

NATURAL GROUND WATER SYSTEMS AND ASSOCIATED
FRESHWATER CARBONATE DEPOSITS
IN SOUTHERN OKLAHOMA

By

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Bachelor of Arts

Boston University

Boston, Massachusetts

1980

Submitted to the Faculty of the
Graduate College of the
Oklahoma State University
in partial fulfillment of
the requirements for
the degree of
MASTER OF SCIENCE
December, 1984

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Date of Degree: December 1984

Institution: Oklahoma State University

Location: Stillwater, Oklahoma

Title of Study: NATURAL GROUND WATER SYSTEMS AND ASSOCIATED
FRESHWATER CARBONATE DEPOSITS IN SOUTHERN
OKLAHOMA

Pages in study: 153

Candidate for Degree of
Master of Science

Major Field: Geology

Scope and Method of Study: The purpose of this investigation was to describe freshwater travertine deposits and to establish relationships between them and the carbonate rich ground water producing them. Two geographic areas, both with springs of Arbuckle Group origin were studied; Area A in the Arbuckle Mountains and Area B in the Slick Hills of Comanche County. The samples were collected between May and July of 1984. The water samples were analyzed by standard techniques and the travertine deposits were examined using thin section analysis, scanning electron microscopy, x-ray diffraction, and chemical methods.

Findings and Conclusions: The travertines examined were texturally of two types; porous and banded. Scanning electron microscopy revealed the presence of algal tubules and diatoms. Needle shaped diatoms, possibly *Synedra* sp., were found only in Pleistocene travertines, whereas, boat shaped diatoms possibly *Noviculla* sp. were found in Pliocene and Recent travertines. Turner Falls travertines were composed of bands of rosettes alternating with bands of algal tubules.

The precipitation of calcium carbonate results primarily because of CO_2 loss. Water saturated with CO_2 will lose CO_2 to the atmosphere by a decrease in pressure and by agitation such as water flowing over rapids or waterfalls. The removal of water by evaporation changes the solubility product and also may lead to precipitation of carbonate. Plants may precipitate CaCO_3 during photosynthesis by removing CO_2 from the water or in the case of some algae, bicarbonate ions. Mosses have a symbiotic relationship with algae and act as excellent traps for calcium carbonate crystals.

ADVISER'S APPROVAL _____

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IN SOUTHERN OKLAHOMA

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PREFACE

This study addresses the geochemical relationships between natural waters and the associated carbonate deposits. The Arbuckle Mountains and the Witichta Mountains, produces carbonate-rich water that under special conditions deposits freshwater carbonates at several locations in southern Oklahoma.

The completion and success of my graduate career would not have been possible without the assistance of several important people and the financial support of the University Center for Water Research. I would like to thank my thesis adviser, Dr. Arthur Hounslow, for his guidance, understanding and assistance throughout the past two years. Recognition and thanks to my thesis committee members for their support and help during my investigation; Dr. Nowell Donovan, helped in choosing carbonate deposit localities and review of the areas geology, Dr. Wayne Pettyjohn for keeping the "thumbs up" during the writing. Without the chemical background and laboratory expertise of Ray Powers this thesis and I would still be in the lab.

Special appreciation to those people who allowed me to obtain my samples and also to those that helped tote, carry, and pump water samples; Charlie and Dixie Oliver, property owners, Bert Speed, Chickasha National Refuge, Jim Blue,

Turner Falls Park, Debbie Ragland, field partner, and Steve and Kathy Bridges, field partners.

I would like to express my gratitude to the Agronomy Department for use of their atomic-adsorption spectrophotometer and to Dr. Al-Shieb for use of three lamps to complete my geophysical analysis.

Without the support and help from Talya Henderson, Dorothy Smith, and the basement floor OSU library personnel, research and writing would have been made more difficult.

Special thanks to my family and extended family (the Henderson's, the Davies' and the Scott's) for their moral support.

I would like to thank my husband Jim, for his love, understanding and moral support.

Finally, a heart felt "thanks" to one and all for enabling me to complete this degree.

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CHAPTER I

INTRODUCTION

Objective and Scope

The primary objective of this investigation was to establish relationships between carbonate rich ground water, found locally in southern Oklahoma, and their associated carbonate deposits. A secondary objective was to use these relationships to determine the depositional environment of older freshwater carbonates.

Chemical analyses of spring, stream and well waters were used to determine if calcium carbonate precipitated or dissolved in four sample areas in southern Oklahoma. These areas were selected because, at one time or another, calcium carbonate was precipitated, and also because the Arbuckle Group was the source of the water. The Arbuckle Group is a combination of limestones, dolomites, and some sandstones of shallow water marine origin. The 6700 feet thick Arbuckle aquifer contains carbonate-rich water with abundant chemical analyses available. This prolific aquifer, characterized by solution openings and fractures does not exist outside the Arbuckle Mountain area, although the Arbuckle Group is reported to contain ground water in the Wichita Mountain area, (Havens, 1977). All the samples obtained for this

investigation where collected between May and July of 1984. During this time of year the region is arid and most of the springs and small streams have no flow, however, the stream water still available is base flow, or the contribution of ground water. The carbonate-rich ground water is assumed to have originated in the Arbuckle Formation.

For this investigation, the limited rock analysis, randomly sampled from outcrops of the Arbuckle Mountains are assumed to represent the entire formation. A comparison was made between the marine carbonates of the Arbuckle Formation and the freshwater carbonates deposited from this water.

Terminology

Freshwater carbonates are a varied group of deposits. Terminology is based on texture and mode of deposition rather than mineral composition. Europeans, particularly in Germany, have a very detailed classification that commonly overlaps. The present usage uses five terms: (Bates and Johnson, 1978)

Hot Spring Deposits - based on those carbonates found
in thermal springs, highly mineralized,

Speleothems - carbonate deposits found in association
with caves,

Calcrete - a pedogenic carbonate found in soil
horizons,

Travertine - a hard dense carbonate, named for an
extensive deposit near Tivoli, Italy,

Tufa - highly porous, spongy deposit, usually associated with plants.

The present trend is to identify as travertine all carbonate incrustation on plants without reference to density or pore volume, (Julia, 1984). Another term used more in European literature is sinter. In Julia's article this term is restricted to those deposits of abiotic origin, more dense and compact than tufa, also including speleothems and flow stones.

Computer Literature Searches

Three computer literature searches for this investigation were done by Oklahoma State University library personnel using two data banks, Water Resources Abstracts and GEOREF (American Geological Institute). The first search conducted in 1983, using the key words hydrology-Oklahoma, yielded two hundred titles. Two searches were conducted in 1984. One using keywords springs-Oklahoma, yielded fifty titles while the third search using key words geochemistry-Arbuckle Group-Oklahoma yielded only five titles, (see Appendix A).

Previous Works

Travertine investigations date back to the early nineteenth century in Europe. European published works include: Klahn (1928), Savelli and Wedepohl (1969), Muller (1969), Jacobson and Usdowski (1975), Flugel (1982), as well

as many others. Carbonate Sedimentology in Central Europe (Muller and Friedman, eds., 1968) is a collection of investigations by authors throughout Europe, which provides an extensive reference list. One investigation within this collection by Irion and Muller (1968) discusses the geochemistry of a German calcareous tufa, containing 89.4-100% CaCO_3 that was reported to be a purely inorganic precipitate rather than biogenetic-inorganic one. One of the earliest works cited is Klahn's (1928) investigation of carbonate-rich waters and associated dolomite-rich spring tufas. Savelli and Wedepohi (1969) discuss the very sensitive conditions needed for travertine formation. Their study showed that travertine formation is related to bicarbonate spring waters which have circulated in faults where calcite solution from subsurface beds was present. An investigation done by Jacobson and Usdowski (1975) reported a spring fed stream that precipitated calcite by inorganic processes in an irregular manner. Analyses of the waters at the spring head as well as downstream allowed the authors to reconstruct the origin of the spring. Many of the major available references such as Flugel (1982), Graf (1960), Kitano (1962), Chilingar and others (1967), and Bathurst (1971) are primarily discussions of marine carbonate sediments with very little information on fresh water carbonates. An excellent recent resource is AAPG Memoir 33 (1983) "Carbonate Depositional Environments", which includes several sections on fresh water carbonate formation. Trent

(1978) analyzed fresh water carbonate travertines found in Colorado using geochemical and petrographic techniques. He concluded that four of the travertine formations studied were an example of hydrothermal "freshwater" carbonate deposits and three factors that contribute to the character of the spring deposit; local topography, seasonal climatic change, and flow rate.

Travertine and tufa found in Oklahoma was first investigated by Emig (1917), who located the major deposits at Turner Falls and Price Falls. Where no geochemical data were mentioned in this initial report although Emig did recognize three periods of travertine deposition at Turner Falls as well as several modes of travertine deposition including the biogenetic contribution of mosses. Wilson and Guest (1961) reported not only the contributions of the mosses but also the association of diatoms in the formation of travertine. Ham (1980) and Donovan (1983) both mention the Turner Falls travertine deposit in discussing the geology of the Arbuckle Mountain area. Other modes of deposition of travertine and tufa have been cited, such as water mixing, which is reported to be responsible for the tufa deposits in Mono Lake, an alkaline environment (Dunn, 1953). Barnes (1965) investigated a travertine depositing creek in an arid climate and concluded that it was not evaporation but rather water lost through seepage and photosynthesis created the conditions for precipitation. There is a rapidly growing area of isotopic geochemistry

Mg, Sr, Na, and Fe in limestones and dolomites. He compares acetic acid and hydrochloric acid digesting. Weberling (1968) discusses mixed alkaline earth standards for several analytical methods with comparisons using carbonate samples.

CHAPTER II

CHEMICAL PROCEDURES

This investigation involved two different wet chemistry procedures; water analysis and rock analysis. Six parameters determined on each water sample but not on the rock were: temperature, pH, alkalinity, sulfate, chloride, and silica. Both water and rock samples were tested for fourteen elements using a Perkin-Elmer Atomic Absorption 403. The settings for each element analyzed were the manufacturers recommended values. The standards used for each element were purchased atomic absorption spectroscopy standards from Fisher Scientific. The detection limits, standards, sensitivity and absorbance values for each element are shown on Table 1. Two of the 14 elements, Al and Pb, were below the detection limits in all samples. Table 2 lists the standards used for each element analyzed.

Water Analysis

The water analyses began in the field with pH and temperature ($^{\circ}\text{C}$) determinations and at a few sites specific conductivity. Two water samples were prepared at each site according to suggestions by EPA (1979), and stored in plastic five hundred milliliter bottles. These bottles had

Table I

WAVELENGTHS, CONCENTRATION RANGES, SENSITIVITIES FOR ELEMENTS
FOR DETERMINATION BY ATOMIC ABSORPTION AND FLAME EMISSION

Atomic Absorption*					
Element	Wave-length angstroms	Optimum conc. range in solution	Detection limit	Sensitivity 1% absorption	Interferences
Al	3092.8	10 - 150	0.1	1.3 (1)	Ionization +
Ba	5515.5	100 - 1000	0.05	0.36 (1)	Ca, ^W Ionization +
Ca	4226.7	1 - 10	0.002	0.09 (2)	PO ₄ , GAl, G SO ₄ , G Si, G
Cu	3247.5	2 - 20	0.005	0.15 (2)	
Fe	2483.3	2 - 20	0.005	0.15 (2)	HNO ₃ , Ni, ^J SiO ₃
K	7664.9	1 - 10	0.005	0.05 (2)	Ionization +
Li	6707.8	0.5 - 5	0.005	0.04 (2)	
Mg	2852.1	0.1 - 2	0.0003	0.01 (2)	AlG (high levels), SiG
Mn	2794.8	2 - 20	0.005	0.04 (2)	
Na	5890.0	0.3 - 3	0.002	0.015 (2)	Ionization +
Pb	2833.1	4 - 40	0.03	0.7 (2)	
Sr	4607.3	2 - 20	0.01	0.2 (2)	Si, G Al, G PO ₄ , G
Zn	2138.6	0.2 - 3	0.002	0.025 (2)	

* (1) Nitrous Oxide-acetylene (2) Air-acetylene

+ Ionization effects can be controlled by the addition of a large excess (1000 ppm) of an alkali metal salt such as KCl.

^W Spectral interferences due to the CaOH absorption bandhead located at the Ba absorption. can be corrected for by subtracting the absorbance of a blank containing Ca.

G Can be controlled by the addition of lanthanum to the sample (1%).

J Can be controlled by a very lean (hot) flame.

(after Issac, 1973)

TABLE II

STANDARDS USED FOR AA ANALYSIS

-
- Al- The ions in the samples were lower than the detection limits. More than .2% HCl decreases the sensitivity. Standards were made of the following ppm - 1, 3, 5, 7,
- Ba- Used a mixed standard (Weberling and others, 1968) diluted Ba standard with 1000 ppm potassium standard and .5 grams of KCl was added to all samples to prevent ionization. Standards were made of the following ppm - 1, 3, 5, 10,
- Ca- Due to the amount of strontium present, a mixed standard was used (Weberling and others, 1968), 1% LaCl_2 was added to eliminate complexation interferences in both samples and standards, Standards were made of the following ppm- 1, 3, 5, 7, 10. The extreme dilution used (1:2000) resulted in unreasonable reduction of accuracy for Ca amounts,
- Cr- Standards were made of the following ppm- .5, 1, 3, 5
- Cu- Standards were made of the following ppm- .25, .5, 1
- Fe- Standards were made of the following ppm- .5, 1, 5, 10
- Li- 1% LaCl_2 was added to both standards and samples Standards were made of the following ppm- .05, .125, .25, .5, 1
- K - Standards were made of the following ppm- .5, 1, 3, 5
- Mg- Samples were diluted, but not to the extent of the Ca analyses
1% LaCl_2 was added to both standards and samples Standards were made of the following ppm- 1, 3, 5, 7
- Mn- Standards were made of the following ppm- 1, 2, .5, 5, 10
- Na- Standards were made of the following ppm- 1, 3, 5, 7

Table II (continued)

Pb-	The ions in the samples were lower than the detection limits.
Si-	Analysis was conducted in the Water Quality Research Lab using a graphite furnace. Standards were made of the following ppm- .5, 1, 3, 5
Sr-	Mixed standards were used (Weberling and others, 1968) - diluting the standards with 1000 ppm Ca standards also adding 1% LaCl_2 to standards and samples. Standards were made of the following ppm- 1, 2, 3, 5
Zn-	Standards were made of the following ppm- .25, .5, 1, 2

been rinsed with sample water three times before the actual sample was taken. The bottles were marked with location, pH, temperature, and time. One bottle was stored on ice to maintain 4°C. The other sample was treated by adding a few drops of 1:1 nitric acid to bring the pH below two. The analyses for alkalinity, sulfate, and chloride were run on the samples within twenty-four hours. The titration used for alkalinity is based on EPA Standard Methods, (1979), using HCl for titration on the refrigerated samples. The sulfate analysis was determined by turbidity, EPA (1979). Chloride determination was based on EPA (1979) mercuric chloride titration. Several other titrations were tried but their end point detection proved too difficult. These procedures are included in Appendix B. Some of the water samples were filtered before analyses to eliminate suspended material. The nitric acid fixed samples were used in all atomic absorption spectrographic analyses. All analyses were completed within four months of sampling.

Rock Analysis

Three types of rocks were analyzed in this investigation. These included the Arbuckle Group, associated freshwater carbonate deposits found at water sample sites, and a group of miscellaneous freshwater carbonates.

All samples were crushed in a Spex Ball Mill using tungsten carbide balls and chamber for 2-4 minutes to

achieve a powder of -80 mesh. An approximate one gram sample was split out of twenty grams to obtain a representative sample. Between each sample the chamber and balls were washed, rinsed with 10% HCl, and rinsed again with distilled deionized water.

For quality control purposes, duplicates were run of each rock sample. If greater than 10% error was found the sample solute was redone. Approximately one gram of sample was weighed and recorded, and placed in a Teflon beaker. The sample was slightly wetted with deionized water and 40 ml of 10% HCl was added slowly. The beaker was covered with a watch glass and placed in a fume hood for 18 hours. The covered beakers were then placed in a boiling water bath or sand bath for an additional seven hours. While still warm, the samples were filtered through a .45 micron membrane filter. The beaker was rinsed with 10% HCl to remove the residue. An additional three washings of 10 ml. of 10% HCl followed. The filtrate was then diluted to 100 ml. with deionized water in a volumetric flask, then transferred and stored in an acid washed plastic bottle. Refer to Appendix B for actual lab procedures followed.

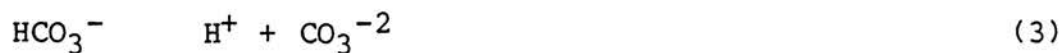
CHAPTER III

CARBONATE EQUILIBRIUM

The solution or precipitation of calcium carbonate in natural waters is dependent on various factors. A detailed investigation of the chemical systems involved in the carbonate cycle was done by Garrels (1960), Garrels and Christ (1965), and Krauskopf (1979). Many discussions of this model are available and will not be considered here.

A chemical reaction, such as the dissolution of calcium carbonate, is usually assumed to reach equilibrium (nothing added or removed). The Law of Mass Action states that if a system at equilibrium is disturbed by temperature, or pressure, or concentration, changes the system will tend to shift its equilibrium position so as to counteract the effect of the disturbance, (Brown and LeMay, 1981).

The carbonate system, assuming constant temperature (25°C) and constant pressure (1 atmosphere) can be modelled by the following five chemical reactions:





(Garrels and Christ, 1963)

In solutions that are sufficiently dilute the solute concentrations are nearly equal to their activities. Activity coefficient is merely an adjustment factor used to convert concentrations into a value used in thermodynamic equations, (Freeze and Cherry, 1979). A measure of the strength of electrostatic field caused by the ions usually is equal to the ionic strength, (Hem, 1970). At a low ionic strength of about $10^{-2.3}$ the Debye-Huckel method was used to determine the activity coefficients.

Solubility is defined by Brown and LeMay (1981) as the amount of solute (CaCO_3) in a given quantity of solvent (natural waters) effected by temperature and pressure, and can change by adding some other substance to solution.

An equilibrium constant, (k), for a system at equilibrium is defined by Garrels and Christ (1965) as:

The product of the activities of the reaction products, each raised to the power indicated by its numerical coefficient, divided by the product of the activities of the reactants, each raised to a corresponding power, and is a constant at a given temperature, independent of total pressure. The equilibrium constants for equations 1 - 5 at 25°C , 1 atm. are:

$$(1) \quad \frac{[\text{Ca}^{+2}] [\text{CO}_3^{-2}]}{[\text{CaCO}_3]} = k_{\text{CaCO}_3} = 10^{-8.3}$$

$$(2) \quad \frac{[\text{H}^+] [\text{HCO}_3^-]}{[\text{H}_2\text{CO}_3]} = k_{\text{H}_2\text{CO}_3} = 10^{-6.4}$$

$$(3) \quad \frac{[H^+][CO_3^{2-}]}{[HCO_3^-]} = K_{HCO_3^-} = 10^{-10.3}$$

$$(4) \quad \frac{[H^+][OH^-]}{[H_2O]} = K_{H_2O} = 10^{-14.0}$$

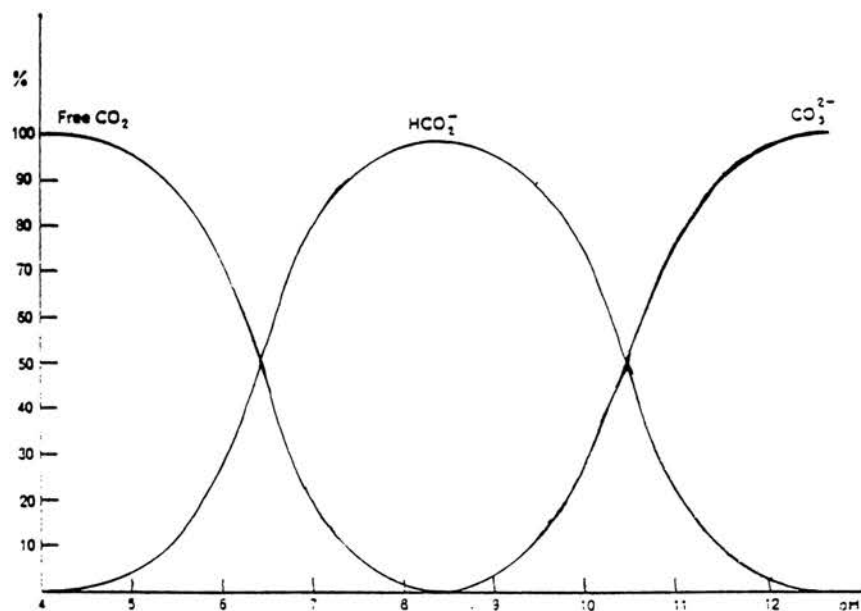
$$(5) \quad \frac{[H_2CO_3]}{P_{CO_2g}} = K_{CO_2} = 10^{-1.47}$$

[] = activity

If the ion activity product is equal to the equilibrium constant, then equilibrium exists and the solution is saturated. Theoretically if the ion product is greater than k then precipitation occurs until $I = k$, if I is less than k the solid dissolves until $I = k$, (Brown and LeMay, 1981).

If the solubility of Ca^{+2} were held constant at equilibrium there are three factors that would influence the chemical reaction to move left or right; pH, temperature, and the partial pressure of CO_2 . Assuming the same temperature and CO_2 the amount of HCO_3^{-1} , H_2CO_3 , and CO_3^{-2} present is controlled by the pH value. As the pH increases (OH^- is added) the $[H_2CO_3]$ decreases while $[HCO_3^-]$ increases, see Figure 1, (Equations 2, 3, and 4). H_2CO_3 has almost entirely dissociated to HCO_3^- at pH 8.5. Increases pass pH 8.5 decreases $[HCO_3^-]$ as $[CO_3^{2-}]$ increases (see Figure 1).

According to LeChatelier's principle, when heat is added to an endothermic solution (natural waters) the equilibrium will shift in such a direction as to reverse the



Source: Golterman (1969).

Figure 1. Relation Between pH and % of Total " CO_2 " As Free CO_2 , HCO_3^- , and CO_3^{2-}

effect of added heat, move the reaction to the right or increase solubility, (Brown and LeMay, 1981).

At 25°C and atmospheric CO₂ (10^{-3.5} atm.) pure water saturated with calcite contains 20 mg/l Ca⁺² and 61 mg/l HCO₃⁻, whereas pure water saturated with calcite at CO₂ = 10 - 2.2 atm. will dissolve 58 mg/l Ca⁺² and 177 mg/l HCO₃⁻, (Jacobson, 1970). Jacobson and Langmuir (1970) also showed that the dissolved CO₂ changes the solubility of various ions. The amount of CO₂ is also controlled by biological systems such as photosynthesis and evaporation which cause CO₂ to be removed and CaCO₃ to be precipitated.

CHAPTER IV

SAMPLE SITES

The sample sites for this investigation were chosen by using two criteria; the water was, or was thought to be of Arbuckle Group origin, and there was evidence of carbonate precipitation from this water at some time.

The best known travertine deposit in the state of Oklahoma, also a favorite tourist attraction, is Turner Falls, T1S, R01E, sec. 36, in Murray County. Another less well known travertine deposit is Price Falls, located south of Turner Falls, T1S, R02E, sec. 33. These two travertine falls and their associated streams are reported to have numerous travertine formations, (Emig, 1917). Fairchild, (1983) reported carbonate formation on many of the stream beds located throughout the Arbuckle Mountain area. This area overlying the Arbuckle aquifer in Murray County, designated Study Area A, (Figure 2) had numerous analyses of ground water, springs, and streams available.

The second area of study, Study Area B, is located in the northeastern corner of Commache County, T2N, R13W and T4N, R14W. This area was chosen because of the numerous springs and spring fed streams of Arbuckle Group origin. Carbonate precipitation had not been reported in the area

and chemical analyses of waters in the area were limited. Havens (1983) reported very limited success in drilling water wells in the Arbuckle of this area and also that the resulting water was of variable quality.

The water samples obtained from the two study areas and the published Arbuckle aquifer data showed very similar water geochemistry. The water analyses graphically shown on a piper diagram, (Figure 3) are Ca-Mg bicarbonate rich water.

