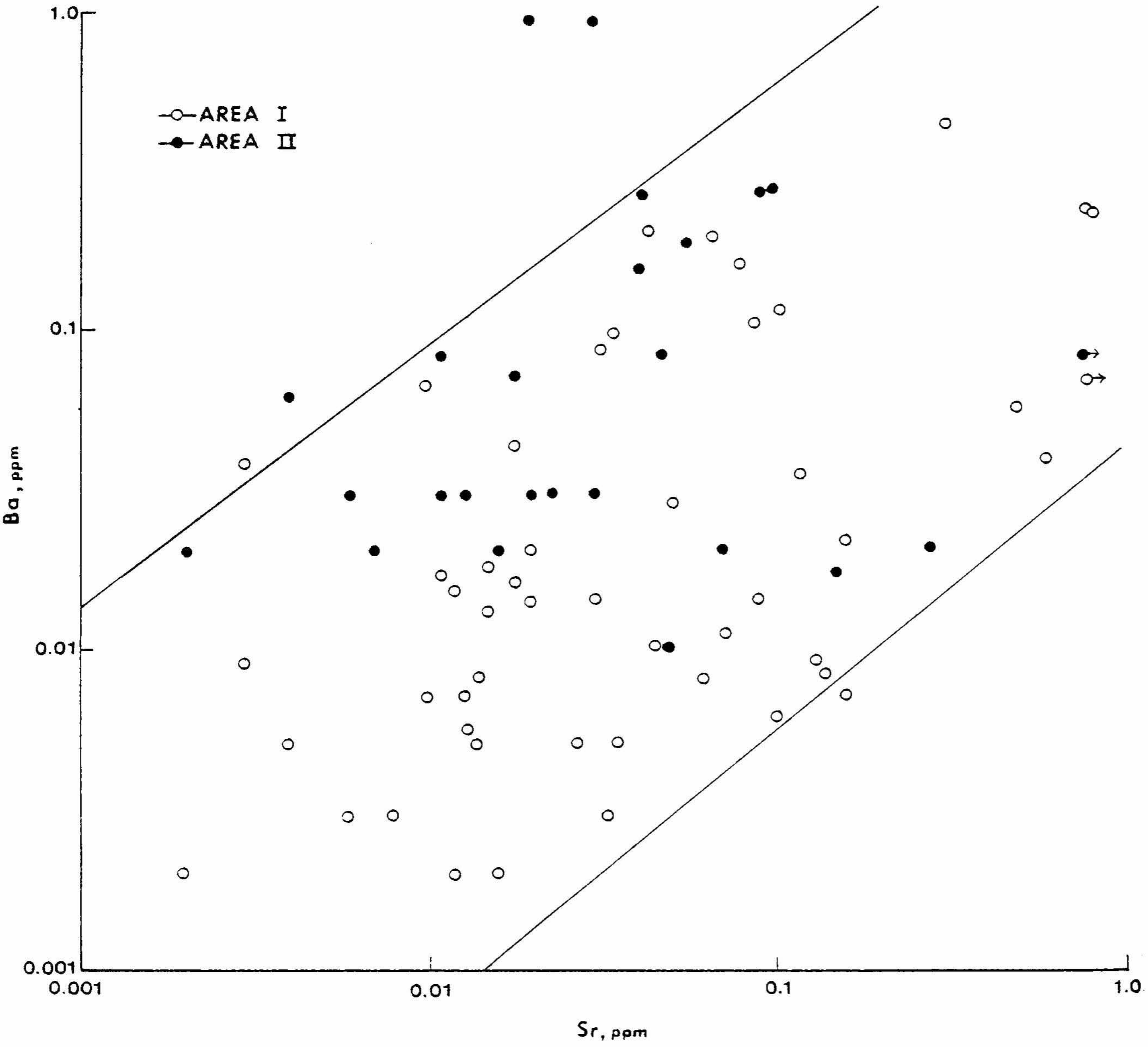

1.0
0.1
0.01
0.001
Ba, ppm
○ AREA I
● AREA II
0.001
0.01
0.1
1.0
Sr, ppm

Figure III-14

Ba^{++} Concentration vs Sr^{++} Concentration
For Ouachita Spring Waters of Areas I and II