The geology of the two study areas is very complex, even though the major geologic formations are the same. Different geologic controls have produced different results. The areas are extensively folded and faulted by different systems and at different times.

The climate of the two study areas differs considerably. Study Area A is a moist, subhumid climate with an average rainfall of 35.9 in/yr. Study Area B is a drier, less humid climate with an approximate annual rainfall 28 in/yr, (Pettyjohn and others, 1983). Both areas of investigation have many intermittent streams and springs that flow only during, and shortly after periods of rain, (Fairchild, 1982). Well water levels at both Study Area A and Study Area B show a relatively quick response to precipitation. Spring and stream discharge is also responsive to the ground-water levels in Study Area A, there is no supportive evidence of the same in Study Area B.

The sampling scheme used in this investigation is based

on sample area and whether the sample was water or rock. In Sample Area A, all samples begin with an A followed by a letter, if water, or a number, if a rock sample. Sample Area B changes only the first letter to B, followed by a letter or number corresponding to water or rock sample. Four Arbuckle Group formation rock samples were used in this study and are designated by a C with a corresponding number; C1 - Cool Creek, C2 - Fort Sill, C3 - McKenzie Hill, C4 - Royer. Any other analyses used from literature are labeled with a D followed by a corresponding letter or number.

Study Area A

The Arbuckle Mountain area is a moist, subhumid zone with precipitation consisting of rain with some light snow or sleet during the winter, (Fairchild, 1983). A weather station at Platt National Park records average rainfall of 35.9 in/yr with the average monthly rainfall being highest during April, May and June, (Figures 4 and 5). Recharge in the Arbuckle aquifer is by precipitation with natural recharge taking place by infiltration of precipitation into the ground or outcrops, and in some locations small sink holes or solution pipes. (Fairchild, 1983).

The occurrence and movement of ground water is strongly controlled by lithology and structure in the Arbuckle aquifer because of extensive folding and faulting (Figure 6). Along with the major fault and fold systems are numerous associated minor faults, folds, and fractures which provide

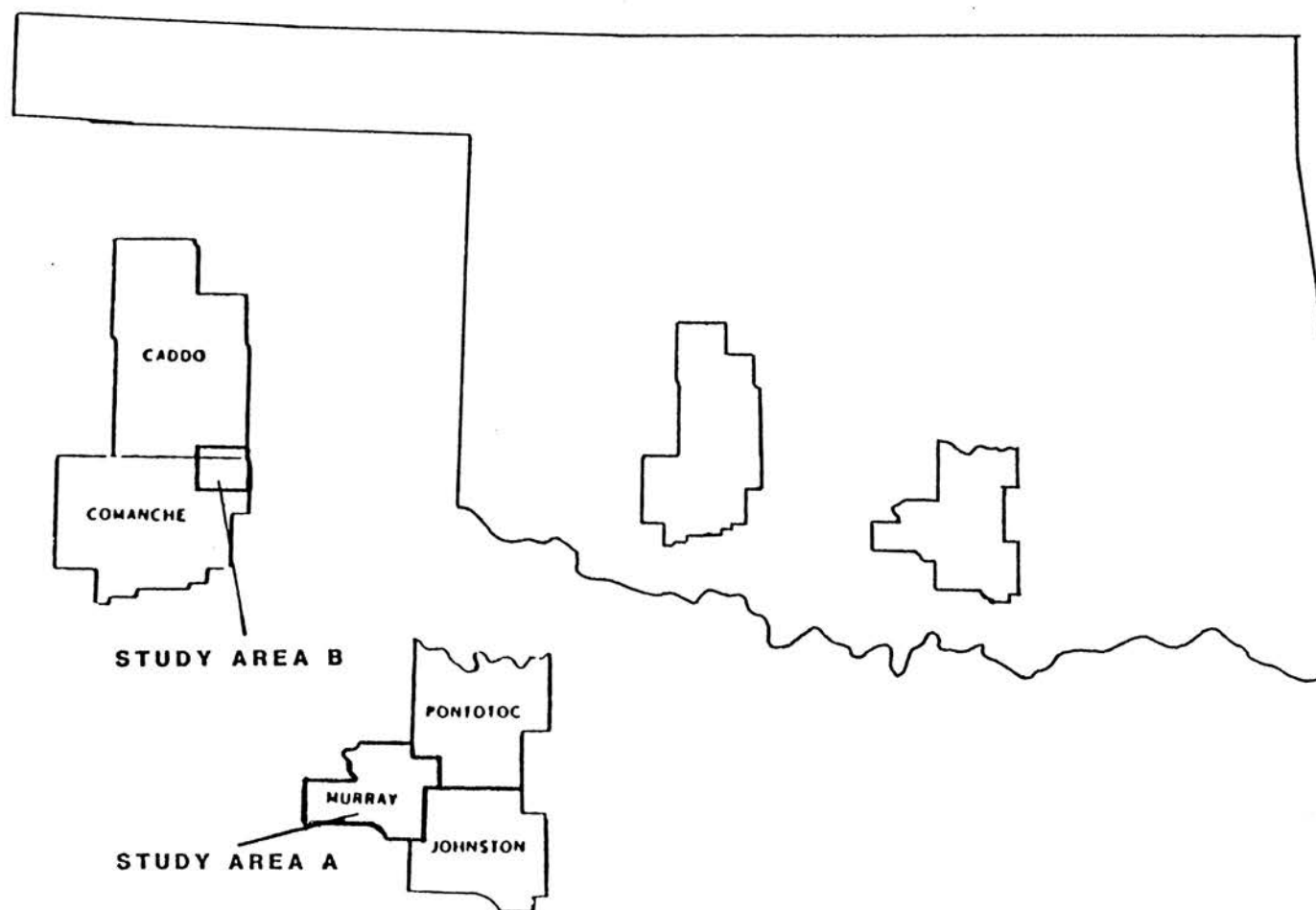
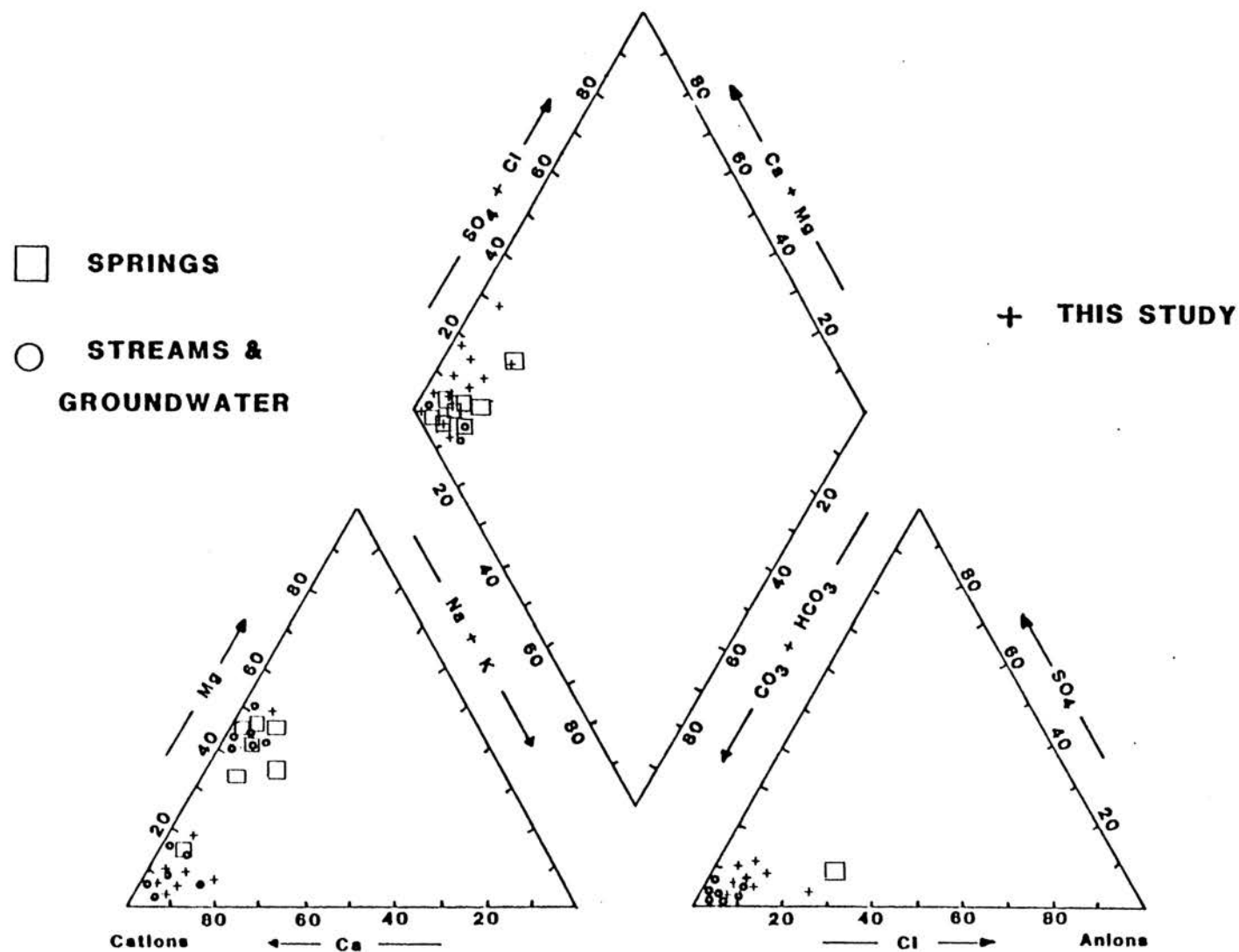
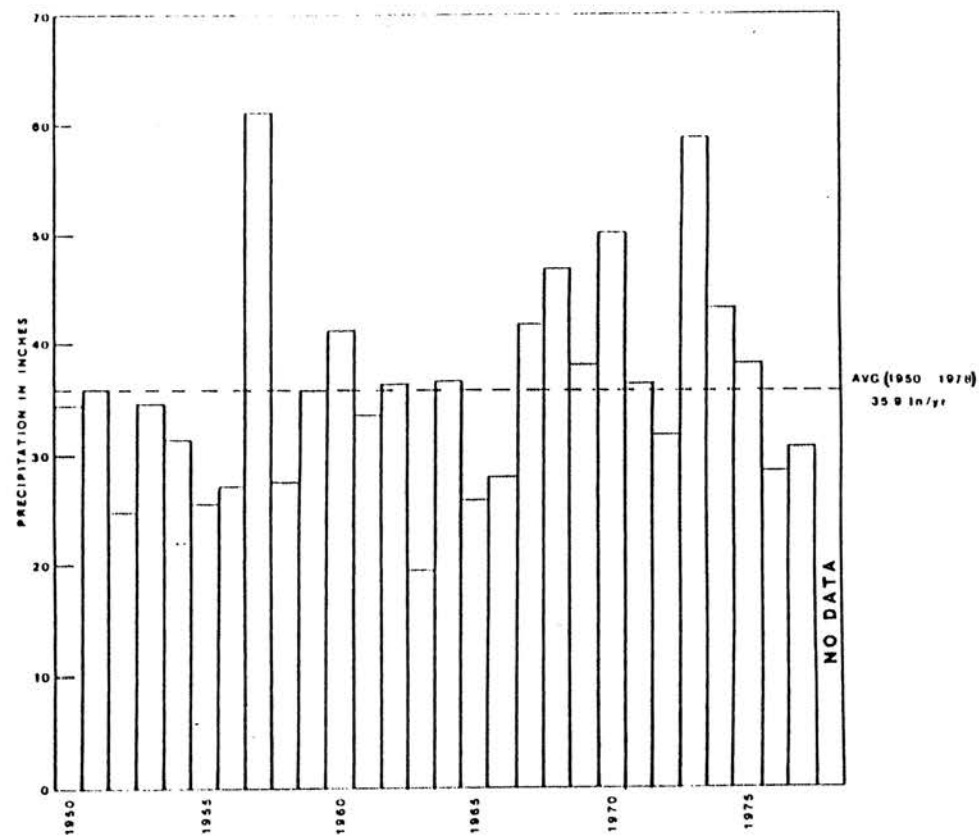


Figure 2. Location Map Showing Study Area A and B



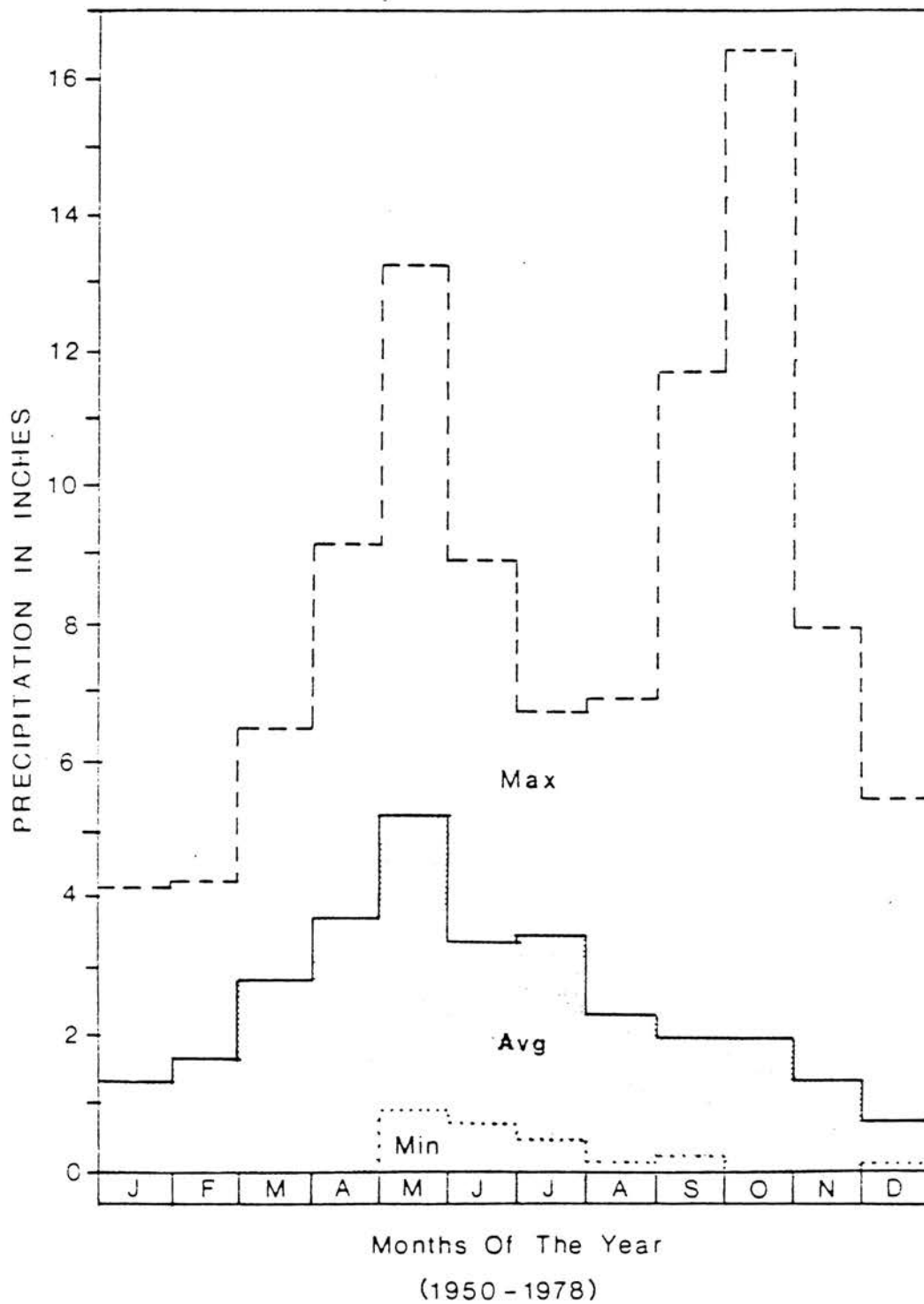
Source: Fairchild (1982)

Figure 3. Piper Diagram of Arbuckle Group Water



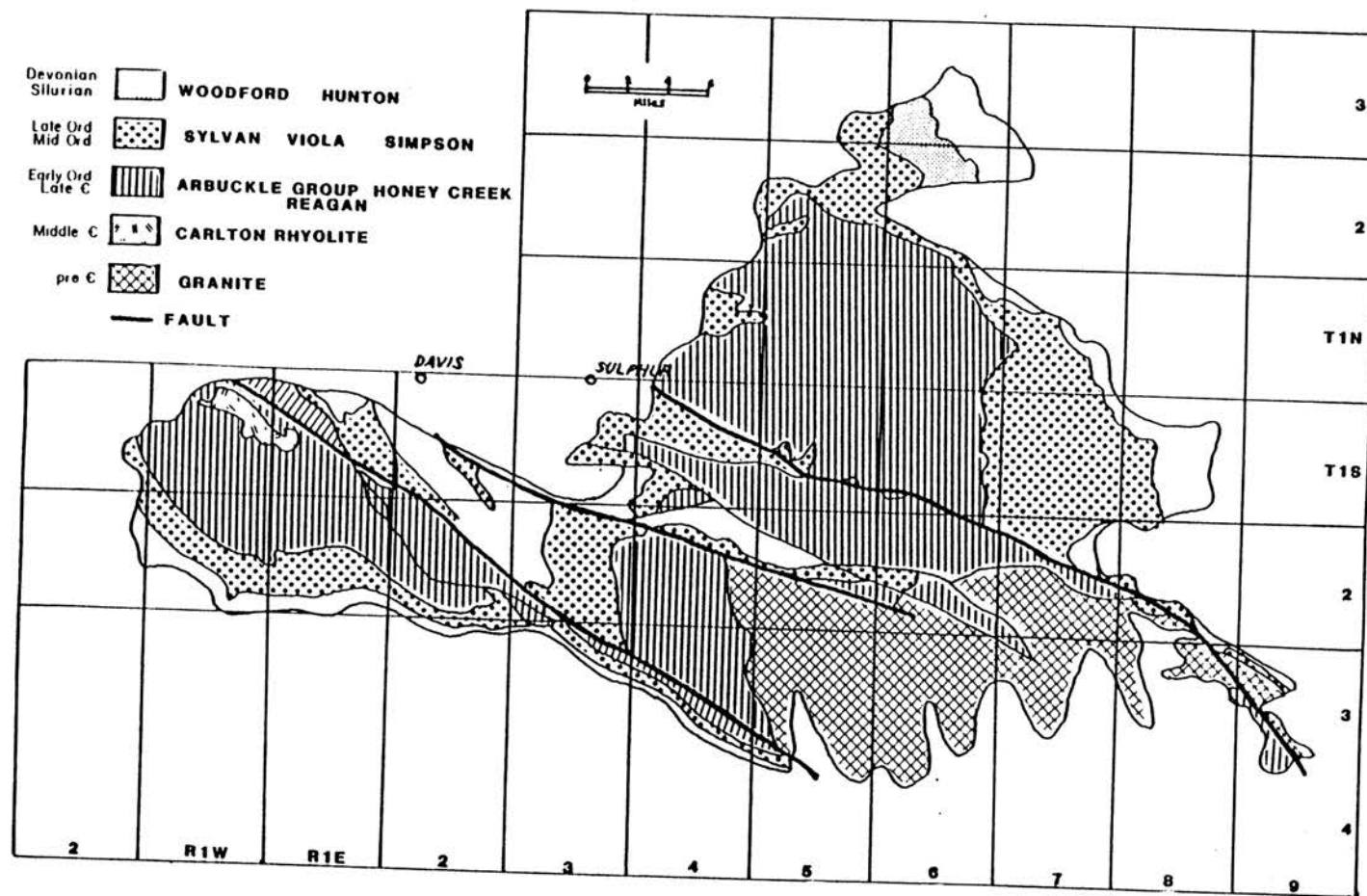
Data: NOAA

Figure 4. Average Yearly Precipitation
for Platt National Park,
Ok (1950 - 1977)



Data: NOAA

Figure 5. Maximum mean, and Maximum Monthly Precipitation For Platt National Park, Ok



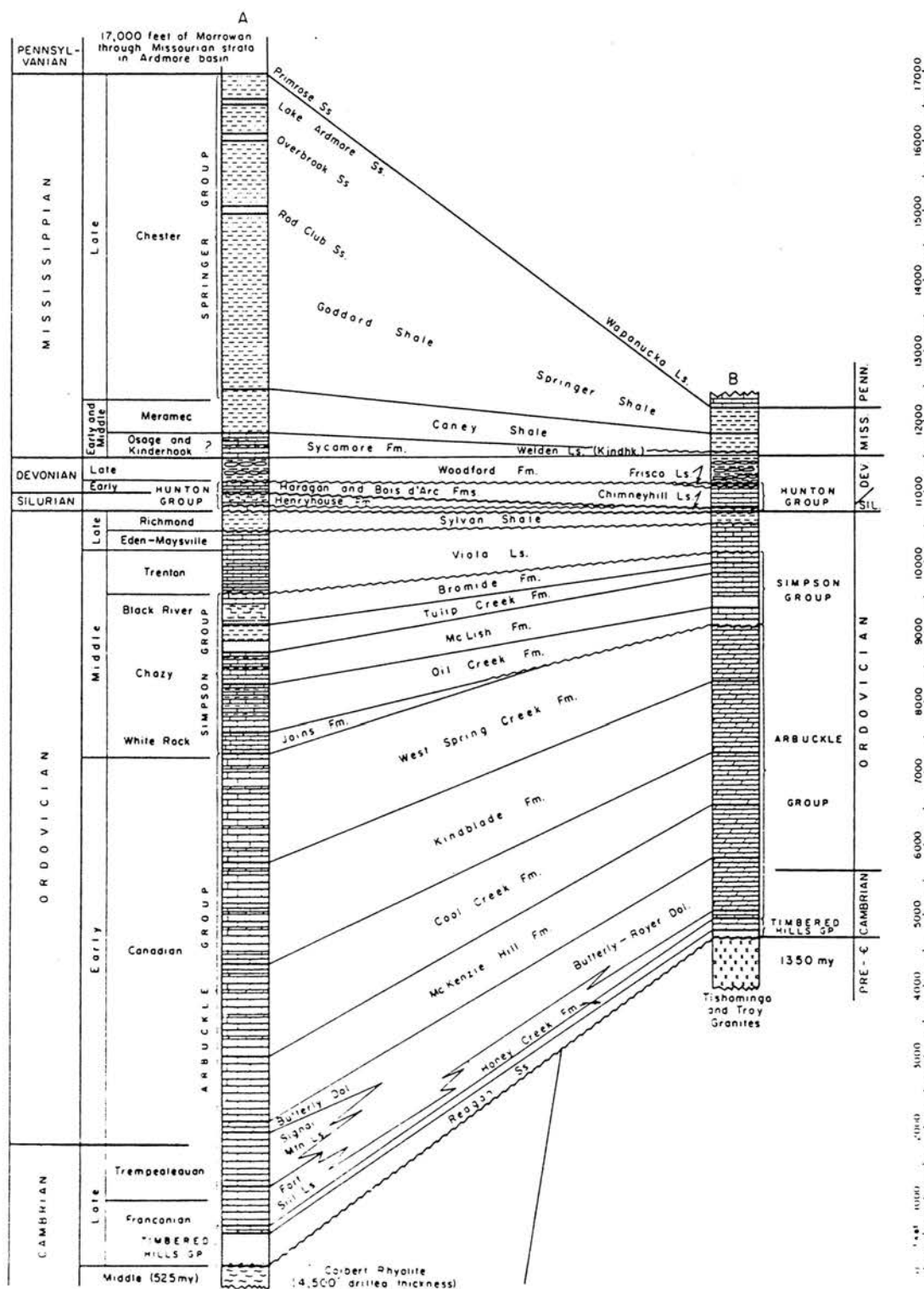
Source: Ham (1980)

Figure6. Geology Map of the Arbuckle Mountains (Study Area A)

ideal channels for ground-water movement. The rainwater, being a dilute acid enters the fractures, joints and bedding planes, enlarging them by dissolving the bedrock which results in an irregular network of openings that extend both vertically and laterally throughout the bedrock. Caliper logs from the area indicate possible openings as deep as 2,000 feet, although some of these could be drilling related. However, the assumption can be made that ground water circulation did or continues to occur at a depth of perhaps 2,000 feet. In addition, numerous cave systems are reported throughout the study area. Minor karst topography, streamline infiltration, and rock fractures all provide recharge to the aquifer. Hydrographs of the water levels in wells within the area indicate a fairly rapid response to changes in precipitation although the rate of recharge from the overall area varies because of differences in permeability of the subsurface formations, soil and vegetation, and evapotranspiration rates, (Fairchild, 1983).

The Arbuckle aquifer consists of several different geologic formations, each of which may have different hydrologic properties, but are still considered to be the Arbuckle aquifer based on stratigraphic correlations. The aquifer is composed of limestones, dolomites, and shale of shallow marine origin, (Figure 7).

The springs found in Study Area A by Fairchild (1984) are predominantly gravity springs occurring where the potentiometric surface intersects the land surface. Most of

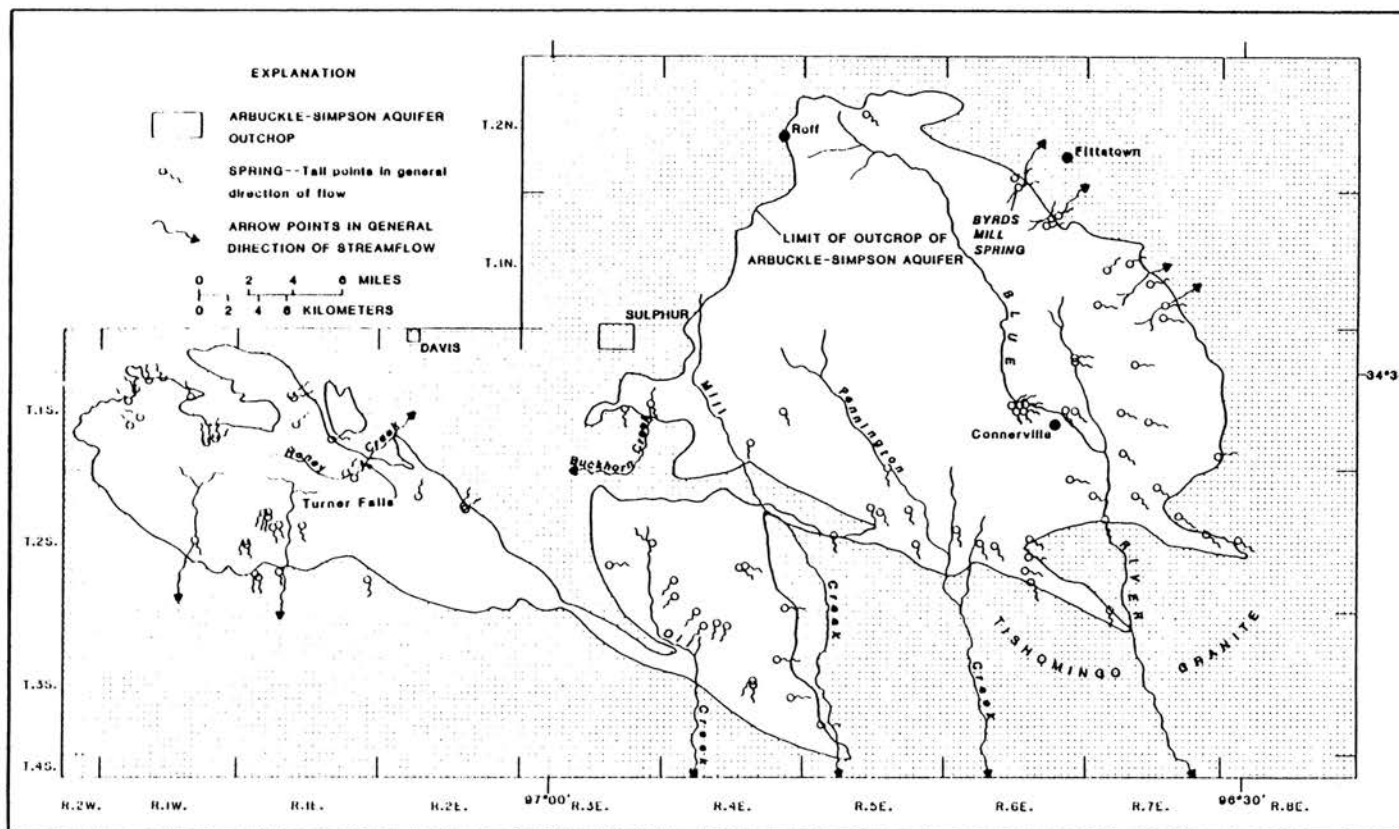


Source: Ham (1980)

Figure 7. Stratigraphic Column of the Arbuckle Mountains (Study Area A)

the springs are near faults or other fracture-like zones, that tend to be enlarged by carbonate solution. In the southeastern part of the area where faulting has brought the Precambrian age Tishmingo Granite of Precambrian age in contact with the Arbuckle Group, numerous springs and seeps are formed (see Figure 8). These springs are fault controlled, the granite acts as an impervious barrier to the ground water flow, and the spring is the natural release of the ground water, (Figure 9). Fairchild (1983) reports larger springs in the eastern part of the Arbuckle Mountain area, which is underlain primarily by dolomite in contrast to the western part of the area which is underlain primarily by limestone. The lithology is less likely to be responsible for this difference, then the size of drainage basin which is larger in the eastern part than the western part of the area.

Some springs that sustain enough discharge year round to produce perennial streams, such as Falls Creek and Honey Creek. Byrds Mill Spring near Fittstown is also a perennial spring. A 1958 hydrograph from a continuous paging station located at Byrds Mill Spring indicates that spring discharges vary with water levels, see Figure 10 (Fairchild, 1984). Fairchild (1984) reports that approximately 60% of the total runoff from the Arbuckle Mountain area is accounted for by the baseflow, or ground-water contribution, of the streams and springs. Tables 3 and 4 contain the chemical analyses for the rock and water samples found in



Source: Fairchild (1984)

Figure 8. Map of Arbuckle Mountain Area Showing Locations of Springs (Study Area A)

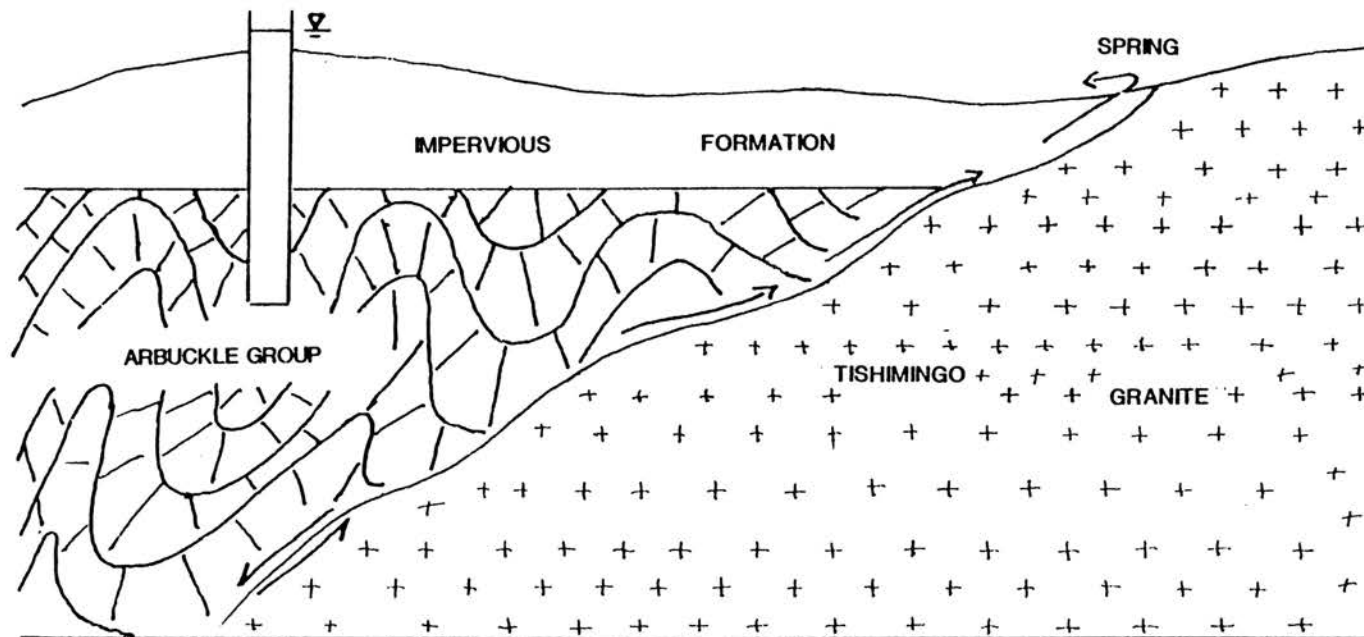
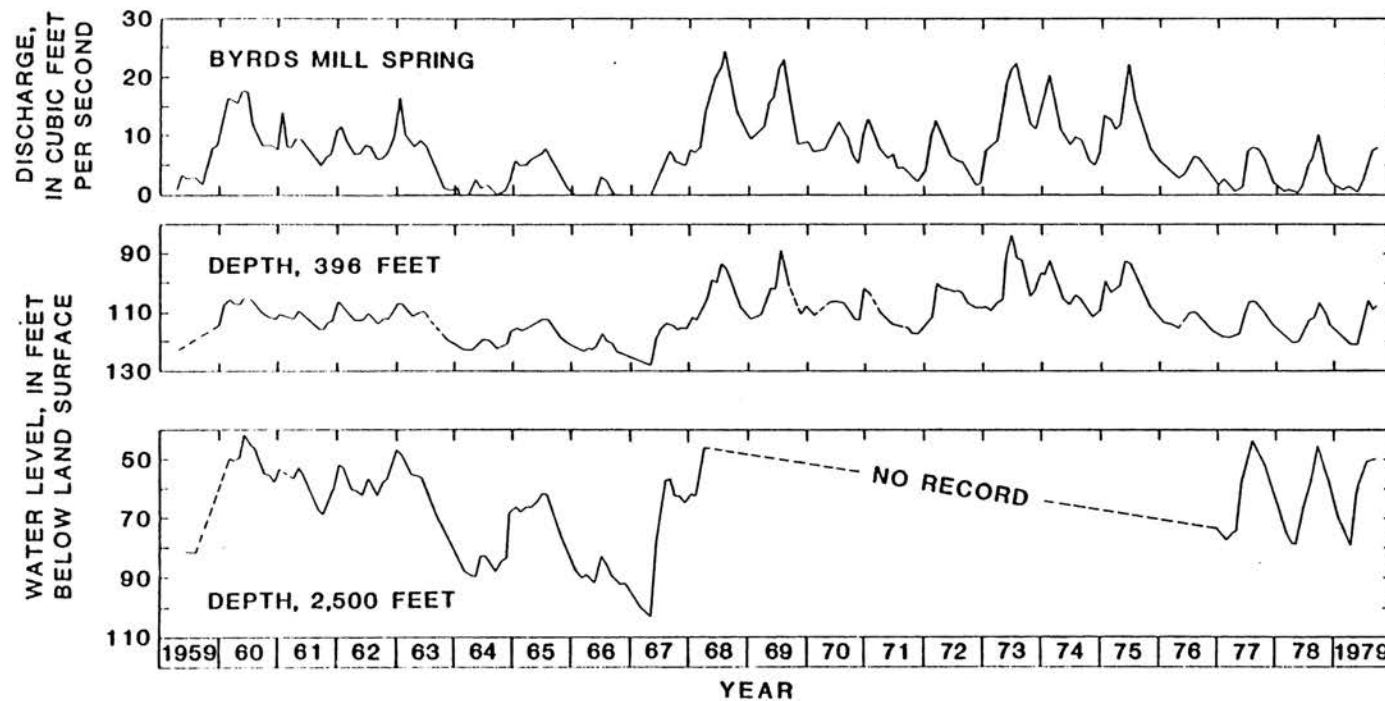


Figure 9. A Possible Hydrologic Mechanisim for
Arbuckle Group Springs



Source: Fairchild (1984)

Figure 10. Hydrographs of Water Levels in Two Wells That Tap the Arbuckle Aquifer and Discharge From Byrds Mill Spring (January 1959 - June 1979)

TABLE III

ROCK ANALYSIS FOR STUDY AREA A

Study Area A	A1 T1NR3E s.1 Pleistocene?	A2 T1SR1E s.36 Recent	A3 T1SR1E s.36 Pleistocene Cave Deposit?	A4 Blue Creek Can. Permanent? Travertine	A5 T1SR2E s.33 Price Falls
Isoluble Residue	5.3%	1.2%	12.3%	0.3%	0.3%
SiO ₂	-	-	-	-	-
CaO	43.2	48.8	60.4	47.6	48.5
K ₂ O	0.18	0.01	0.07	0.0	0.08
MgO	0.82	0.20	0.45	0.35	0.41
Na ₂ O	0.25	0.29	0.29	0.11	0.14
mol Ca/Ca+Mg	0.97	0.99	0.99	0.99	0.99
mol Sr/Ca	-	0.24	0.27	-	0.51
Trace Elements (pph of rock)					
Al ⁺³	nd	nd	nd	nd	nd
Ba ⁺²	0.045	0.003	0.011	0.009	0.069
Cr ⁺²	0.002	0.003	0.003	0.002	0.003
Cu ⁺²	0.001	0.001	0.001	0.001	0.001
Fe ⁺²	0.479	0.072	0.233	0.029	0.110
Mn ⁺²	0.043	0.018	0.028	0.001	0.011
Sr ⁺²	nd	0.019	0.025	nd	0.039
Zn ⁺²	0.005	0.001	0.002	0.001	0.002
Pb ¹	nd	nd	0.039	0.020	nd

Table III (Continued)

Study Area	A1 T1NR3E s.1 Pleistocene?	A2 T1SR1E s.36 Recent	A3 T1SR1E s.36 Pleistocene Cave Deposit?	A4 Blue Creek Can. Permanent? Travertine	A5 T1SR2E s.33 Price Falls
Thorium ¹	nd	nd	nd	nd	0.022
Uranium ¹	nd	nd	nd	nd	0.010
mol Mn/Fe	0.09	0.26	0.12	0.03	0.10

Table III (Continued)

Study Area A	C1 Cool Creek Farm	C2 Fort Sill Farm	C3 McKenzie Hill Farm	C4 Royer Farm
Insoluble Residue	7.8%	6.3%	9.0%	6.2%
SiO ₂	-	-	-	-
CaO	36.8	48.9	28.5	46.0
K ₂ O	0.03	0.01	0.00	0.00
MgO	3.9	0.88	1.4	3.6
Na ₂ O	0.49	0.31	0.24	0.40
mol Ca/Ca+Mg	0.87	0.98	0.96	0.93
mol Sr/Ca	0.12	0.01	0.18	-
Trace Elements (pph of rock)				
Al ⁺³	nd	nd	nd	nd
Ba ⁺²	0.011	0.015	0.007	0.002
Cr ⁺²	0.002	0.002	0.002	0.002
Cu ⁺²	0.001	0.001	0.001	0.001
Fe ⁺²	0.110	0.300	0.418	0.312
Mn ⁺²	0.029	0.010	0.042	0.023
Sr ⁺²	0.007	0.001	0.013	nd
Zn ⁺²	0.002	0.001	0.001	0.001
Pb ¹	-	-	-	-

Table III (Continued)

Study Area	C1 Cool Creek Farm	C2 Fort Sill Farm	C3 McKenzie Hill Farm	C4 Royer Farm
Thorium ¹	-	-	-	-
Uranium ¹	-	-	-	-
mol Mn/Fe	0.26	0.03	0.10	0.07

¹ = x-ray flourescent semi-qualitative pph
values are an average of duplicates

% by weight

nd = none detectable

TABLE IV

WATER ANALYSIS FOR STUDY AREA A **

STUDY AREA A	AA T1NR3E s.1 stream	AB T1SR1E s.36 stream	AC T1SR1E s.36 below falls	† T2NT6E s.34 spring	† T1NR7E s.19 spring
Temp °C	21	26	30	10	18
pH	7.5	6.8	6.4	7.9	7.3
Cations					
Ca ⁺²	38.4	84.8	67.8	61.0	85.0
Mg ⁺²	27.4	3.1	3.2	37.0	40.0
Na ⁺¹	3.1	5.7	2.8	4.1	31.0
K ⁺¹	1.6	.65	.66	1.0	2.6
Anions					
HCO ₃ ⁻¹	233.2	374.8	168.6	372.0	400.0
CO ₃ ⁻²	0	0	0	0	0
SO ₄ ⁻²	10.7	10.8	10.3	6.0	30.0
Cl ⁻¹	11.0	21.2	13.7	5.8	62.0
mol Ca/Ca+Mg	.46	.94	.93	.50	.56
mol Sr/Ca	.25	.25	-	-	-

TABLE IV (CONTINUED)

STUDY AREA A	AA T1NR3E s.1 stream	AB T1SR1E s.36 stream	AC T1SR1E s.36 below falls	† T2NT6E s.34 spring	† T1NR7E s.19 spring
Trace Elements					
Al ⁺³	nd	nd	nd	nd	.01
Ba ⁺²	.23	nd	nd	nd	-
Cr ⁺²	nd	nd	nd	nd	-
Cu ⁺²	nd	nd	nd	nd	.01
Fe ⁺²	.20	.20	nd	nd	.03
Mn ⁺²	.01	.06	.03	nd	nd
Sr ⁺²	nd	.15	.24	-	-
Zn ⁺²	nd	nd	nd	nd	.50
mol Mn/Fe	.25	.25	-	-	-

TABLE IV (CONTINUED)

STUDY AREA A	† T1NR6E s.11 spring	† T1SR4E s.27 spring	† T1SR3E s.24 spring	† T1SR5E s.34 spring	† T1NR6E s.24 spring
Temp °C	17	18	17	17	18
pH	7.2	7.3	7.4	7.5	7.4
Cations					
Ca ⁺²	75.0	80.0	73.0	72.0	77.0
Mg ⁺²	38.0	27.0	36.0	39.0	38.0
Na ⁺¹	2.0	4.4	8.8	2.5	2.7
K ⁺¹	1.0	1.3	1.5	.90	1.4
Anions					
HCO ₃ ⁻¹	400.0	300.0	400.0	400.0	400.0
CO ₃ ⁻²	0	0	0	0	0
SO ₄ ⁻²	5.5	7.5	8.7	8.3	6.8
Cl ⁻¹	2.9	5.4	12.0	3.5	3.7
mol Ca/Ca+Mg	.54	.55	.53	.64	.55
mol Sr/Ca	-	-	-	-	-

TABLE IV (CONTINUED)

STUDY AREA A	† T1NR6E s.11 spring	† T1SR4E s.27 spring	† T1SR3E s.24 spring	† T1SR5E s.34 spring	† T1NR6E s.24 spring
Trace Elements					
Al ⁺³	nd	.03	.03	.03	.01
Ba ⁺²	-	-	-	-	-
Cr ⁺²	-	.01	nd	nd	nd
Cu ⁺²	nd	nd	.01	.01	.01
Fe ⁺²	.03	.02	.07	.05	.08
Mn ⁺²	.01	.01	nd	nd	.01
Sr ⁺²	-	-	-	-	-
Zn ⁺²	.03	.06	.20	.03	.80
mol Mn/Fe	-	-	-	-	1.0

** - analyses reported in mg/l

* - value calculated by difference

nd - none detectable

† - Fairchild, 1984

Study Area A, respectively.

Honey Creek

In this investigation Honey Creek and Turner Falls are considered to be representative of carbonate rich waters and associated freshwater carbonate deposits. Turner Falls is a unique situation in that it is a creation of Honey Creek and not the destruction (stream erosion) of more resistant rock layers. Honey Creek is a permanent stream of water supplied by numerous subsurface fault springs in the McKenzie Hill Limestone. The surrounding drainage area is primarily limestone terrain, with numerous intermittent springs and streams. Honey Creek flows in a northeasternly direction into the Washita River downstream.

The travertine deposit, Turner Falls, is situated on a cliff face of McKenzie Hill Limestone located in Murray County, T1S, R1E sec. 36. A fault trace parallels the valley of Honey Creek, downfaulting the Cool Creek Limestone on the northeast against the immediately underlying McKenzie Hill Limestone of the southwest. Flowing over the rapids and small waterfalls in the stream, it precipitates travertine throughout the length of the canyon until it plunges approximately 77 feet to the valley floor. Emig (1917) suggested that the valley was once filled with travertine and the falls had a maximum height of approximately 150 feet. His reconstruction of this event is shown in Figure 11. After the initial deposition during



Source: Emig (1917)

Figure 11. Reconstruction of Turner Falls

the Pleistocene the travertine deposits were eroded, in some cases to a lower level than the original base. At Turner Falls this period of erosion produced a distinct gorge. Following this erosion period a second period of travertine deposition began, producing a second series of smaller waterfalls and rapids, which ended about 1850. Since this time a period of equilibrium has existed between erosion and deposition.

Emig (1917) identified three periods of travertine deposition at Turner Falls. The oldest period of formation is recorded in the large cliffs and caves above the level of Honey Creek above the falls. These deposits are approximately 60 feet thick immediately above the natural falls at the lower end of the gorge. Extending upstream for a distance of 450 feet they gradually diminish to only a few feet in thickness. This travertine is cavernous and porous with a large amount of clays. A sample of travertine was taken from a cave located approximately 50 feet directly above the present falls, A2. Another travertine sample, taken from below the falls, consisted of travertine encrusting a branch, A1 (see Figure 12). Calcium Carbonate precipitates on anything that falls into Honey Creek, an example of this is seen in Figure 13. Two water sample locations, AB and AC, were chosen to represent this area, see Figure 14. AB was taken above the falls near a small waterfall. the second was taken below the falls near the travertine sample site A1, also near small waterfalls.



Figure 12. Banded Travertine Deposit on a Branch, Honey Creek, Below Turner Falls



Figure 13. Calcium Carbonate Coating Leaves, Honey Creek



Figure 14. Honey Creek and Turner Falls

Fairchild (1982 and 1984) reported ground water, stream, and spring water chemistry throughout the Arbuckle Mountain area. His data was used throughout this investigation.

Falls Creek

Falls Creek and Price Falls are very similar to Honey Creek and Turner Falls. Emig (1917) identified many periods of deposition and erosion, including the formation of Table Mountain. Price Falls is divided into a Lower Falls and Upper Falls. The Upper Falls is approximately 19 feet high and is formed by a natural fall of Viola Limestone while the Lower Falls is a natural fall on the Chimneyhill Limestone, both fault controlled. Unlike Honey Creek, which is at equilibrium, Falls Creek is causing erosion of the travertine in this area. Falls Creek flows in a northeasterly direction into the Washita River and is fed by numerous fault controlled springs. The travertine sample taken from this area, A3, was a grab sample collected by Dr. Donovan. No water sample was obtained from this site.

Chickasha National Refuge

Chickasha National Refuge a very interesting site because of the complexity of the geology and the hydrology. Within the confines of this park there are numerous hydrogen sulfide flowing wells and springs as well as carbonate rich wells and springs. The geology has as yet to be fully understood. Travertine Creek begins at the eastern corner

of the park, fed by two springs, Buffalo and Antelope Springs, and flows westeardly meandering through the park. Travertine deposits begin approximately 0.25 miles from the springs. Several objects are shown in the visitor center coated with calcium carbonate, the visitor center is also constructed, in part, by travertine taken from the area. A water sample was taken approximately 100 feet from the dried up springs in Travertine Creek, AA. There appeared to be no carbonate precipitation occuring at this location. A travertine sample was taken 0.5 miles further downstream, approximately 8 feet above the present stream level, A1, (see Figure 15).