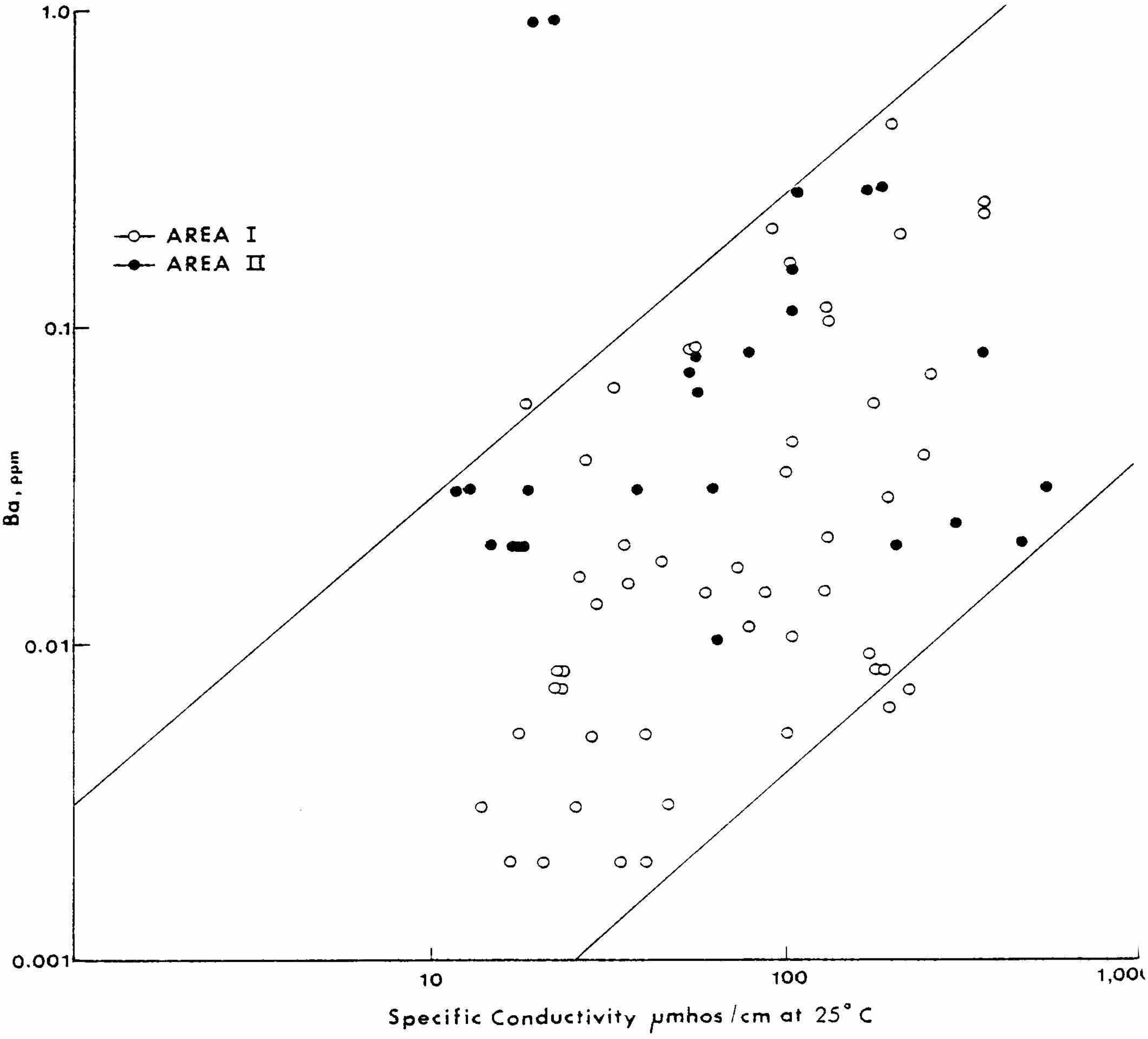

1.0
0.1
0.01
0.001
Ba, ppm
AREA I
AREA II
10
100
1,00
Specific Conductivity µmhos/cm at 25° C

Figure III-15

Ba^{++} Concentration vs Specific Conductivity
For Ouachita Spring Waters in Areas I and II