Study Area B

There are seven investigation sites located in the Slick Hills of Comanche County, Study Area B. This area is geologically very complex with several major fault systems cutting across the region, specifically the Meers Fault, Blue Creek Canyon Fault Complex, and the Ketch Creek Fault, see Figure 16. The Stratigraphic section of the Slick Hills (Figure 17) shows that the Arbuckle Group is well represented. The fault systems are responsible for the discharge mechanism of the Arbuckle Group water, fault controlled springs and spring-fed streams, see Figures 18 and 19. Precipitation provides the only means for recharge into the Arbuckle Group. The water moves along the many exposed tilted bedding planes, fractures, and faults of the



Figure 15. Pleistocene Age Travertine, Sample A

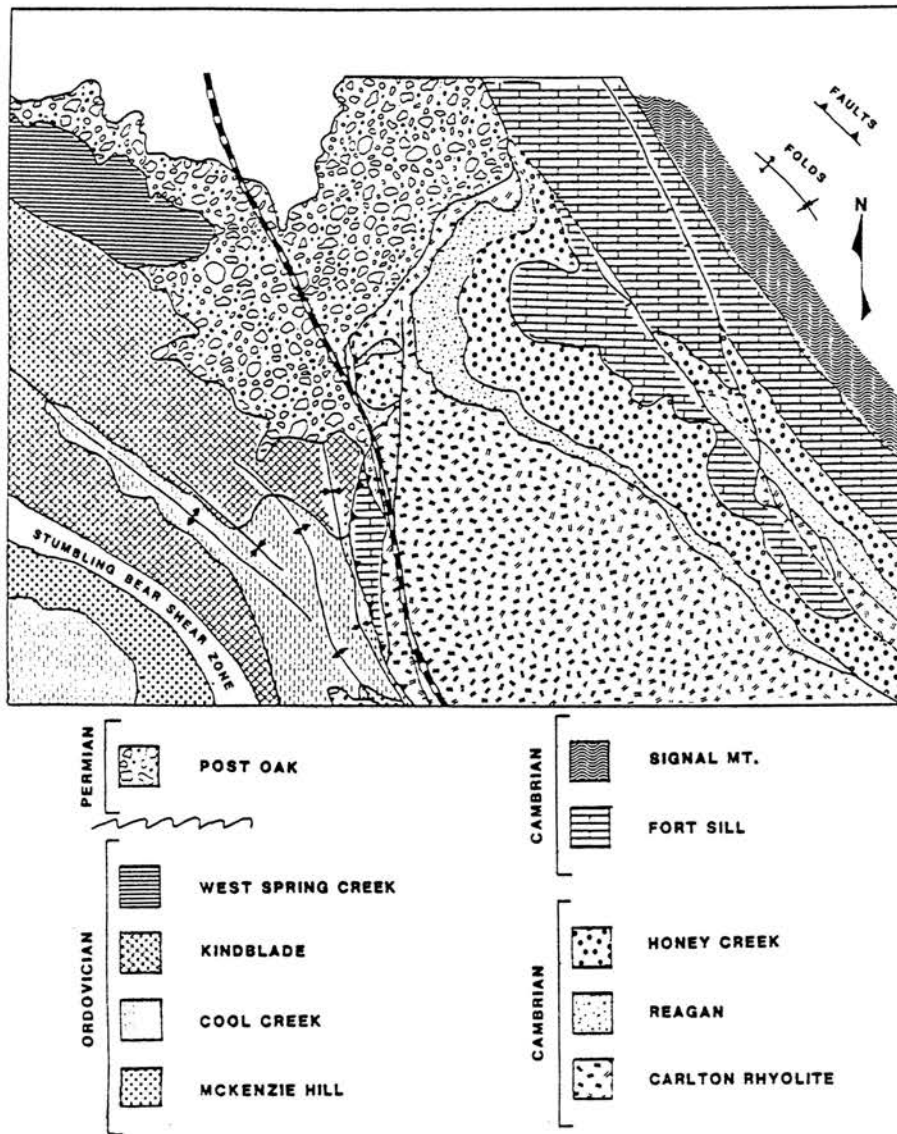


Figure 16. Geologic Map of Blue Creek Canyon, Study Area B

GENERAL STRATIGRAPHIC LOG FOR THE SLICK HILLS OF SOUTHWESTERN OKLAHOMA						
ERA	PERIOD	AGE	LITHOLOGY	FORMATION	AVERAGE THICKNESS	GROUP
Early Paleozoic	Late Paleozoic	Permian	Wolf-campian	Wichita (Post Oak Member)	120 m (400 ft)	Hem- sac
				West Spring Creek	90 m (300 ft)	
	Early Ordovician	Canadian		Kindblade	425 m (1400 ft)	Upper Ar- buckle
				Cool Creek	425 m (1400 ft)	
				McKenzie Hill	300 m (1000 ft)	
	Cambrian	Crotinian		Signal Mountain	150 m (500 ft)	Lower Arbuckle
				Fort Sill	120 m (400 ft)	
				Honey Creek	90 m (300 ft)	Timbered Hills
				Reagan Sandstone	45 m (150 ft)	
				Carlton Phylolite		

Figure 17. Stratigraphic Log of the Slick Hills, Study Area B

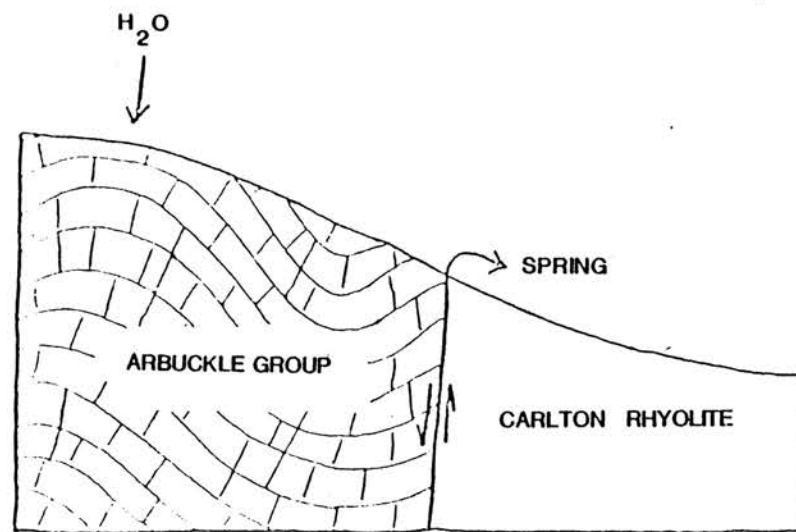


Figure 18. The Hydrologic Mechanism
for Ketch Creek Spring

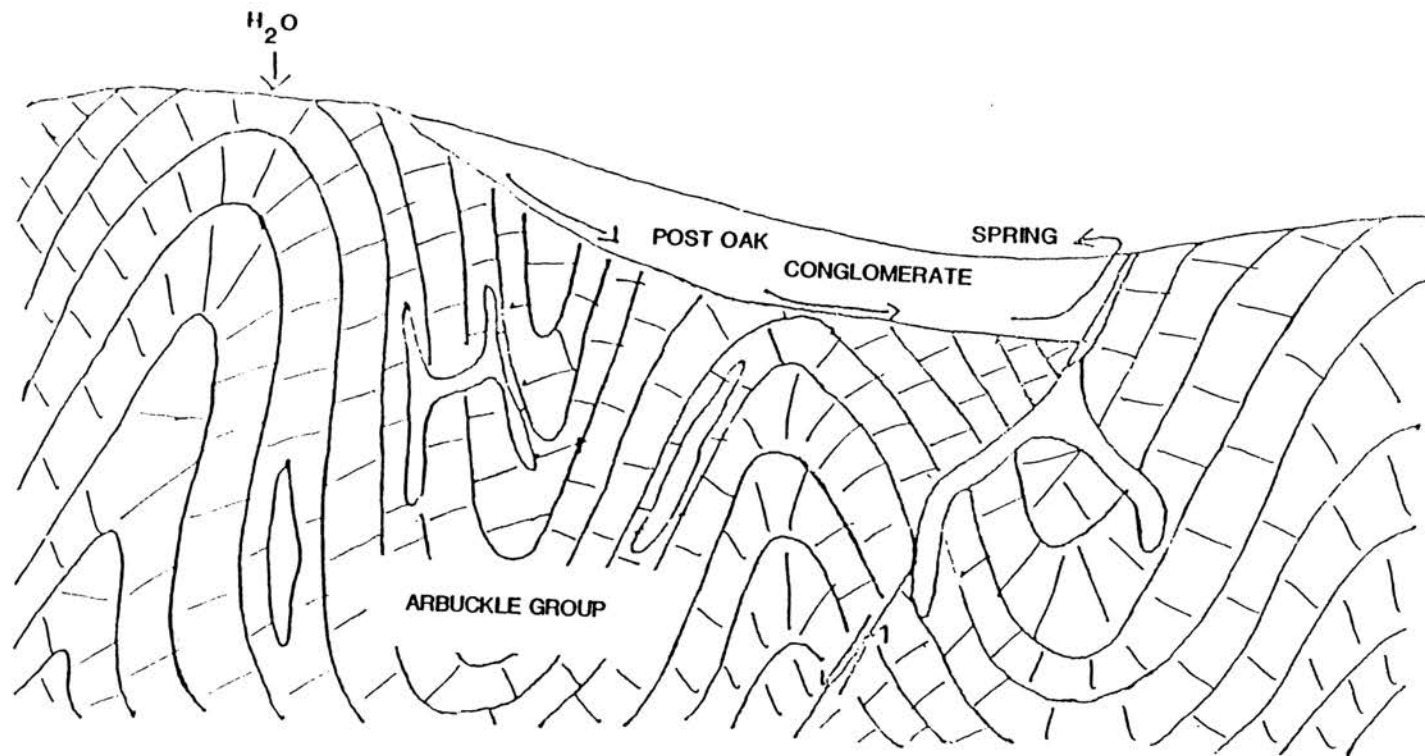


Figure 19. A Possible Hydrologic Mechanism
for Jimmy Creek

predominately limestone, dolomite, and shale formation, ultimately reaching the regional water table. The geologic complexity of the area creates problems in water well drilling. Many times a dry hole is encountered at 600 or more feet. On the other hand, many wells and springs flow under artesian conditions. The springs found in this study area, as well as many of the small spring-fed streams, are ephemeral, in that they flow only during, and for a short time after, a recharge event.

Tables 5 and 6 contain the chemical analyses of Study Area B rock and water samples, respectively. The sample site descriptions follow.

Ketch Creek Area

Ketch Creek spring also an example of a fault controlled spring, (Figure 18) is located at T1S, R14E, sec. 8. Several other springs along the same fault plane have been reported. The spring, in May, was reduced to a seep with all the other springs dry. The water sample, BE, unlike any of the other water samples, reacted immediately to the addition of 1:1 nitric acid, used as a preserving agent, indicating an abundance of carbonate. There were some green mosses still present along the damp spring path as well as a soft "chalky" deposit, precipitated on clumps of grass, see Figure 20. These deposits were found along the edge of what appeared to be the creek bed, and occurred in scattered deposits approximately 10 feet downstream from

TABLE V

ROCK ANALYSIS FOR STUDY AREA B

Study Area B	B1 T4NR13W s. 2 Recent stream	B2 T4NR12W s. 7 Recent stream	B3 T4NR12W s. 8 Float sample	B4 T4NR13W s. 8 near waterfall
Isoluble Residue	28.6%	3.0%	6.4%	25.8%
SiO ₂	-	-	-	-
CaO	30.2	42.2	48.5	36.5
K ₂ O	0.04	5.2	1.2	1.2
MgO	0.30	0.47	0.60	0.92
Na ₂ O	0.61	0.18	0.38	0.23
mol Ca/Ca+Mg	0.99	0.80	0.98	0.97
mol Sr/Ca	0.24	0.04	0.17	1.35
Trace Elements (pph of rock)				
Al ⁺³	nd	nd	nd	nd
Ba ⁺²	0.049	0.016	0.030	0.017
Cr ⁺²	0.003	0.003	0.003	0.002
Cu ⁺²	0.001	0.001	0.001	0.001
Fe ⁺²	0.360	0.078	0.314	0.324
Mn ⁺²	0.050	0.004	0.010	0.030
Sr ⁺²	0.012	0.003	0.013	0.077
Zn ⁺²	0.002	0.001	0.002	0.002
Pb ¹	-	0.020	-	-

Table V (Continued)

Study	B1	B2	B3	B4
Area	T4NR13W s. 2	T4NR12W s. 7	T4NR12W s. 8	T4NR13W s. 8
B	Recent stream	Recent stream	Float sample	near waterfall
Thorium ¹	-	nd	-	-
Uranium ¹	-	nd	-	-
mol Mn/Fe	0.14	0.05	0.03	0.08

Table V (Continued)

Study Area B	B5 T4NR13W s. 8 Recent travertine	B6 T4NR13W s. 8 Recent travertine	B7 T4NR13W s. 8 Recent travertine	B8 T4NR13W s. 8 Pleistocene travertine
Insoluble Residue	1.2%	3.8%	4.9%	4.3%
SiO ₂	-	-	-	-
CaO	44.2	49.2	45.9	45.0
K ₂ O	6.9	1.0	0.83	2.3
MgO	0.43	0.43	0.46	0.54
Na ₂ O	0.18	0.15	0.28	0.18
mol Ca/Ca+Mg	0.99	0.99	0.99	0.98
mol Sr/Ca	0.51	0.52	0.72	0.61
Trace Elements (pph of rock)				
Al ⁺³	nd	nd	nd	nd
Ba ⁺²	0.041	0.031	0.004	0.041
Cr ⁺²	0.003	0.003	0.003	0.003
Cu ⁺²	0.001	0.001	0.001	0.001
Fe ⁺²	0.111	0.142	0.196	0.137
Mn ⁺²	0.015	0.018	0.016	0.014
Sr ⁺²	0.052	0.040	0.052	0.043
Zn ⁺²	0.001	0.005	0.002	0.001
Pb ¹	-	-	-	0.059

Table V (Continued)

Study	B5	B6	B7	B8
Area	T4NR13W s. 8	T4NR13W s. 8	T4NR13W s. 8	T4NR13W s. 8
B	Recent travertine	Recent travertine	Recent travertine	Pleistocene travertine
Thorium	¹ -	-	-	-
Uranium	¹ -	-	-	-
mol Mn/Fe	0.14	0.13	0.08	0.10

¹ = x-ray flourescent semi-qualitative pph
values are an average of duplicates

% by weight

nd = none detectable

TABLE VI

WATER ANALYSIS FOR STUDY AREA B **

Study Area Area	BA T4NR13W s. 2 stream	BB T4NR12W s. 7 stream	BC T4NR13W s. 8 pond	BD T4NR13W s. 8 well
Temp °C	17	18	18	15
pH	8.0	7.8	6.9	7.4
Cations				
Ca ⁺²	85.0	91.0	87.0	47.0
Mg ⁺²	6.0	7.0	8.0	4.0
Na ⁺¹	5.1	5.1	1.4	8.5
K ⁺¹	1.0	1.3	0.51	2.0
Anions				
HCO ₃ ⁻¹	284.0	264.0	232.0	160.0
CO ₃ ⁻²	0	0	0	0
SO ₄ ⁻²	25.22	25.62	17.38	21.82
Cl ⁻¹	14.61	18.70	32.86	7.30
mol Ca/Ca+Mg	0.89	0.89	0.87	0.88
mol Sr/Ca	-	-	-	-

TABLE VI (CONTINUED)

Study Area Area	BA T4NR13W s. 2 stream	BB T4NR12W s. 7 stream	BC T4NR13W s. 8 pond	BD T4NR13W s. 8 well
Trace Elements				
Al ⁺³	nd	nd	nd	nd
Ba ⁺²	nd	0.98	nd	nd
Cr ⁺²	nd	nd	nd	nd
Cu ⁺²	nd	nd	nd	nd
Fe ⁺²	nd	nd	nd	nd
Mn ⁺²	0.06	0.01	0.06	0.01
Sr ⁺²	nd	nd	nd	nd
Zn ⁺²	nd	nd	nd	nd
mol Mn/Fe	-	-	-	-

TABLE VI (CONTINUED)

Study Area B	BE TO4NT12W s. 7 spring	BF TO4NR12W s. 7 stream	BG TO4NR13W s. 8 stream	BH TO4NR13W s. 8 stream
Temp °C	27	19	23	24
pH	7.1	7.6	8.2	7.6
Cations				
Ca ⁺²	59.0	60.0	75.0	67.0
Mg ⁺²	9.0	1.7	12.0	5.1
Na ⁺¹	3.3	0.92	1.2	1.8
K ⁺¹	2.5	1.0	0.63	0.61
Anions				
HCO ₃ ⁻¹ *	250.0	* 146.0	* 259.0	* 166.0
CO ₃ ⁻²	0	0	0	0
SO ₄ ⁻²	18.82	3.26	28.19	15.10
Cl ⁻¹	7.30	33.67	4.78	28.68
mol Ca/Ca+Mg	0.80	0.00	0.00	0.00
mol Sr/Ca	0.10	-	0.04	-

TABLE VI (CONTINUED)

Study	B5	B6	B7	B8
Area	T4NR13W s. 8	T4NR13W s. 8	T4NR13W s. 8	T4NR13W s. 8
B	Recent travertine	Recent travertine	Recent travertine	Pleistocene travertine
Trace Elements				
Al ⁺³	nd	nd	nd	nd
Ba ⁺²	nd	nd	nd	nd
Cr ⁺²	0.41	nd	nd	nd
Cu ⁺²	0.13	nd	nd	nd
Fe ⁺²	2.60	0.64	nd	nd
Mn ⁺²	0.63	0.51	nd	nd
Sr ⁺²	1.27	nd	0.73	nd
Zn ⁺²	0.06	nd	nd	nd
mol Mn/Fe	0.22	0.96	-	-

** - analyses reported in mg/l

* - value calculated by difference

nd - none detectable

† - Fairchild, 1984



Figure 20. Ketch Creek Calcium Carbonate Spring Deposit,
Sample B

the spring head. This deposit was labeled B2 and contained an unusual amount of trace elements, similar to the associated water sample BE.

Another water sample was obtained from a small stream located 25 miles away. This stream appeared to be spring-fed because of the amount of flow and no appearance of ever being dry, BF. There was no evidence of carbonate deposits at this site.

Blue Creek Area

The Blue Creek Canyon Fault system is most likely responsible for controlling the springs of this area. Water samples were taken along Hwy. 58, T4N, R13W, sec. 2. A pond on the west side of the road was formed by the intersection of several faults. This pond is reported to be spring fed but at the sampling times no springs were noticed, and the level of the water appeared to stay constant throughout the year, BC. On the opposite side of the road an ephemeral stream flows across Carlton Rhyolite. Two water samples were taken one week apart, BA and BB. It appeared that there was a decrease in stream flow between the time BA was taken and BB water was sampled. Evaporation appeared to be the mechanism responsible for a white, soluble deposit on the rhyolite at the water's edge. This deposit never had any degree of build-up, nor were there any carbonate deposits found along the stream site. A shallow alluvial domestic well, approximately 30 feet in depth was sampled and

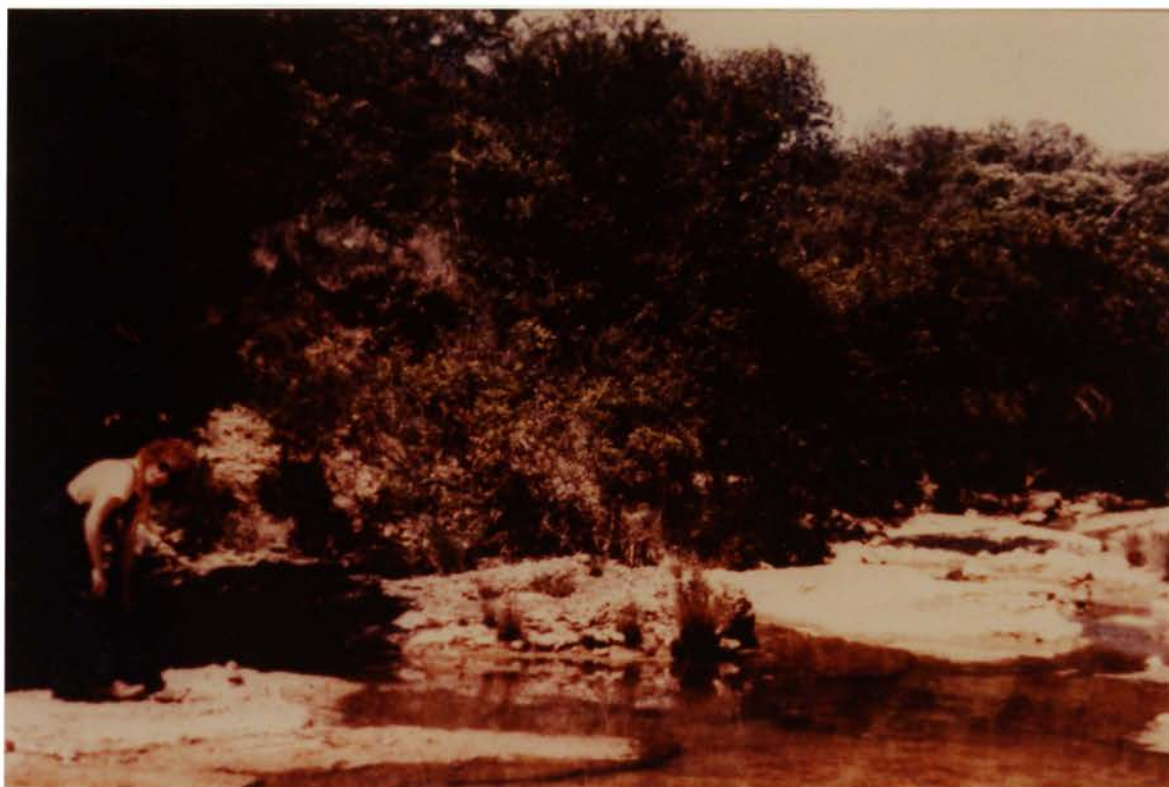


Figure 21. Water Sample BC, Taken at Jimmy Creek near
Meer's Fault

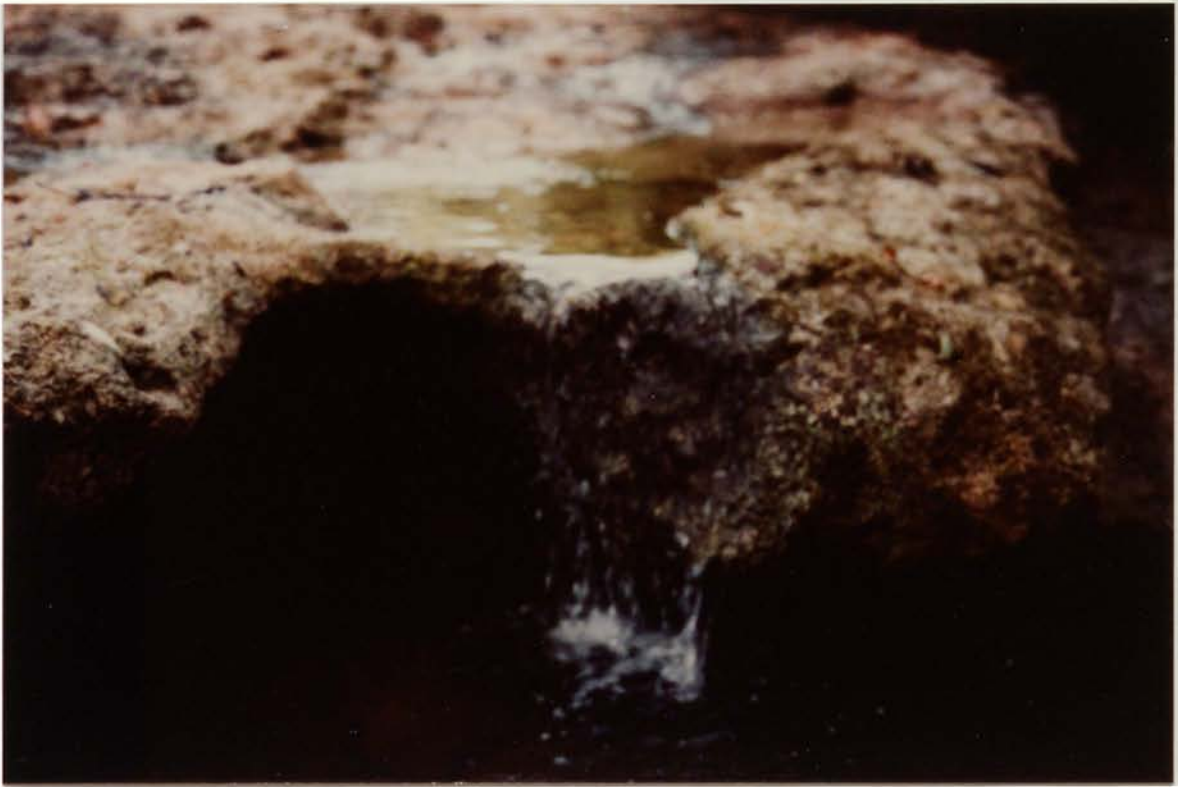


Figure 22. Small Travertine Waterfall Along Jimmy Creek

falls, and contained a leaf impression similar to the leaves found along the stream edge, (Figure 23).



Figure 23. Leaf Impression in Pleistocene Age Travertine,
Sample B

CHAPTER V

TEXTURAL DESCRIPTIONS

Travertine textures are varied as the environments in which they can be found. Porous, massive, plant impressions, crystalline, and banded are only a few of the descriptive terms that may be applied to them. Colors are generally white to light brown, with crystalline travertines having a wider variety of colors.

The travertines in this investigation are predominately of two textural types in hand sample; banded and porous. These travertines of Pleistocene through present age do not have any crystalline textures as do some Permian travertines seen elsewhere in Oklahoma. The textural descriptions given below are based on hand sample descriptions, thin section analysis, and scanning electron microscope interpretations of selective travertine samples. Both Study Area A and Study Area B were described using these three methods.

Study Area A

Banded and porous travertines of Pleistocene and Recent age are found in Study Area A. The Recent travertines of Falls Creek and Honey Creek have banded textures. A Pleistocene age cave deposit from Turner Falls and a

Pleistocene age travertine from Travertine Creek have a porous texture.

The banded travertine, from Turner Falls, sample A1, taken from an encrusted travertine stick showed alternate bands of calcium carbonate varying in texture and color. White, dense, striated bands, with what appeared to be growth layers of 0.5 to 4 mm. in thickness alternated with a light brown layer. This light brown layer contained various fragments of plant pieces with a very dense, porous texture. A thin section was not made of this sample because of its friability. A scanning electron microscope examination of these bands showed completely different textures. The light brown bands, at a magnification of 206x, appear as algal tubules, similar to those described by Scholle (1984), (Figure 24). The dense white bands appear as fields of rosettes at 206x magnification, (Figure 25a). At 845x these rosettes appear dense and admixed with small crystals of calcite, (Figure 25b).

The other banded travertine sample, A5, located at Price Falls, had a similar texture in hand sample although the banding was not as prominent as in sample A4. A thin section of sample A5 showed fibrous calcite with several growth bands, (Figures 26 and 27).

Sample A3, a travertine cave deposit obtained from the Turner Falls area, has a reddish-brown color and a porous texture. X-ray analysis of the sample showed it to be a low-magnesium calcite. Electron microscope analysis showed

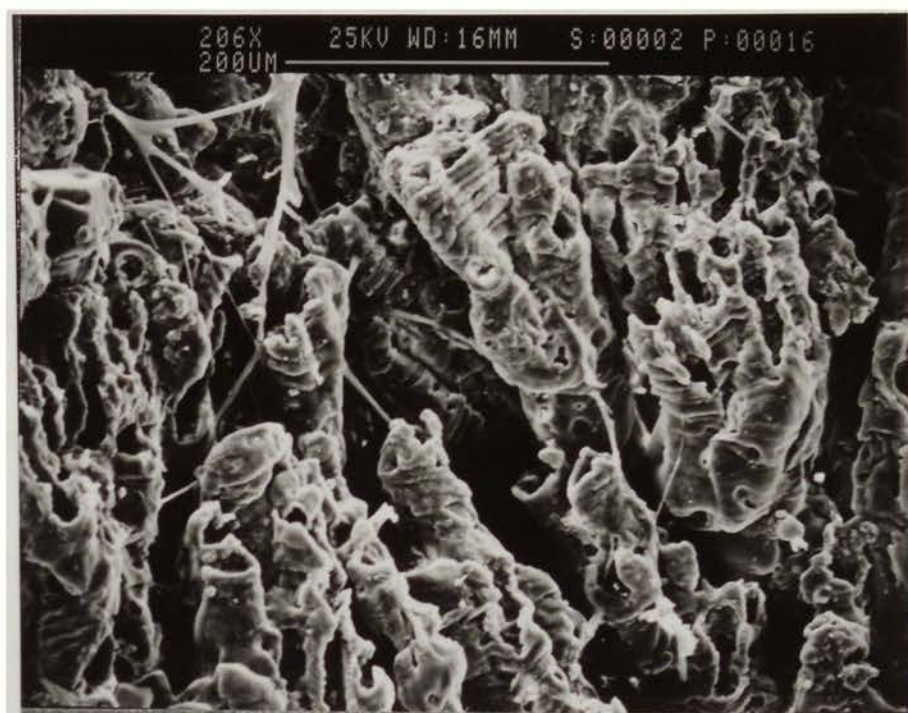
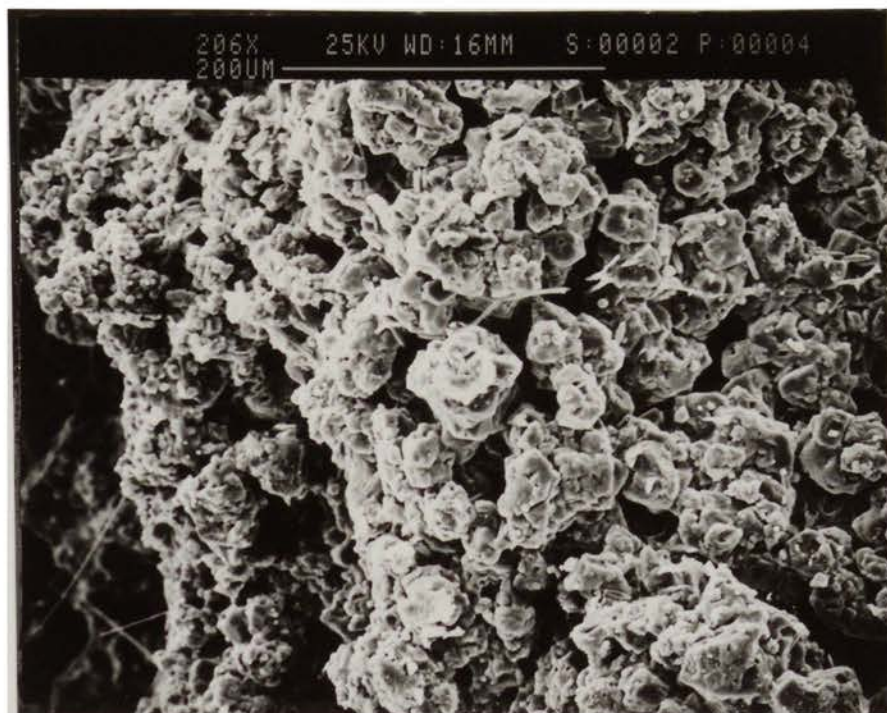


Figure 24. SEM Photograph of a Recent Banded Travertine From Turner Falls, light brown band, algal tubules. Magnification 206x

a.

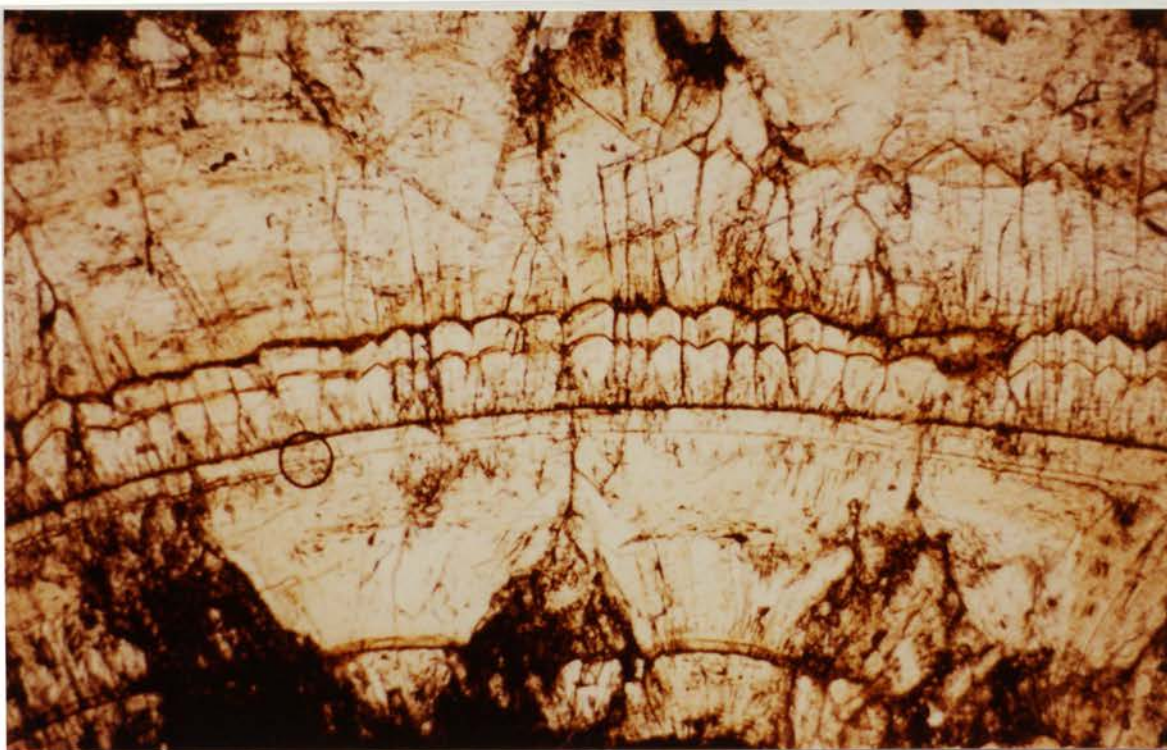


b



Figure 25. SEM Photographs of a Recent
Banded Travertine From Turner
Falls, White Band,
a) Magnification 206x
b) Magnification 845x

a.



b.



Figure 27. Photomicrograph of a Recent banded Travertine
From Price Falls. Magnification 40x.
a) Plane Polarized light
b) Crossed Polars

that the sample contains an amorphous algal material with a few microscopic crystals, (Figure 28). At a higher magnification (4000x) needle like shapes were seen. Based on the literature example Allanson (1973), identification of these needles indicates they are the diatom, *Synedra* sp..

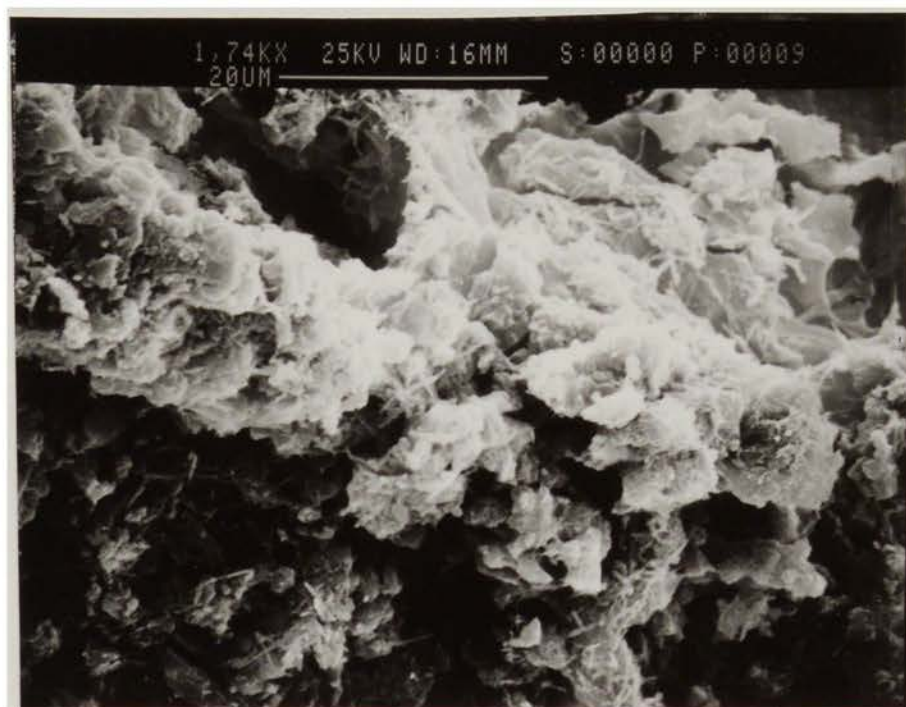
Sample A4, also a Pleistocene age travertine, was obtained from Chickasha National Refuge and is a very porous, dark beige, travertine with numerous plant impressions. X-ray diffraction analyses of the sample showed it to be a low-magnesium calcite. A thin section of this sample showed calcified plant parts, (Figure 29). There were very small calcite crystals forming along the inside edges of the pore spaces, (Figure 30). The electron microscopic analysis (magnification 1040x) showed algal material and the needle like shapes seen in sample A3, possibly *Synedra* sp., (Allanson, 1973), (Figure 31).

Study Area B

Travertines found in Study Area B are porous in texture, with on exception; the Ketch Creek spring deposit, which has a spongy amorphous texture deposited on grass.

A Pleistocene age travertine sample from Jimmy Creek, sample B7, was porous, light brown travertine and contained numerous plant impressions and a variety of pore sizes and shapes. There appeared to be a white, dense layer around some non-carbonate pebbles, and some pores had a smooth, darker brown surface. X-ray analysis of the sample showed a

a.

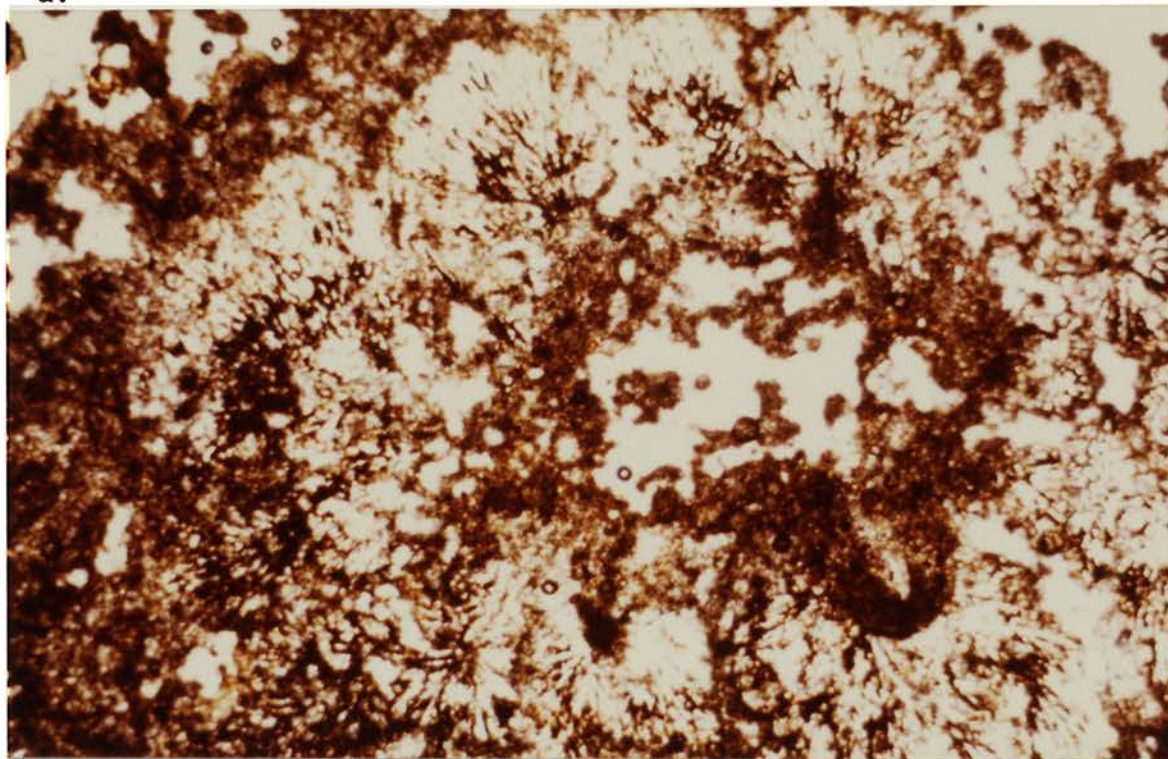


b.



Figure 28. SEM photographs of a Pleistocene cave deposit From Turner Falls
a) Magnification 1740x and
b) Magnification 4000x

a.



b.

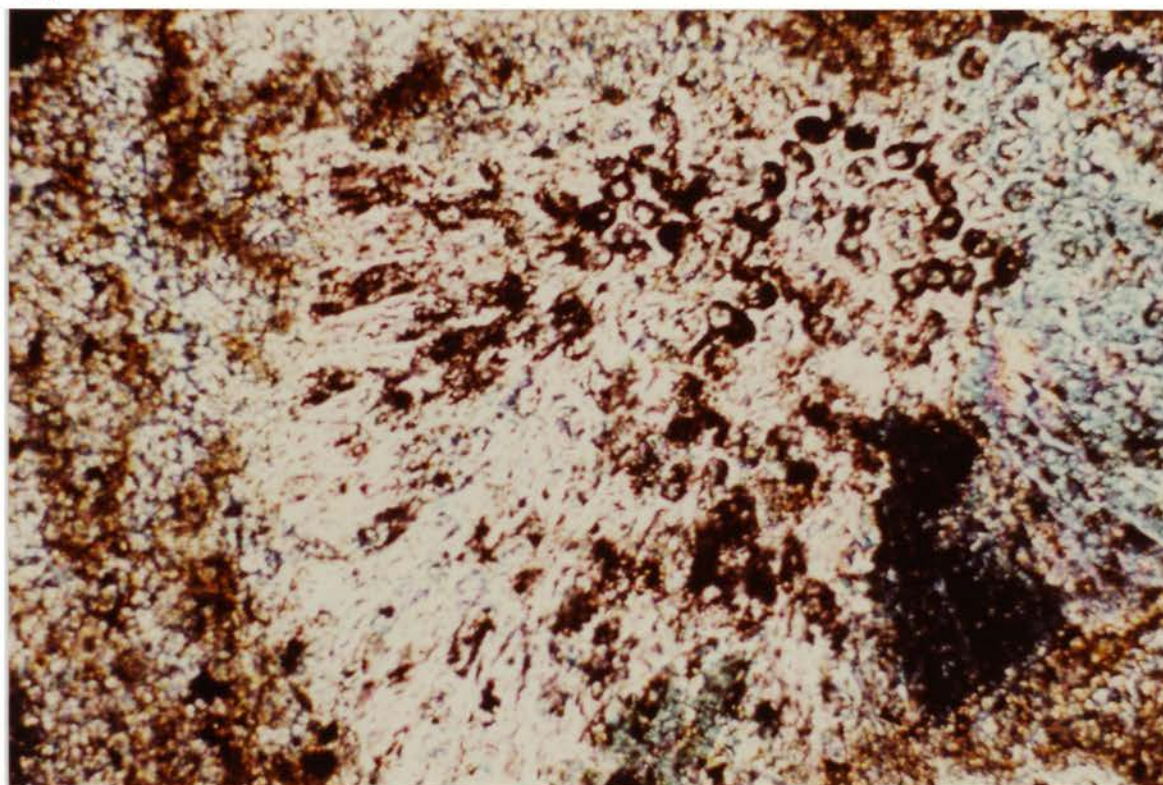


Figure 29. Photomicrograph of a Pleistocene Travertine From
Chickasha National Refuge. Crossed Polars
a) Magnification 40x
b) Magnification 200x

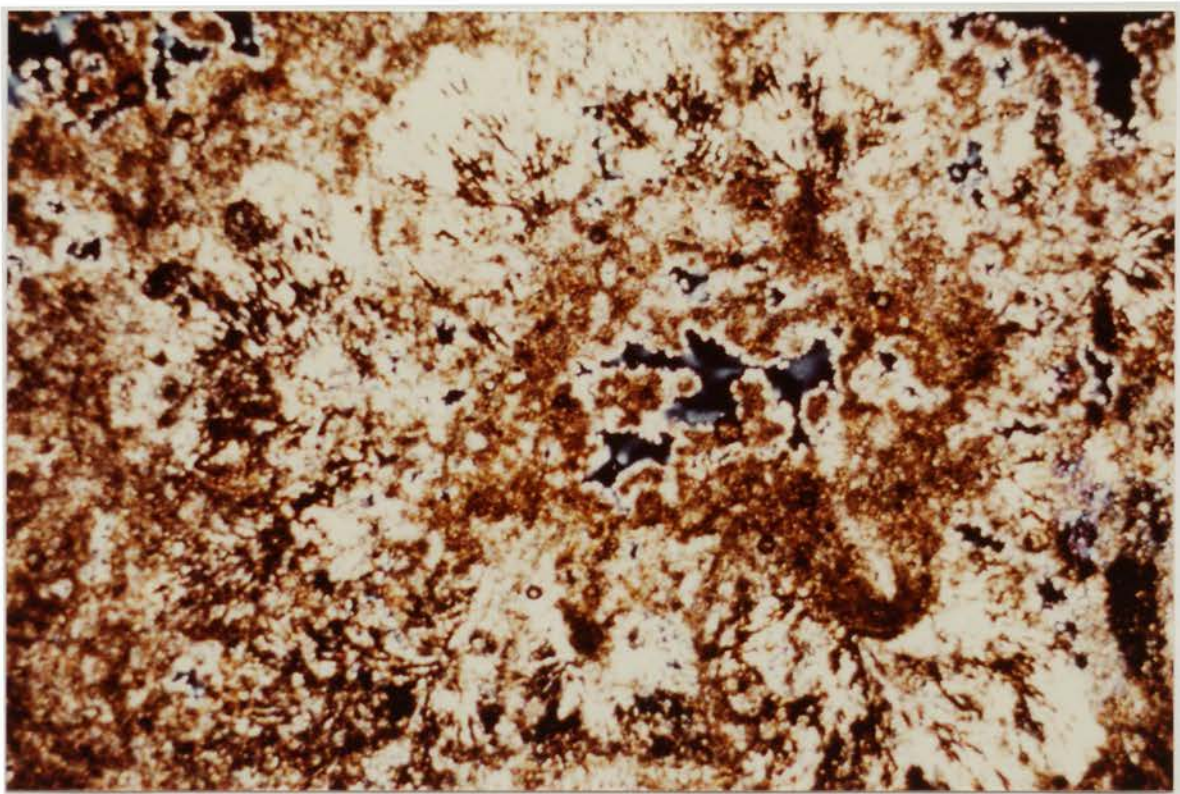


Figure 30. Photomicrograph of a Pleistocene Travertine From Chickasha National Refuge Showing Calcite Crystals Fringing the Pore Spaces. Crossed Polars. Magnification 40x



Figure 31. SEM Photomicrograph of a
Pleistocene Travertine
From Chickasha National
Refuge.
Magnification 40x

low-magnesium calcite. Electron microscopic interpretations showed algal material with very few crystals present, (Figure 32). The Recent travertine samples from Jimmy Creek were all similar in hand sample. Mosses made up the surface layer, which was a light brown cellular textured layer. Indistinct banding could be seen in the samples B2, B4, and B5. Thin section analysis showed calcified plant pieces at 40x magnification, with lime mud coating the edges, (Figure 33). Small calcite crystals were also found growing along the lime mud edge into the pore spaces in this sample. Electron microscopic examination at a magnification of 1090x showed boat shaped diatoms, perhaps *Novicula* sp., (Figure 34). The Ketch Creek spring deposit was unique in both texture and location. Found on small clumps of grass a short distance from the spring head, this deposit was a moist, off-white, amorphous calcium carbonate precipitate. X-ray examination of this sample showed it to be a low-magnesium calcite. Microscopically at a magnification of 1790x, diatoms, algal material, and very small crystals of less than 10 μm are seen, (Figures 35 and 36). These boat shaped diatoms are perhaps *Novicula* sp.