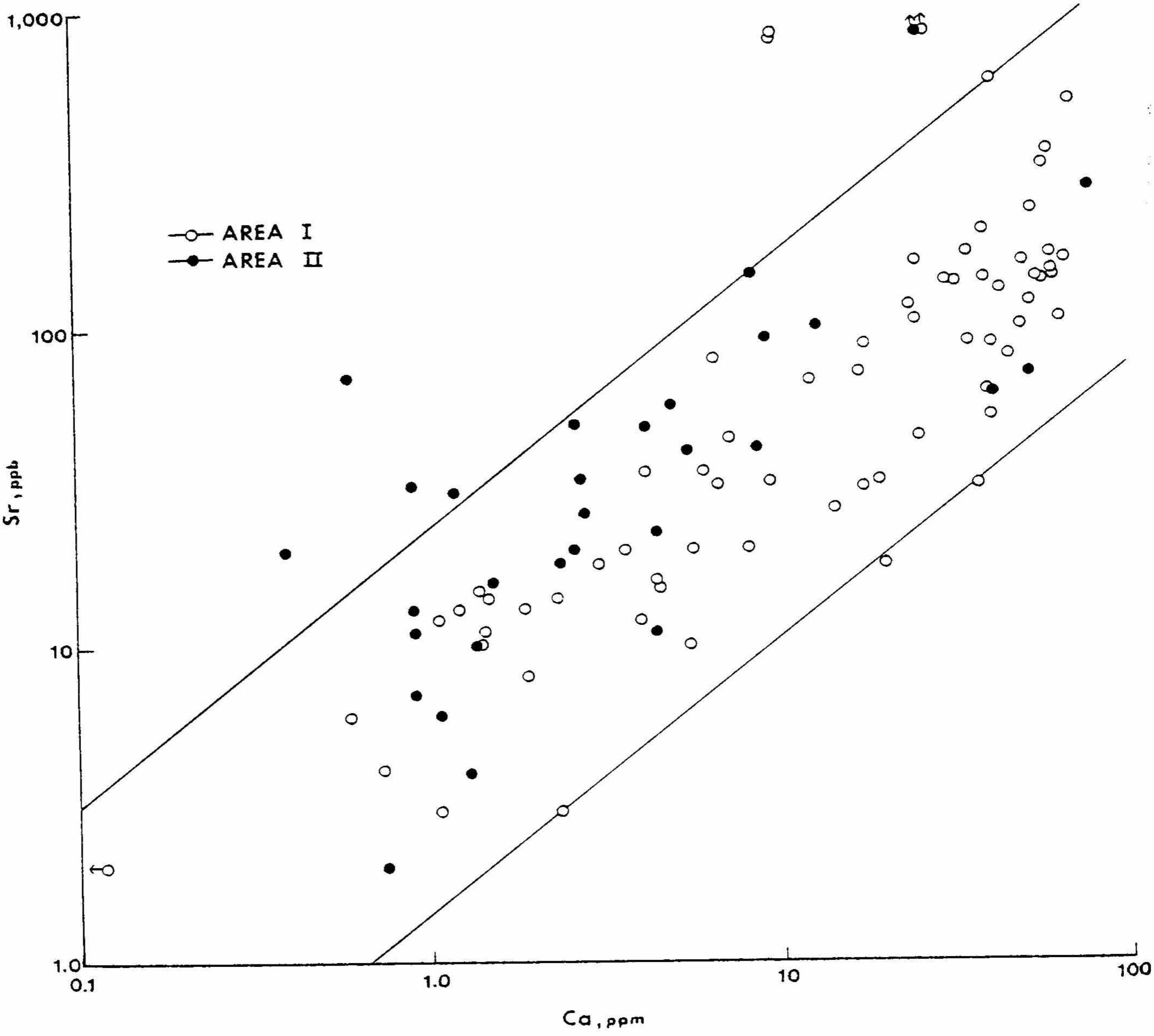

1,000
100
10
1.0
Sr, ppb
0.1
1.0
10
100
Ca, ppm
AREA I
AREA II

Figure III-16

Sr^{++} Concentration vs Ca^{++} Concentration
For Ouachita Spring Waters in Areas I and II