Figure 32. SEM Photograph of a Pleistocene
Travertine From Jimmy Creek
Magnification 1090x

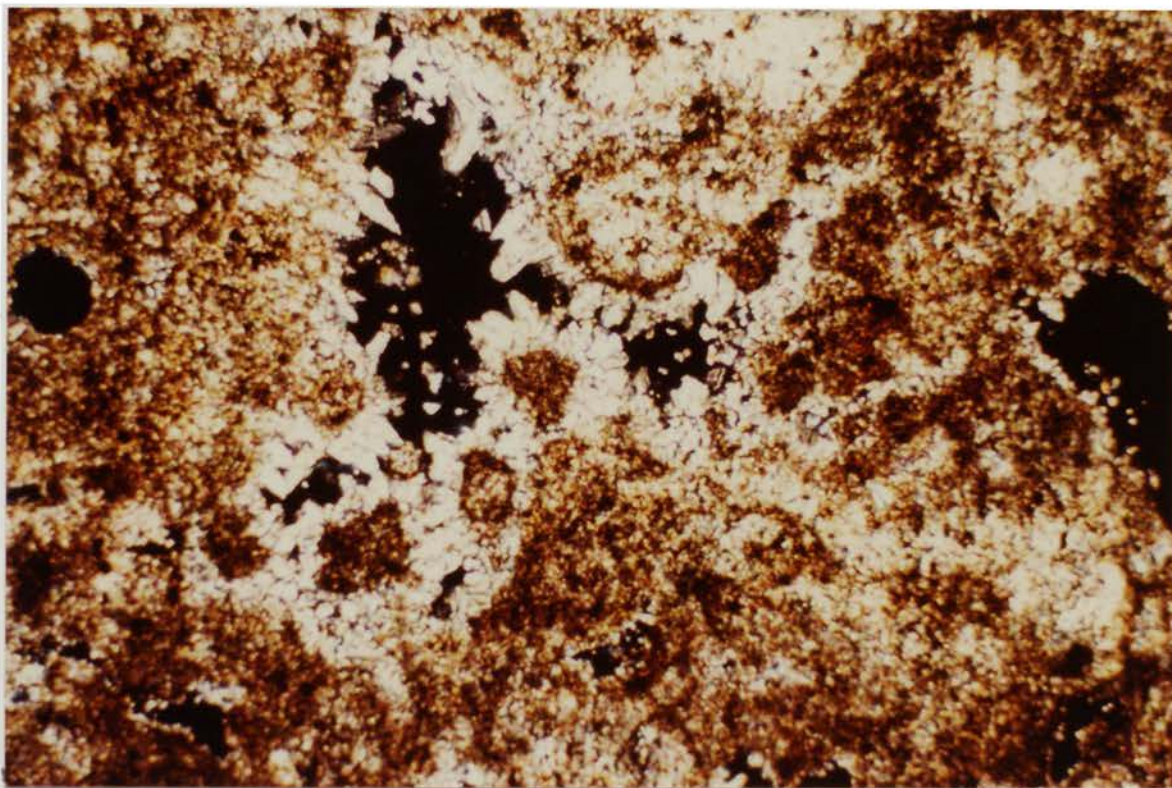


Figure 33. Photomicrograph of a Recent Travertine From Jimmy Creek Showing Calcite Crystals Fringing the Pore Spaces Crossed Polars. Magnification 40x



Figure 34. SEM Photograph of a Recent
Travertine From Jimmy
Creek Showing *Novicula*
sp. Diatoms
Magnification 1090x



Figure 35. SEM photograph of a Spring
Deposit From Ketch Creek
Spring
Magnification 1760x

a.



b.



Figure 36. SEM Photographs of a Spring Deposit From Ketch Creek Spring Showing *Novicula* sp. Diatoms
a) Magnification 1790x
b) Magnification 8120x

CHAPTER VI

ROCK-WATER RELATIONSHIPS

The three groups of samples being considered are 1) freshwater deposits (travertines and tufas), 2) carbonate-rich springs, streams, and ground water, and 3) freshwater carbonates which have natural waters still associated with them. A Ca/Mg or Mg/Ca ratio was used in water and rock interpretations as a determination of the degree of limestone or dolomite present. Two other ratios associated primarily with marine rock geochemistry are a Sr/Ca (Graf, 1960, and others) and Mn/Fe (Trent, 1978). Friedman (1969) reported the use of trace elements (barium, manganese and iron) as indicators of environments. There was little published material found by this author that describes the possible relationships between freshwater carbonates and the associated natural waters, such as carbonate-rich springs. In the present study, Ca/(Ca+Mg) has been used, as well as, (when data are available) Sr/Ca and Mn/Fe for both water and rocks. Electron Microscopy was also used to determine relationships between travertine deposits and associated waters. In this study, however, electron microscope examination was conducted only on the travertine samples and not the waters, producing very interesting

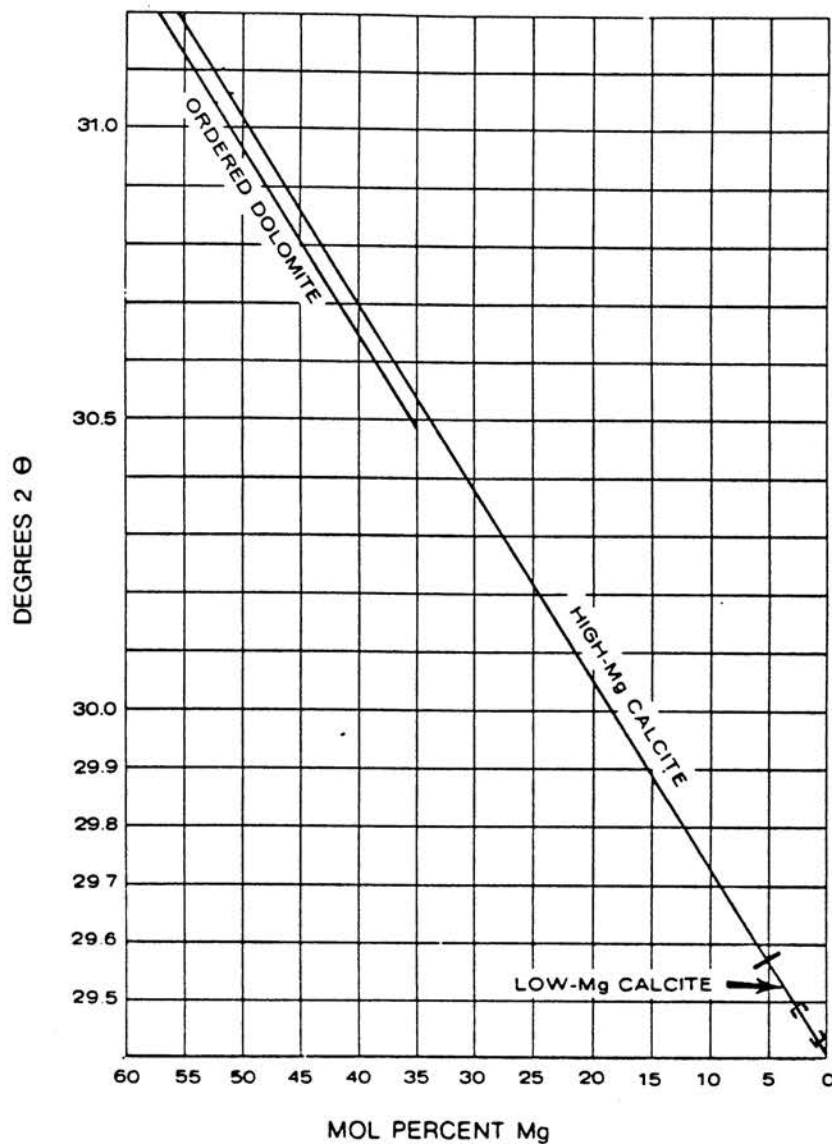
results.

Carbonate Rocks

Published data describing the elemental content and geochemical relationships of carbonate rocks is abundant, however little deals specifically with freshwater carbonates. The geochemistry of fresh water differs considerably from that of sea water, therefore the geochemistry of fresh water carbonates is different in many aspects from carbonate rocks of marine origin.

The data analyzed in this investigation is reported as percent by weight whole rock (having used 10% HCl acid for digestion), Tables 3 and 5.

The mineralogical composition of five travertines was determined by x-ray diffraction. The magnesium within the calcite lattice was found by measuring the (112) peak of calcite using quartz as an internal standard. All samples showed a low-magnesium calcite according to Schollo's classification (Figure 37). Trent (1978) using the same classification showing that three travertine samples from Colorado were high-magnesium calcite/argonite. The trace element contents of the seven powdered travertine samples was accomplished by semi-quantitative analysis using x-ray fluorescent spectrography (done by FLUO-X-SPEC analytical laboratory); see Appendix C for the analyses. Three analyses showed varying amounts of columbium, rubidium, yttrium, and zirconium. One sample, A2, contained 100 ppm



Source: Scholle, 1984

Figure 37. Plot of Degrees 2θ Versus Mol % Mg. Graph Based on (112) Peak Shift in Carbonate Rocks. Data Obtained From This Study Plot Along a Line Between Parentheses.

of titanium, 220 ppm thorium, and 95 ppm uranium.

The electron microscopic examination provided further differentiation between travertine deposits by showing different microscopic textures. Algal material, diatoms, and rosettes of unknown origin were found in the travertines sampled.

Calcium Content

The small insoluble residue and large calcium content of most of the travertines investigated indicated a relatively pure form of calcium carbonate (found to be calcite by x-ray diffraction) for the freshwater limestones associated with the Arbuckle Group waters. Trent (1978) also found high calcium content and low insoluble residues for the various freshwater travertine samples in Colorado. He did not look at the chemistry of any of the associated waters.

Magnesium Content

The magnesium content is proportionally lower than calcium. All the travertines sampled except A4 showed an average of 2966 ppm of magnesium. Using Scholle's classification and corrected 20 values from x-ray analysis the freshwater travertines sampled are low-magnesium calcite, as are Armstrong's (unpubl. thesis) travertines. Irion and Muller (1968) reported low magnesium contents in German travertines. However, Klahn (1928) reported an occurrence

of dolomitic tufas associated with magnesium rich waters in Germany.

Iron Content

The iron content of freshwater carbonates is extremely variable within the study areas. Irion and Muller (1968) reported iron contents from 46 to 3900 ppm in German travertines. Trent (1978) reported iron contents as high as 10% by weight in Colorado deposits. This investigation resulted in iron contents ranging from none detectable to 2.6 ppm in waters and from 200 to 4787 ppm in the travertines.

Manganese Content

Manganese content in freshwater carbonates is also extremely variable. However the content of manganese in this study of freshwater carbonates is well below the average for sedimentary carbonate rocks, (Graf, 1960).

Strontium and Barium Content

The average Sr/Ca ratio of limestone is 0.71, derived primarily from marine limestones in waters of high strontium, sea water, (Armstrong, unpubl. thesis).

Literature does report a definite decrease in strontium content with increasing age, (Graf, 1960). Strontium content does seem to decrease with a decrease in Ca/Ca+Mg content as shown in Figure 38. The use of strontium to

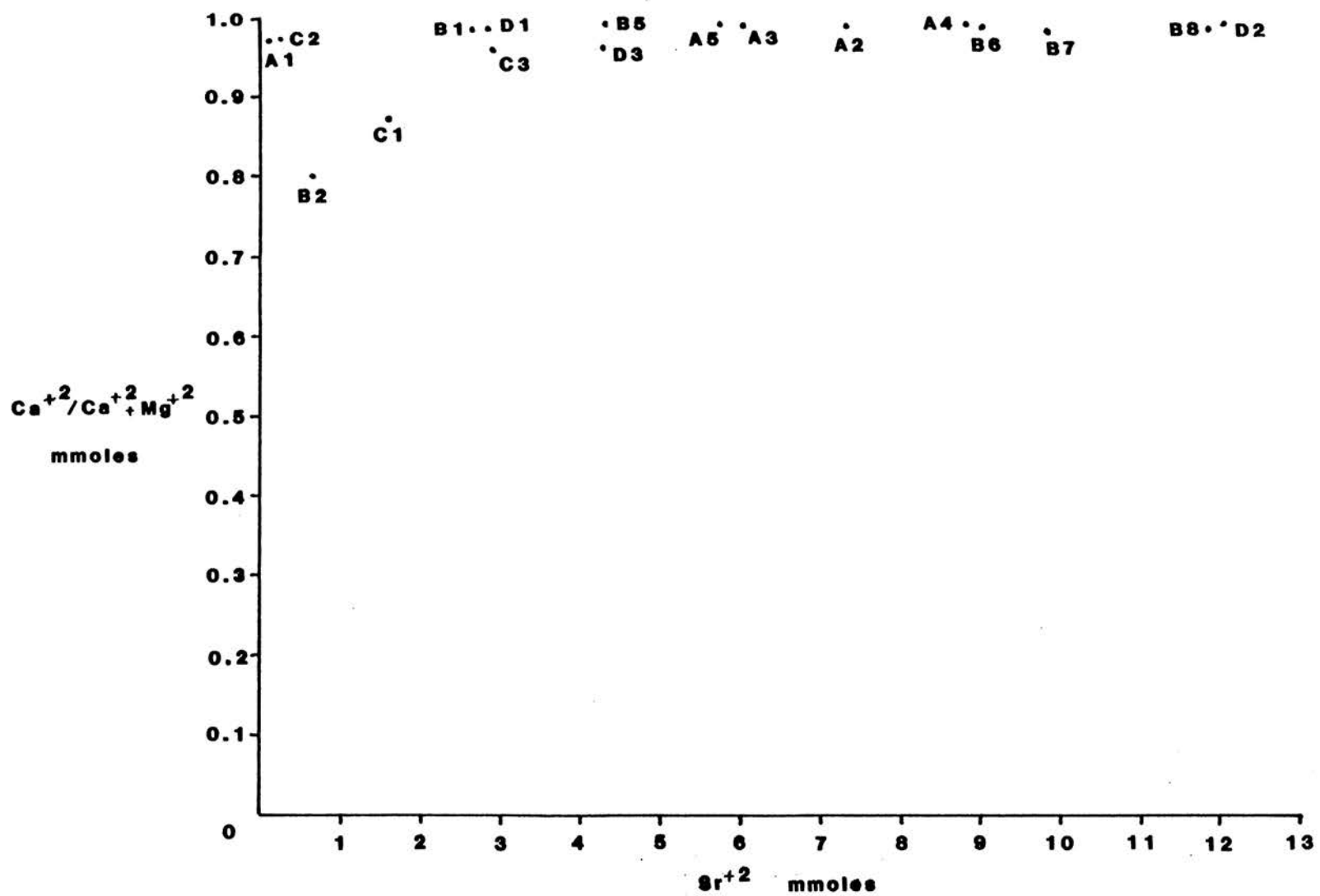


Figure 38. Graph of $\text{Ca}^{+2}/\text{Ca}^{+2}+\text{Mg}^{+2}$ vs. Sr^{+2} Using Samples In This Study

distinguish between recent and Pleistocene deposits was not possible because of the lack of significant variability. The strontium range found in this investigation was 1 ppm to 77 ppm with barium ranging between 2ppm and 69 ppm.

Water

The Arbuckle aquifer is a limestone-dolomite aquifer, recharged primarily by precipitation. In the Arbuckle Mountain area approximately 78% of annual precipitation is lost through evapotranspiration. The Slick Hills in Commache County lose even more precipitation to evapotranspiration, approximately 93%.

The magnesium content of the water from the Arbuckle Group varies depending on bedrock. Nearly all of the Arbuckle Group formations are limestone in the western half of the Arbuckle Mountains (Study Area A) grading into dolomites, sandstone, and shales to the east. The chemistry of the water directly reflects this transition. Magnesium-poor water is seen in the Piper diagram of Murray County, limestone dominant, Figure 39, and magnesium-rich waters in the Piper diagrams of Pontotoc and Johnson Counties, predominantly dolomite, Figures 40 and 41, (Hart, 1974). Fairchild (1984) analyzed the springs located in the eastern part of the Arbuckle Mountains, Figure 42. The majority of the springs he sampled contained a higher content of magnesium than the springs sampled in this investigation, because of the primary dolomitic lithology. Study Area B

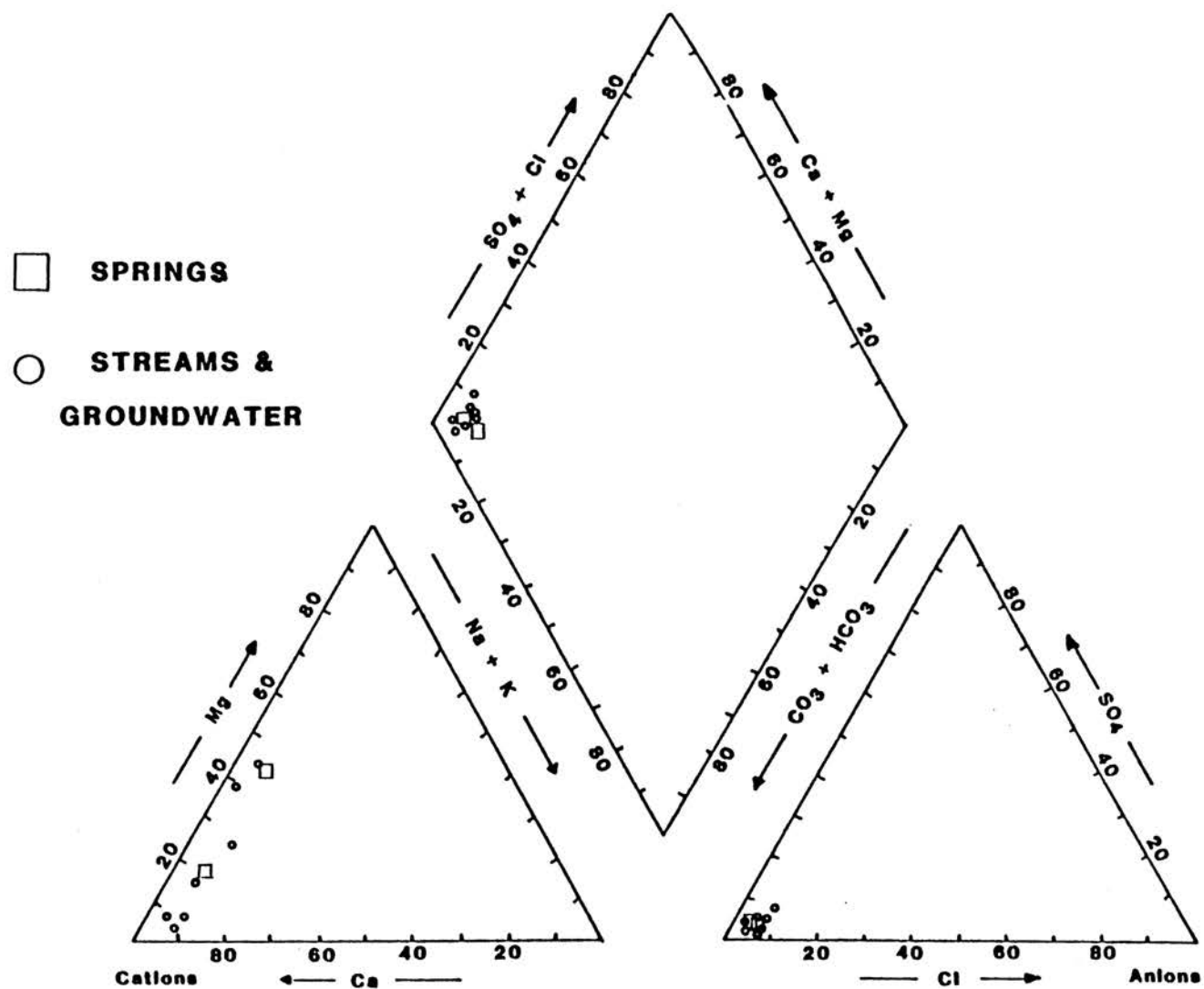


Figure 39. Piper Diagram of Murray County

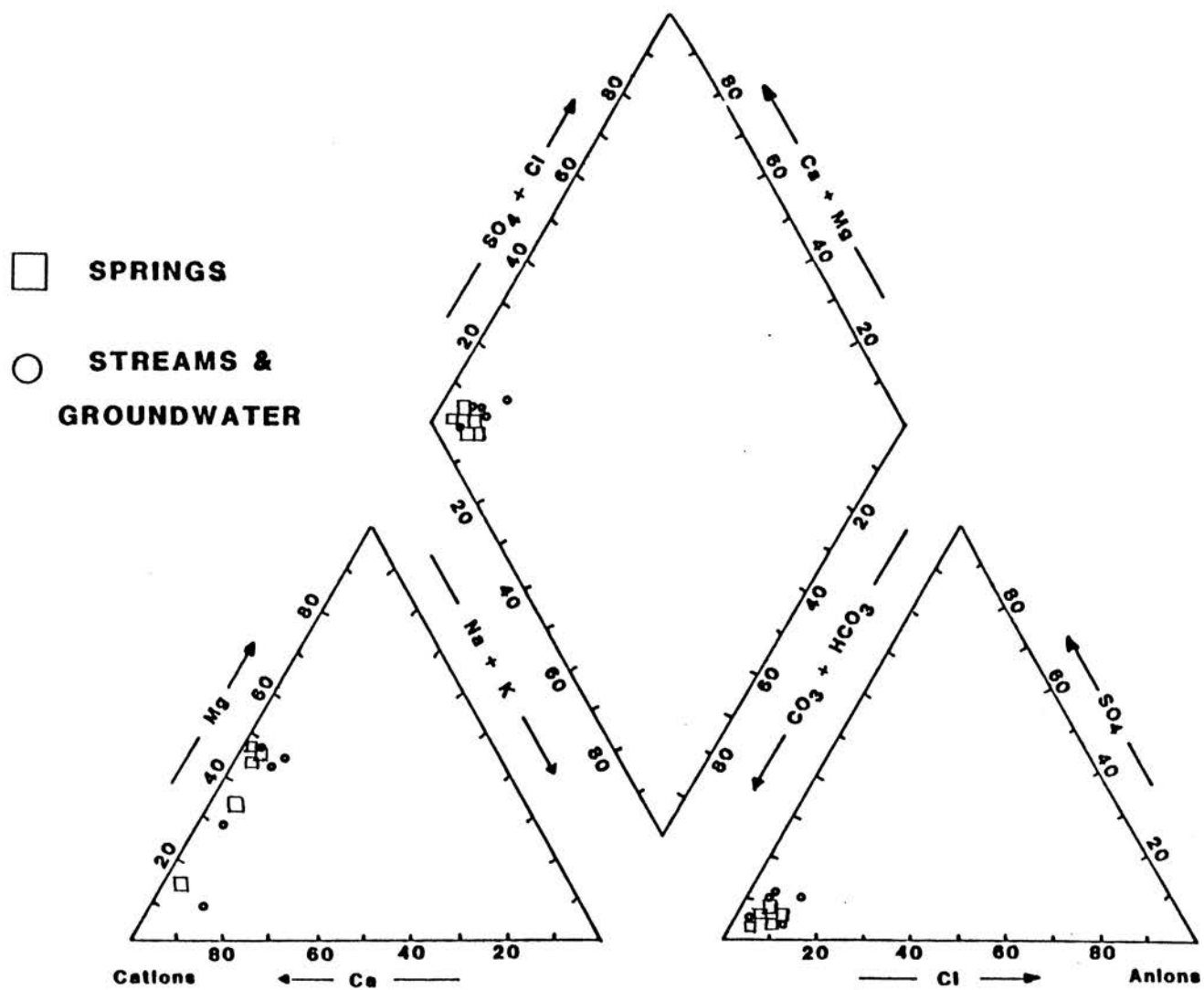
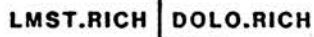


Figure 41. Piper Diagram of Johnson County



Source: Fairchild, 1984

Figure 42. Location of Limestone Rich and Dolomite Rich Springs in the Arbuckle Mountain Area

showed similar low magnesium waters typical of the limestone rich western half of Study Area A.

Chickasha National Refuge, in Study Area A, is a complex problem. Fairchild (1983) reported various wells being shut down due to an oily residue of various amounts appearing on the surface of the water. The water sample, A, analyzed from Travertine Creek in Chickasha County showed an above normal amount of sulfate and chloride present. Except for this area around Sulfur, Ok., which lies in the north part of the Arbuckles, the sodium, potassium, chloride, and sulfate content of the ground water are low and exhibit little variation. It may be assumed therefore that these anomalous values could be the result of deeper subsurface brines mixing with the Arbuckle aquifer water. There does not however seem to be a corresponding increase in sodium and chloride as one would expect.

The bicarbonate ion concentrations from the waters in this investigation, though relatively high are typical for limestone aquifers of various ages, see Table 7. The concentration found in this study does not seem to be unusually high. Several travertine producing waters reported by White and others (1969) had a much higher bicarbonate ion concentration.

Trace elements analyzed in the Arbuckle Group waters were: Al, Ba, Cr, Cu, Fe, Mn, Sr, and Zn, see Tables 4 and 5. Most of these trace elements were not detectable except for manganese and iron which had maximum concentrations of

TABLE VII

Bicarbonate Ion Levels in Selected Waters

Locality	This invest- igation	HCO_3^{-2} meq/l	TDS	Ca ----- Ca+Mg	Aquifer Type	Age	Prod. Trav. Y/N
Iceland, warmspring (White, 1963)		24.91	-	0.89	basalt- rhyolite	Quat.	+
KeeneWonder, CA spring (White, 1963)		19.8	3630	0.56	-	Paleo.	+
Lebanon Lmst., TN well (White, 1963)		7.5	720	0.73	Lmst.	Ord.	?
Austrian Spring (Clarke, 1924)		6.6	-	0.67	?	?	+
Arbuckle Group Ground Water (Avg.) (Fairchild, 1982)	*	6.0	-	0.65	Lmst.	Ord.	+
AL well (310 ft. deep) (White, 1963)		4.8	722	0.62	Lmst.	Camb.	?

TABLE VII (continued)

Locality	This invest- igation	HCO ₃ ⁻² meq/l	TDS	Ca ----- Ca+Mg	Aquifer Type	Age	Prod. Trav. Y/N
Study Area B Hwy. 58, stream	*	4.6	-	0.89	Lmst.	Ord.	+
Jimmy Creek upstream Study Area B	*	4.2	-	0.89	Lmst.	Ord.	+
Texas, well (White, 1963)		4.5	450	0.82	Lmst.	Cret.	?
New Mexico, well (White, 1963)		3.9	823	0.67	Lmst.	Per.	?
Travertine Creek Study Area A	*	3.8	-	0.46	?Lmst.	?Ord.	-
Florida, well (White, 1963)		3.2	297	0.61	Lmst.	Eoc.	?
Jimmy Creek downstream Study Area B	*	2.7	-	0.79	Lmst.	Ord.	-
Honey Creek Study Area A	*	2.7	-	0.94	Lmst.	Ord.	+
Alaska, spring		2.6	230	0.59	Dolo.	Camb.	?

6300 ppm and 2600 ppm respectively. The water sample, BE, from Ketch Creek spring contained more of a variety of trace elements than any of the other water samples. The variety could indicate a deeper water mixing or a lithologic change in the subsurface.

Rock and Associated Waters

The chemical process for dissolving calcium carbonate, CaCO_3 , within the bedrock requires the addition of CO_2 to the ground water, thus moving the equilibrium equation to the left dissolving CaCO_3 . Addition of CO_2 could be the result of O_2 brought into the subsurface through rain combining with the organic matter present in the carbonate rock. As the water moves deeper into the bedrock, there is a decrease in the amount of O_2 , with a corresponding increase in CO_2 , producing an increase in HCO_3^- , Ca^{+2} , and Mg^{+2} in the water, Figure 43. When this water is discharged at the surface it will precipitate calcium carbonate only if it is supersaturated with respect to CaCO_3 , and other conditions are appropriate. The precipitation of calcium carbonate is primarily the result of CO_2 removal from the waters. There are three major ways, by which, CO_2 is removed from water; 1) a change in chemical parameters, pH, ionic strength, pressure, 2) a change in physical conditions of the water such as pressure, aeration, and evaporation and 3) biological systems. There is frequently disagreement in the literature as to the method of CO_2 removal. Many

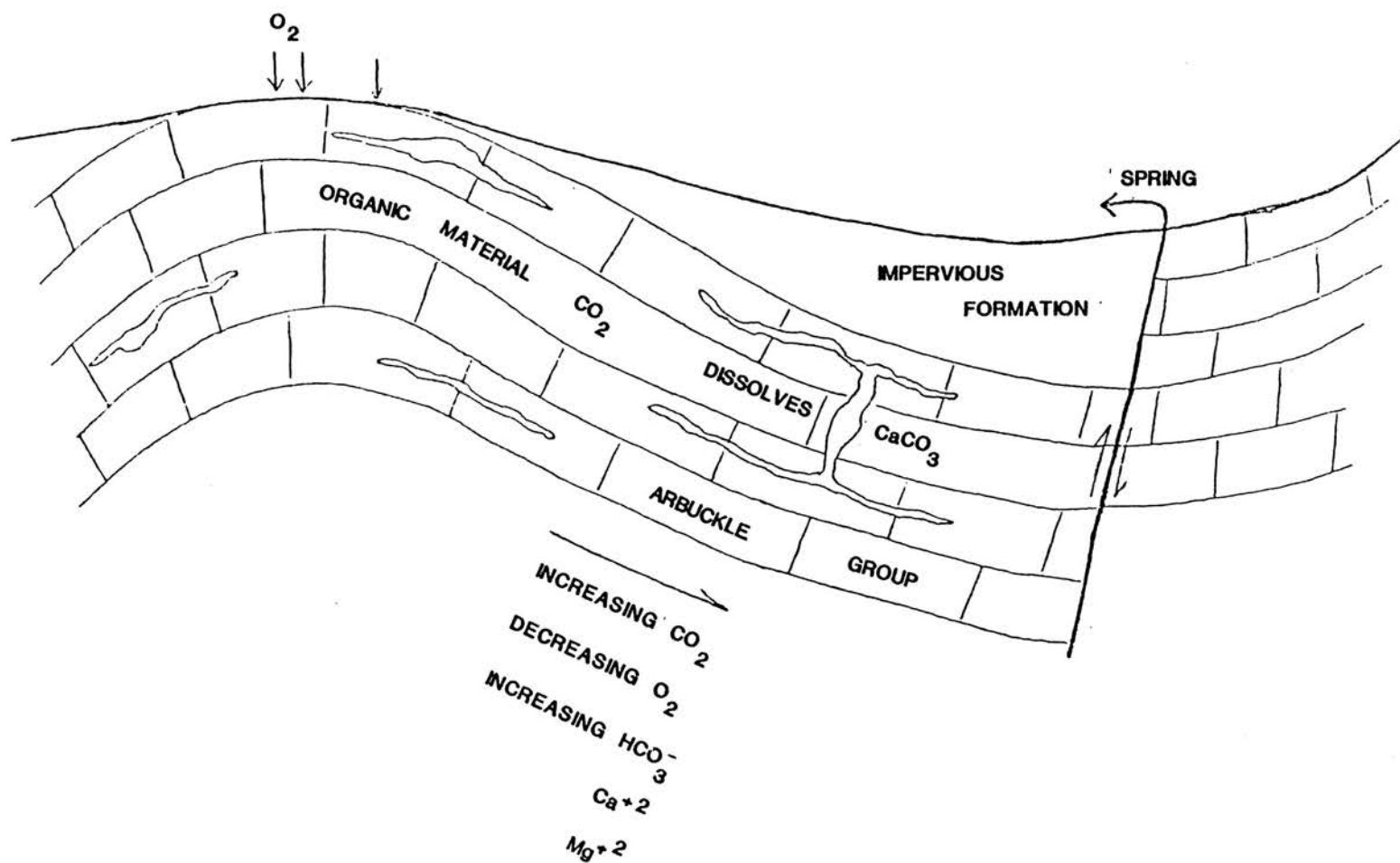


Figure 43. Dissolving of Calcium Carbonate

freshwater carbonate deposits are the combination of several methods of CO_2 removal, combined together, or acting separately, for example the result of environmental changes (such as seasonal changes).

The terminology of freshwater carbonates frequently reflects this classification, for example, tufa used to describe CaCO_3 associated with plant life, travertines are dense, sometimes banded CaCO_3 deposits associated with physio-chemical CO_2 removal, and a very slow physio-chemical removal of CO_2 produces speleothem deposits.

Physical methods of CO_2 removal are: changes in air temperature, aeration or removal of CO_2 . Evaporation of the surface water can also occur but this method does not lead to major calcium carbonate deposits, but is responsible for the deposits along the stream edge during hot weather. These deposits are removed with the increase in stream flow, Ketch Creek spring deposit, sample BE, and deposits found along the stream at Highway 58, sample BD, are examples of this method of CO_2 removal. The cooling of geothermal waters, specifically around Yellowstone National Park, is another way of removing CO_2 from the water. Trent (1978) suggested several of the travertines he sampled were of this type. Aeration is probably the most familiar method of removing CO_2 from water. Emig (1917) tested several objects under Turner Falls for calcium carbonate build-up. All of the objects were coated to some degree with calcium carbonate after three weeks. Jimmy Creek and Turner Falls

are the products, in part, of CO_2 removal by aeration. Jacobson and Usdowski (1975) found travertine deposits caused by water running over uneven stream beds.

Chemical removal of CO_2 is basically the removal of CO_2 through changes in pH, ionic strength, and pressure. Mixing of dissimilar waters either in the subsurface, an example is the stream studied by Barnes and O'Neil (1971) in the Coast Range, or changes at the surface with springs mixing with alkaline lakes. Mono Lake and Pyramid Lake are examples of springs mixing with lake water to form large deposits of calcium carbonate. Another example is the degassing of supersaturated CO_2 waters upon reaching the surface and mixing with stream waters at atmospheric pressure. Savelli and Wedepohl (1969) and Shuster and White (1971) investigated the CO_2 change from ground water to surface water and the resultant precipitation of calcium carbonate.

Biochemical removal of CO_2 is the result of plant life found in, and around, natural waters. Photosynthesis as a biochemical method has been investigated by Jones (1914), Emig (1917), and Wilson (1963). It is the algae that, even in microenvironments, chemically change the equilibrium of the surrounding water by absorbing HCO_3^- for photosynthesis. Mosses and bacteria are unable to use HCO_3^- for photosynthesis and thus it is the symbiotic relationship between mosses and algae, plus the filamentous structure of the mosses, that give the appearance that the mosses were instrumental in the precipitation of calcium carbonate.

Most water plants use the CO_2 dissolved in the water for photosynthesis, however if the carbon is present mostly as bicarbonate only some varieties of plants can utilize it, primarily the algae.

Irion and Muller (1968) make the statement that, biogenetic-inorganic formation of CaCO_3 is only of a slight importance and may be neglected as compared against the purely inorganic precipitation. This may not hold true if we consider that the microenvironments created by algae can drastically change the water chemistry in their immediate vicinity.

CHAPTER VII

RESULTS AND CONCLUSIONS

The following principal conclusions may be drawn from this investigation:

1) The waters sampled in this investigation are a calcium bicarbonate water with varying amounts of magnesium. Changes in bedrock cause a distinct change in water chemistry. As the limestone formations of the Arbuckle Mountain grade into dolomite to the east the water becomes more magnesium rich.

2) An increase in SO_4 and Cl is noticed to the north, in Study Area A, especially around Sulfur, Oklahoma. This increase of sulfate and chloride could be associated with deep brine water mixing however there was not an associated increase in sodium or potassium.

3) Generally, the chemistry of the water was influenced by a) whether the bedrock was limestone or dolomite dominant, b) length of residence, the longer time the greater the degree of saturation, c) flow path; fault controlled waters can introduce deep subsurface brines and

water mixing from outside the regional water table.

4) The chemistry of the recent carbonate deposits were influenced by the depositing waters, as demonstrated by trace element comparisons. Unfortunately published studies seldom contain analyses of carbonate deposits and associated waters which thus limits direct comparisons with those of this investigation.

5) Freshwater carbonate deposits can be classified according to the method of CO_2 removal from the precipitating waters. Physical removal is the release of CO_2 from the water by evaporation, cooling, or turbulence. Chemical precipitation of CaCO_3 can result from a change in ionic strength and pH by the mixing of dissimilar waters or the change in pressure from saturated waters reaching the surface. Removal of CO_2 by biochemical means is accomplished by the absorption of CO_2 during photosynthesis or in the case of some algae the removal of bicarbonate ions during photosynthesis or the vegetal activity of calcareous algae.

6) The textural description in hand sample of the travertine samples ranged from porous to banded. Porous texture was evident in both Recent and Pleistocene age travertines. Banded texture was only seen in Recent travertines.

7) The electron microscopic textures of the travertines varied considerably. Algal material was identified in many of the travertines, independent of age and hand sample texture. A banded travertine from Turner Falls showed bands of algal tubules with alternating bands of rosettes, origin unknown. Diatoms, possibly *Novicula* sp., were present in travertines of Recent and Pleistocene age. Needle-like diatoms, possibly *Synedra* sp., were found in travertine samples from Jimmy Creek and Turner Falls, both of Pleistocene age.

8) The microenvironment revealed by the scanning electron microscope is a delicate and complex system that suggests many further facets of research that could help solve some of the questions concerning freshwater travertine deposits.

9) Chemical parameters such as temperature, pH, and alkalinity need to be field calculated due to the changes caused by time and temperature.

10) Due to the lack of significant samples no relationship could be established to distinguish between Pleistocene age travertines and Recent deposits.

11) More emphasis on lab techniques and quality

control could reduce the substantial error in reported geochemical data.

12) A definite need for standards (in nomenclature, analysis procedures, and reporting of data) was seen throughout this investigation.

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APPENDIX A

COMPUTER LITERATURE SEARCHES

File89:GEOREF - 29-84/May
 (Conn. American Geological Institute)
 Set .Items Description

? S .GEOCHEMISTRY.
 1 86061 .GEOCHEMISTRY
 ? S .ARBUCKLE (W).GROUP AND .OKLAHOMA .
 123 .ARBUCKLE (W).GROUP
 5842 .OKLAHOMA
 2 . 78 .ARBUCKLE (W).GROUP AND .OKLAHOMA
 ? S .SIMPSON (W).GROUP AND .OKLAHOMA .
 110 .SIMPSON (W).GROUP
 5842 .OKLAHOMA
 3 . 88 .SIMPSON (W).GROUP AND .OKLAHOMA
 ? S .CARLTON (W).RHYOLITE AND .OKLAHOMA .
 9 .CARLTON (W).RHYOLITE
 5842 .OKLAHOMA
 4 . 9 .CARLTON (W).RHYOLITE AND .OKLAHOMA
 ? S .COLBERT (W).RHYOLITE AND .OKLAHOMA .
 2 .COLBERT (W).RHYOLITE
 5842 .OKLAHOMA
 5 . 2 .COLBERT (W).RHYOLITE AND .OKLAHOMA
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 6 . 0 . 1 AND 2 AND 3
 ? C .1 AND .2 .
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 ? C .1 AND .3 .
 8 . 0 . 1 AND 3
 ? C .1 AND .4 .
 9 . 2 . 1 AND 4
 ? C .1 AND .5 .
 10 . 0 . 1 AND 5
 ? .TYPE 7/3/1-3 .
 7/3/1
 1145821 83-04436

Enid Quadrangle, Oklahoma and Kansas
 Eutsler, R. L.; Bloch, S.; Johnson, K. S.
 Okla. Geol. Surv.; Norman, OK, USA
 39p., 1982
 180 REFS.
 Subfile: B
 Doc.Type: REPORT; MAP Bibliographic Level: MONOGRAPHIC
 Language: English
 Report No.: PSJ/F-095(82).
 Availability: Bendix Field Eng. Corp., Tech. Lib., Grand Junction, CO,
 United States
 Note: National Uranium Resource Evaluation Program. Includes microfiche,
 illus.; 1:500,000; econ. geol. maps

7/3/2

895668 78-28878

Petroleum source-rock potential of Arbuckle and Ellenburger groups,
southern mid-continent, United States

Cardwell, A. L.

Union Oil Co., Calif., Midland, Tex., USA

Colo. Sch. Mines, Q. 72: 3, 134p., 1977

CODEN: QCSMAC 78 REFS.

Subfile: B

Country of Publ.: United States

Doc. Type: SERIAL Bibliographic Level: MONOGRAPHIC

Language: English

illus., tables, sketch map

7/3/3

811476 76-37722

Chemical and isotopic investigation of stratigraphic and tectonic
dolomites in Arbuckle Group, Arbuckle Mountains, South-central Oklahoma

Sargent, K. A.

Furman Univ., Dep. Geol., Greenville, S.C., USA

Am. Assoc. Pet. Geol., Bull. 60: 4, AAPG-SEPM annual meetings, 719p.,
1976

CODEN: AAPGBS

Subfile: B

Doc. Type: SERIAL Bibliographic Level: ANALYTIC

Language: English

7. TYPE 9/3/1-2.

9/3/1

970320 80-09283

Petrology and geochemistry of the Carlton Rhyolite, southern Oklahoma

Hanson, R. E.

Oklahoma State Univ., Stillwater, Okla., USA

161p., 1977

Subfile: B

Degree Level: Master's

Country of Publ.: United States

Doc. Type: THESIS Bibliographic Level: MONOGRAPHIC

Language: English

9/3/2

865628 77-47795

Geochemistry of Wichita Mountain igneous rocks as related to copper and
uranium mineralizations in southwestern Oklahoma

Al-Shaleb, Z.; Hanson, R. E.; Adams, S. R.

Okla. State Univ., Stillwater, Okla., USA

The Geological Society of America, 89th annual meetings, Denver, Colo.,
United States, Nov. 8-11, 1976

Geol. Soc. Am., Abstr. Programs, 8: 6, 752p., 1976

CODEN: GAAPBC

Subfile: B

Country of Publ.: United States

Doc. Type: SERIAL, CONFERENCE PUBLICATION Bibliographic Level: ANALYTIC

Language: English

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SAMPLE RECORD

The positions of the key fields are shown in the following sample record.

AN 1012344 80-48454
TI Manganese and copper geochemistry of interstitial fluids from manganese nodule-rich pelagic sediments of the northeastern equatorial Pacific Ocean
AU Callender, E.; Bowser, C. J.
CS U. S. Geol. Surv., Reston, Va., USA; Univ. Wis., USA
JN PY Am. J. Sci. 280: 10, 1063-1096p., 1980
CO SN CODEN: AJSCAP ISSN: 0002-9599
SF Subfile: B
CP Country of Publ.: United States
DT BL Doc Type: SERIAL Bibliographic Level: ANALYTIC
LA Languages: English
LT LN Latitude: N000000; N200000 Longitude: W1800000;
E1400000
DE Descriptors: *Pacific Ocean; *nodules; *manganese; *diagenesis; *metals; *sediments; *copper; oceanography; geochemistry; pore water; genesis; secondary structures; sedimentary structures; Equatorial Pacific; Northeast Pacific; remobilization; solubility; desorption; precipitation
SH Section Headings: 07 (MARINE GEOLOGY AND OCEANOGRAPHY)
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Key to Data Fields

AB	Abstract	JN	Journal Name
AN	GEOREF Accession Number	LA	Language
AU	Author	LN	Longitude
BL	Bibliographic Level	LT	Latitude
BN	ISBN	PU	Publisher
CL	Conference Location	PY	Publication Year
CO	CODEN	RN	Report Number
CP	Country of Publication	SF	Subfile
CS	Corporate Source	SH	Section Heading Code
CT	Conference Title	SL	Summary Language
CY	Conference Year	SN	ISSN
DE	Descriptor	TI	Title
DT	Document Type		

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- 3 0 YS (SPRING OR SPRINGS) (F) OKLAH
- 4 0 (SPRING OR SPRINGS) (F) OKLAHOMA
- 5 45 SPRINGS(F)OKLAHOMA
- 6 0 SPRINGS(F)OKLAHOMA/DES
- 7 46 SPRINGS AND OKLAHOMA/DE
- 8 0 (SPRINGS AND OKLAHOMA)/DE
- 9 1 TRAVERTINE AND OKLAHOMA
- 10 0 TUFA AND OKLAHOMA

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Search Time: 0.183 Prints: 45 Descs.: 13

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1184380 83-38283

An evaluation of water resources for enhanced oil recovery operations, Cement Field, Caddo and Grady counties, Oklahoma

Preston, D. A.; Harrison, W. E.; Luza, K. V.; Prater, L.; Reddy, R.

Okla. Geol. Surv., Norman, OK, USA

Special Publication - Oklahoma Geological Survey 82-5, 64 p., 1982

ISSN: 0275-0929 75 REFS.

Subfile: B

Country of Publ.: United States

Doc Type: SERIAL; MAP Bibliographic Level: MONOGRAPHIC

Languages: English

illus., 6 tables, geol. sketch map; 1:250,000; geol. maps

Univ. Missouri-Rolla, Dep. Geol. and Geophys., Rolla, MO, USA; Univ. New Orleans, Dep. Earth Sci., New Orleans, LA, USA

Abstracts of the 15th annual meeting of the Geological Society of America, South-Central Section

Anonymous

Geological Society of America, South-Central Section, 15th annual meeting, San Antonio, TX, United States, April 13-14, 1981

Abstracts with Programs - Geological Society of America 13: 5, 264p., 1981

CODEN: GAAPBC ISSN: 0016-7592

Subfile: B

Country of Publ.: United States

Doc Type: SERIAL; CONFERENCE PUBLICATION Bibliographic

Level: ANALYTIC

Languages: English

1164799 83-23626

Fluvial processes and geology in Washita River area, South-central Oklahoma

Harlin, J. M.

Univ. Okla., Norman, OK, USA

Oklahoma Geology Notes 42: 4, 168-178p., 1982

CODEN: OKGNBO ISSN: 0030-1736 21 REFS.

Subfile: B

Country of Publ.: United States

Doc Type: SERIAL Bibliographic Level: ANALYTIC

Languages: English

illus., sketch map

1119635 82-41830

Lawton Quadrangle, Oklahoma and Texas

Al-Shaleb, Z.; Thomas, R. G.; Stewart G. F.

Okla. State Univ., Dep. Geol., Stillwater, OK, USA

48p., 1982

Subfile: B

Doc Type: REPORT; MAP Bibliographic Level: MONOGRAPHIC

Languages: English

Report No.: GJQ-017(82)

Availability: Bendix Field Eng. Corp., Tech. Libr., Grand

Junction, CO, United States

Note: National Uranium Resource Evaluation Program,

illus., 5 tables, geol. maps; 1:500,000; geol. maps

1150623 83-08948

Clinton Quadrangle, Oklahoma

Bloch, S.; Johnson, K. S.; Eutsler, R. L.; Myers, J. J.

Okla. Geol. Surv., Norman, OK, USA

36p., 1982

137 REFS.

Subfile: B

Doc Type: REPORT; MAP Bibliographic Level: MONOGRAPHIC

Languages: English

Report No.: PG/I/F-096(82)

Availability: Bendix Field Eng. Corp., Tech. Libr., Grand Junction, CO, United States

Note: National Uranium Resource Evaluation Program; includes microfiche, illus., 4 tables; 1:500,000; econ. geol. maps

1111051 82-29041

Geochemistry of the Cambrian Wichita Granite Group and revisions of its lithostratigraphy

Myers, J. D.; Gilbert, M. C.; Loiselle, M. C.

Univ. Wyo., Dep. Geol., Laramie, WY, USA; Okla. Geol. Surv.,

USA

Oklahoma Geology Notes 41: 6, 172-195p., 1981

CODEN: OKGNBO ISSN: 0030-1736 36 REFS.

Subfile: B

Country of Publ.: United States

Doc Type: SERIAL Bibliographic Level: ANALYTIC

Languages: English

illus., 9 tables

1145091 83-01079

Origin of the intermediate rocks of the Cold Springs intrusion breccia, Wichita Mountains, southwestern Oklahoma

Vidrine, D. M.; Fernandez, L. A.; Grant, S. K.



 DIALOG

1107968 82-28713

Relationships between the new species *Sorex scottensis* and the fossil shrews *Sorex cinereus* Kerr

Jammot, D.
Mammalia 36: 3, 449-458p., 1972
CODEN: MAMLAN ISSN: 0025-1461 13 REFS.
Subfile: B
Country of Publ.: France
Doc Type: SERIAL Bibliographic Level: ANALYTIC
Languages: English Summary Languages: French
illus., 1 table

1107876 82-31809

Uranium potential of the Cement District, southwestern Oklahoma

Allen, R. F.
Oklahoma State Univ., Stillwater, OK, USA
85p., 1980
Subfile: B
Degree Level: Master's
Country of Publ.: United States
Doc Type: THESIS Bibliographic Level: MONOGRAPHIC
Languages: English

1096580 82-20951

Assessment of geothermal potential in Oklahoma
Prater, M. L.; Luza, K. V.; Harrison, W. E.
Univ. Okla., Okla. Geol. Surv., Norman, OK, USA

Geothermal Direct Heat Program; Glenwood Springs technical conference proceedings; Volume 1, Papers presented; State Coupled Geothermal Resource Assessment Program
Ruscetta, C. A. (EDITOR); Foley, D. (EDITOR)
Geothermal energy exploration and resource assessment technical conference, Glenwood Springs, CO, United States, May 4-6, 1981
247-248p., 1981
Subfile: B

Doc Type: REPORT; CONFERENCE PUBLICATION Bibliographic Level: ANALYTIC
Languages: English
Report No.: DOE/ID/12079-39; ESL-59
Availability: Univ. Utah Res. Inst., Earth Sci. Lab., Salt Lake City, UT, United States

1084348 82-10227

Uranium potential of the Cement District, southwestern Oklahoma

Allen, R. F.
Oklahoma State Univ., Stillwater, OK, USA
85p., 1980
Subfile: B
Degree Level: Master's
Country of Publ.: United States
Doc Type: THESIS Bibliographic Level: MONOGRAPHIC
Languages: English

1063953 81-52128

Oil in the fascinating Ouachitas

Morrison, L. S.
Lamina Oil, Ardmore, OK, USA
Oil and Gas Journal 79: 19, 170-179p., 1981
CODEN: OIGJAV ISSN: 0030-1388
Subfile: B
Country of Publ.: United States
Doc Type: SERIAL Bibliographic Level: ANALYTIC
Languages: English
Note: Full version appeared in Oct. 1980 issue of Shale Shaker, illus., sect., geol. sketch map

1063951 81-52115

Southwest finds may open up overlooked oil province

McCaslin, J. C.
Oil and Gas Journal 79: 17, 203-204p., 1981
CODEN: OIGJAV ISSN: 0030-1388
Subfile: B
Country of Publ.: United States
Doc Type: SERIAL Bibliographic Level: ANALYTIC
Languages: English
sketch map

1057643 81-44289

Radioactive springs in the watershed of a proposed reservoir in Sequoyah County, Oklahoma; origin and environmental effectBloch, S.; Craig, R. L.
Okla. Geol. Surv., Norman, OK, USA; Okla. State Dep. Health,
USA

Geology (Boulder) 9: 5, 195-199p., 1981

CODEN: GLGYBA ISSN: 0091-7613 21 REFS.

Subfile: B

Country of Publ.: United States

Doc Type: SERIAL Bibliographic Level: ANALYTIC

Languages: English

illus., tables, geol. sketch map

Ground water resources of the Rush Springs Sandstone of southwestern Oklahoma

Roles, J. S.

Hydrologic investigation maps

Publ: Okla. Water Resour. Board

unknownp., 1976

9 REFS.

Subfile: B

Country of Publ.: United States

Doc Type: MAP Bibliographic Level: MONOGRAPHIC

Languages: English

Note: In three sheets, colored hydrogeol map

1043604 81-30331

Zur Kenntnis seltener Petralidae (Anthozoa, Rugosa) aus dem amerikanischen Obersilur**Rare Petralidae (Anthozoa, Rugosa) from the Upper Silurian of the United States**

Weyer, D.

Z. Geol. Wiss. 8: 9, 1209-1216p., 1980

CODEN: ZGWSA7 ISSN: 0303-4534 26 REFS.

Subfile: B

Country of Publ.: German Democratic Republic

Doc Type: SERIAL Bibliographic Level: ANALYTIC

Languages: German Summary Languages: Russian

illus.

1006793 80-43983

Lithostratigraphic classification of basement rocks of the Wichita Province, Oklahoma

Powell, B. N.; Gilbert, M. C.; Fischer, J. F.

Rice Univ., Dep. Geol., Houston, Tex., USA; Va. Polytech.

Inst. and State Univ., USA

Geol. Soc. Am., Bull. 91: 9, I 509-I 514, II 1875-II 1994 p., 1980

CODEN: BUGMAF ISSN: 0016-7606 85 REFS.

Subfile: B

Country of Publ.: United States

Doc Type: SERIAL Bibliographic Level: ANALYTIC

Languages: English

illus., tables, geol. sketch map; print, microfiche

1037843 81-25805

Geologic importance of zooplankton fecal pellets in black shale associated with phosphate deposits

Robbins, E. I.; Porter, K. G.

U. S. Geol. Surv., Reston, VA, USA; Univ. Ga., USA

Proceedings of the Eleventh annual meeting of the American Association of Stratigraphic Palynologists

Christopher, R. A. (EDITOR)

Eleventh annual meeting of the American Association of

Stratigraphic Palynologists, Phoenix, AZ, United States,

Oct. 24-28, 1978

Palynology 4, 249-250p., 1980

ISSN: 0191-6122

Subfile: B

Country of Publ.: United States

Doc Type: SERIAL CONFERENCE PUBLICATION Bibliographic

Level: ANALYTIC

Languages: English

1029973 81-16993

976488 80-15195

Correlation of the Carboniferous rocks of the Ouachita trough with those of the adjacent foreland
Gordon, M., Jr.; Stone, C. G.
U. S. Geol. Surv., Washington, D.C., USA; Arkansas Geol. Comm., USA

Symposium on the geology of the Ouachita Mountains, Volume I, Stratigraphy, sedimentology, petrography, tectonics, and paleontology

Stone, C. G. (EDITOR)
Symposium on the Geology of the Ouachita Mountains; 7th Annual Meeting of the South-Central Section of GSA, Little Rock, Arkansas, United States, April 5-7, 1973
Publ: Arkansas Geol. Comm.
70-91p., 1977
76 REFS.

Subfile: B
Country of Publ.: United States
Doc Type: BOOK; CONFERENCE PUBLICATION Bibliographic Level: ANALYTIC
Languages: English
Illus., geol. sketch maps, sects., plates, tables

969023 80-11814

Garber and Rush Springs aquifers, Oklahoma
Bellis, W. H.; Haws, A.
Eng. Enterp., USA

National Water Well Association, Ground Water Technology Division, Technical education session
Giddings, T. (moderator)
National Water Well Association, Ground Water Technology Division, Technical education session, Oklahoma City, Okla., United States, Oct. 10, 1979
Ground Water 17: 5, 496p., 1979
CODEN: GRWAAP ISSN: 0160-0974
Subfile: B
Country of Publ.: United States
Doc Type: SERIAL; CONFERENCE PUBLICATION Bibliographic Level: ANALYTIC
Languages: English

964864 80-07864

Basic data report on ground water levels in the Rush Springs Sandstone area of southwestern Oklahoma
Oklahoma Water Resources Board, Okla., USA
Okla. Water Resour. Board, Publ. 74, 7p., 1976
ISSN: 0472-0687 3 REFS.
Subfile: B
Country of Publ.: United States

Doc Type: SERIAL Bibliographic Level: MONOGRAPHIC
Languages: English
Illus., tables, sketch maps

Geohydrology of the Arbuckle aquifer, south-central Oklahoma

Geohydrology of the Arbuckle aquifer, south-central Oklahoma
Fairchild, R. (investigator); Davis, R. E. (investigator)
U. S. Geol. Surv., Prof. Pap. 1100, 119p., 1978
CODEN: XGPPA9

Subfile: B
Country of Publ.: United States
Doc Type: SERIAL Bibliographic Level: ANALYTIC
Languages: English
Descriptors: *Oklahoma; *ground water; hydrogeology; surveys; Arbuckle Aquifer; Arbuckle Group; Simpson Group; hydrology; aquifers; United States; Arbuckle Mountains; Cambrian; Paleozoic; Ordovician; recharge; water quality; springs; seepage; carbonate rocks; levels
Section Headings: 21 (HYDROGEOLOGY AND HYDROLOGY)

901095 78-31212

Ground-water records for eastern Oklahoma; Part 2, Water-quality records for wells, test-holes, and springs
Havens, J. S.
U. S. Geol. Surv., Open-File Rep. 78-357, 130p., 1978
CODEN: XGROAG
Subfile: B
Country of Publ.: United States
Doc Type: SERIAL; REPORT Bibliographic Level: MONOGRAPHIC
Languages: English
Availability: U. S. Geol. Surv., Open-File Serv. Sect., Br. Distrib., Denver, Colo., United States
table

886601 78-20282

Geologic applications of remote sensing

Sabins, F. F.

Remote sensing of environment

Lintz, J., Jr.(EDITOR); Simonett, D. S.(EDITOR)

Publ: Addison-Wesley Publ. Co.

508-571p., 1976

ISBN: 0201042452

Subfile: B

Country of Publ.: United States

Doc Type: BOOK Bibliographic Level: ANALYTIC

Languages: English

illus., plates, tables, sketch maps

882615 78-14103

Major sources of chlorides in the Arkansas River in Oklahoma

Johnson, K. S.; Gay, S. T.

Univ. Okla., Okla. Geol. Surv., Norman, Okla., USA; U. S. Army Corps. Eng.

The Geological Society of America, South-central Section, 12th annual meeting, Tulsa, Okla., United States, March 6-7, 1978

Geol. Soc. Am., Abstr. Programs 10: 1, 8p., 1978

CODEN: GAAPBC

Subfile: B

Country of Publ.: United States

Doc Type: SERIAL; CONFERENCE PUBLICATION Bibliographic

Level: ANALYTIC

Languages: English

882595 78-14073

Structural control of ground-water flow in the Arbuckle Mountain area, South-central Oklahoma

Fairchild, R. W.; Davis, R. E.

U. S. Geol. Surv., Oklahoma City, Okla., USA

The Geological Society of America, South-central Section, 12th annual meeting, Tulsa, Okla., United States, March 6-7, 1978

Geol. Soc. Am., Abstr. Programs 10: 1, 5p., 1978

CODEN: GAAPBC

Subfile: B

Country of Publ.: United States

Doc Type: SERIAL; CONFERENCE PUBLICATION Bibliographic

Level: ANALYTIC

Languages: English

860448 77-40989

Texture of Arkansas novaculite indicates thermally induced metamorphism

Keller, W. D.; Viole, G. W.; Johnson, C. H.

Univ. Mo., Columbia, Mo., USA

J. Sediment. Petrol. 47: 2, 834-843p., 1977

CODEN: JSEPAK 12 REFS.

Subfile: B

Country of Publ.: United States

Doc Type: SERIAL Bibliographic Level: ANALYTIC

Languages: English

illus., sketch map

860204 77-41605

Observations on Cibolocrinus Weller, a late Paleozoic flexible crinoid from the North American Midcontinent

Pabian, R. K.; Strimple, H. L.

Univ. Neb., Lincoln, Neb., USA; Univ. Iowa

The Geological Society of America, North-central Section, 11th annual meeting, Carbondale, Ill., United States, April 28-29, 1977

Geol. Soc. Am., Abstr. Programs 9: 5, 638-639p., 1977

CODEN: GAAPBC

Subfile: B

Country of Publ.: United States

Doc Type: SERIAL; CONFERENCE PUBLICATION Bibliographic

Level: ANALYTIC

Languages: English

825478 77-05074

Arkansas Novaculite

Sholes, M.; McBride, E. F.

Pa. Topogr. Geol. Surv., Harrisburg, Pa., USA; Univ. Tex. Austin, United States

A guidebook to the sedimentology of Paleozoic flysch and associated deposits, Ouachita Mountains; Arkoma Basin, Oklahoma

Briggs, G.(leader); McBride, E. F.(leader); Molola, R. J.(leader)

Publ: Dallas Geol. Soc.

69-87p., 1975

Subfile: B

Country of Publ.: United States

Doc Type: BOOK Bibliographic Level: ANALYTIC

Languages: English

illus., charts, strat. col., geol. sketch map

822340 77-03819

Geochemical anomalies, uranium potential of South-central Oklahoma
 Olmsted, R. W.; Al-Shaleb, Z.
 Atl. Richfield Co., Denver, Colo., USA; Okla. State Univ., United States
 Geol. Soc. Am., Abstr. Programs 7: 7, 1219p., 1975
 CODEN: GAAPBC
 Subfile: B
 Doc Type: SERIAL Bibliographic Level: ANALYTIC
 Languages: English

817902 76-44148

Texture of Arkansas novaculite indicates thermally-induced metamorphism
 Keller, W. D.; Viele, G. W.; Johnson, C. H.
 Univ. Mo.-Columbia, Columbia, Mo., USA
 Geol. Soc. Am., Abstr. Programs 7: 7, 1141p., 1975
 CODEN: GAAPBC
 Subfile: B
 Doc Type: SERIAL Bibliographic Level: ANALYTIC
 Languages: English

723658 74-28799

Five Illinoian molluscan faunas from the southern Great Plains
 Miller, Barry B.
 Malacologia Vol. 4, No. 1, p. 173-260 (with Span., Russ. sum.), illus., 1966
 CODEN: MALAAJ
 Subfile: B
 Doc Type: SERIAL
 Languages: English

723500 74-28641

Five Illinoian molluscan faunas from the southern Great Plains [abstr.]
 Miller, Barry Bennett.
 Vol. 25, No. 4, p. 2449
 CODEN: DIASA9
 Subfile: B
 Degree Level: Diss. Abstr. Int.
 Doc Type: THESIS
 Languages: English

721623 74-26763

Hypothetical circulation of ground water around salt springs in western Oklahoma, Texas, and Kansas
 Ward, P. E.; Leonard, A. R.
 U. S. Geol. Surv., Prof. Pap. No. 424-D, Art. 341, p. D150-D151, illus., 1961
 CODEN: XGPPA9
 Subfile: B
 Doc Type: SERIAL
 Languages: English

714104 74-19238

Petroleum Microseepage at Cement, Oklahoma; Evidence and Mechanism
 Donovan, Terrence J.
 Am. Assoc. Pet. Geol., Bull. Vol. 58, No. 3, p. 429-446, illus. (incl. sketch maps), 1974
 CODEN: AAPGBS
 Subfile: B
 Doc Type: SERIAL
 Languages: English
 Mineralogic and chemical changes, Permian

713182 74-18316

Water quality effects of seepage from earthen dams
 Vost, Coyd, Jr.; Naney, James W.
 J. Hydrol. Vol. 21, No. 1, p. 15-26, illus. (incl. sketch map), 1974
 CODEN: JHYDA7
 Subfile: B
 Doc Type: SERIAL
 Languages: English

712532 74-17666

Tertiary springs of western Kansas and Oklahoma
 Gould, Charles Newton.
 Am. J. Sci. Ser. 4, Vol. 11, p. 263-268, 1901
 CODEN: AJSCAP
 Subfile: B
 Doc Type: SERIAL
 Languages: English

669342 73-08606

Sedimentary analysis of artesian spring sands, Meade County, Kansas [abstr.]

Rebertus, Donald Gene.
Vol. 33, No. 7, p. 31468
CODEN: DIASA9
Subfile: B
Degree Level: Diss. Abstr. Int.
Doc Type: THESIS
Languages: English

464207 69-07275-N

SPRINGS IN THE OZARK REGION, NORTHEASTERN OKLAHOMA
BINGHAM, ROY H.
OKLAHOMA GEOLOGY NOTES, V. 29, NO. 6, P. 135-145 1969
Subfile: N

415914 66-04738-N

Five Illinoian molluscan faunas from the southern Great Plains
Miller, Barry B.
Malacologia v. 4, no. 1, p. 173-260, illus., tables, 1966
Subfile: N
with Spanish and Russian abs.,

405920 65-01970-N

Pleistocene vertebrates from the Butler Spring local fauna, Meade County, Kansas
Schultz, Gerald E.
Michigan Acad. Sci., Arts. and Letters Papers 1964 v. 50, p. 235-265, illus., table, 1965
Subfile: N

400918 64-04872-N

Five Illinoian molluscan faunas from the southern Great Plains [abs.]
Miller, Barry Bennett
Dissert. Abs. v. 25, no. 4, p. 2449, 1964
Subfile: N

394866 63-07340-N

Geology and water resources of Okmulgee County,

Oklahoma--Pt. 2, Water resources of Okmulgee County

Motts, Ward S.
Oklahoma Geol. Survey Bull. 91 p. 81-128, illus., table, 1963
Subfile: N

393639 63-06083-N

Ground-water resources of the Rush Springs Sandstone in the Caddo County area, Oklahoma
Tanaka, Harry H.; Davis, Leon V.
Oklahoma Geol. Survey Circ. 61 63 p., illus., tables, 1963
Subfile: N

375390 61-00400-N

Salt springs in Oklahoma
Ward, Porter E.
Oklahoma Geology Notes v. 21, no. 3, p. 82-84, illus., 1961
Subfile: N

375086 61-00089-N

Hypothetical circulation of ground water around salt springs in western Oklahoma, Texas, and Kansas, Art. 341
Ward, P. E.; Leonard, A. R.
U.S. Geol. Survey Prof. Paper 424-D p. D150-D151, illus., 1961
Subfile: N

DP DIALOG

A SEARCH FROM THE

WATER RESOURCES ABSTRACTS DATABASE

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The attached report is the result of a search of the WATER RESOURCES ABSTRACTS (WRA) database using the DIALOG Information Retrieval Service.

WATER RESOURCES ABSTRACTS (WRA) is prepared from materials collected by over 50 water research centers and institutes in the United States. The file covers a wide range of water resource topics including water resource economics, ground and surface water hydrology, metropolitan water resources planning and management, and water-related aspects of nuclear radiation and safety. The collection is particularly strong in the literature on water planning (demand, economics, cost allocations), water cycle (precipitation, snow, ground-water, lakes, erosion, etc.), and water quality (pollution, waste treatment). WRA covers predominantly English-language materials and includes monographs, journal articles, reports, patents, and conference proceedings.

SAMPLE RECORD

The positions of the key fields are shown in the following sample record.

AN 127158 W78-10051
TI Hydrological Application of LANDSAT Imagery Used in the Study of the 1973 Indus River Flood, Pakistan
AU Deutsch, M.; Ruggles, F. H. Jr
CS Geological Survey, Reston, VA. Geography Program; and Geological Survey, Reston, VA. Water Resources Div.
JN SO Water Resources Bulletin, Vol 14, No 2, p 261-274.
PY April 1978. 7 fig, 1 tab, 6 ref..
JA Journal Announcement: SWRAJ121
AB During August and September 1973, the Indus River Valley of Pakistan experienced one of the largest floods on record, resulting in damages to homes, businesses, public works, and crops amounting to millions of rupees. Tremendous areas of lowlands were inundated along the Indus River and major tributaries. Landsat data made it possible to easily measure the extent of flooding, totaling about 20,000 sq km within an area of about 400,000 sq km south from the Punjab to the Arabian Sea. The Indus River data were used to continue experimentation in the development of rapid, accurate, and inexpensive optical techniques of flood mapping by satellite begun in 1973 for the Mississippi River floods. The research work on the Indus River not only resulted in the development of more effective procedures for optical processing of flood data and synoptically depicting flooding, but also provided potentially valuable ancillary information concerning the hydrology of much of the Indus River basin. (Woodward-USGS)
DE Descriptors: *Flood data ; *Remote sensing ; *Satellite(Artificial) ; *Photogrammetry ; *Indus River ; *Pakistan; Flood damage ; LANDSAT
SH Section Heading Codes: 7B .(Resources Data--Data Acquisition); 4A .(Water Quantity Management and Control--Control of Water on the Surface.

Key to Data Fields

AB	Abstract	JN	Journal Name
AN	SWRA Accession Number	PY	Publication Year
AU	Author	SH	Section Heading
CS	Corporate Source	SO	Source
DE	Descriptor	TI	Title
JA	Journal Announcement		

Data present in record depends on output format requested and type of record.

2688

User: 4939 Date: 16dec83 Time: 14:31:58 File: 117

Set Items Description
1 41 (SPRING OR SPRINGS) AND OKLAHOMA

Print 1/3/1-41

Search Time: 0.048 Prints: 41 Descs.: 3

of DIALOG

164494 W83-03347
The Biota of Oklahoma Springs: Natural Biological Monitoring of Groundwater Quality
 Matthews, W. J.; Hoover, J. J.; Milstead, W. B.
 Oklahoma Univ., Kingston, Biological Station.
 Available from the National Technical Information Service, Springfield, VA 22161 as PB83-222455. Price codes: A04 in paper copy, A01 in microfiche. Water Resources Research Institute Completion Report, Oklahoma State Univ., Stillwater, May 1983. 64 p., 2 Fig., 4 Tab., 17 Ref., 1 Append. OWRT A-099-OKLA(1), 14-34-0001-1138..

164319 W83-03109
Factors Controlling Blue-Green Algae Dominance in a Southwestern Reservoir
 Toetz, D.
 Oklahoma State Univ., Stillwater, Dept. of Zoology.
 Available from the National Technical Information Service, Springfield, VA 22161 as PB83-208892. Price codes: A03 in paper copy, A01 in microfiche. Water Resources Research Institute Completion Report, Oklahoma State Univ., Stillwater, 39 p., 12 Fig., 1 Tab., 22 Ref., 1 Append. OWRT A-106-OKLA(1), 14-34-0001-1138..

162888 W83-01675
Water-Conserving Wheat Irrigation Schedules Based on Climatic Records
 Greene, D. M.; Kirkham, M. B.
 Baylor Univ., Waco, TX, Dept. of Geology.
 Irrigation Science, Vol 1, No 4, p 241-246, 1980. 2 Fig., 15 Ref..

161335 W83-00110
Hydrologic Data for the Alluvium and Terrace Aquifer of the Beaver-North Canadian River from the Panhandle to Canton Reservoir, Northwestern Oklahoma
 Davis, R. E.; Christenson, S. C.; Blumer, S. P.
 Geological Survey, Oklahoma City, OK. Water Resources Div.
 Open-File Report 80-159, January 1981. 77 p., 1 Plate, 4 Tab., 3 Ref..

161264 W83-00031
Distribution of Chironomids in the Littoral Zone of Lake Texoma, Oklahoma and Texas
 Vaughn, C. C.
 Oklahoma Univ., Norman, Dept. of Zoology.
 Hydrobiologia, Vol 89, No 2, p 177-188, April, 1982. 5 Fig., 3 Tab., 59 Ref..

160950 W82-06897
Effect of Artificial Destratification on Iron, Manganese, and Zinc in the Water, Sediments, and two Species of Benthic Macroinvertebrates in an Oklahoma Lake
 Cover, E.; Wilhm, J.
 Oklahoma State Univ., Stillwater, School of Biological Sciences.
 Hydrobiologia, Vol 87, No 1, p 11-16, February, 1982. 3 Tab., 24 Ref..

160211 W82-06161
A Faunal Analysis of the Springs off the Ouachita Mountains, Arkansas
 Robison, H. W.
 Arkansas Univ., Fayetteville, Water Resources Research Center.
 Available from the National Technical Information Service, Springfield, VA 22161 as PB82-254871. Price codes: A03 in paper copy, A01 in microfiche. Publication No 83, September 1981. 33 p., 1 Fig., 3 Tab., 39 Ref. OWRT A-047-ARK(1), 14-34-0001-9004..

152960 W81-05281
Radioactive Springs in the Watershed of a Proposed Reservoir in Sequoyah County, Oklahoma: Origin and Environmental Effect
 Bloch, S.; Craig, R. L.
 Oklahoma University, Norman; and Geological Survey, Norman, OK.
 Geology, Vol 9, No 5, p 195-199, May, 1981. 3 Fig., 4 Tab., 21 Ref..

152764 W81-05108
Taxation of Water Rights
 Moses, R. J.; Witten, M. W.
 Moses, Wittenmyer, Harrison and Woodruff, Boulder, CO.
 South Dakota Law Review, Vol 25, No 3, p 475-496, Summer, 1980. 102 Ref..

148443 W81-00811
Water-Conserving Wheat Irrigation Schedules Based on
Climatic Data

Kirkham, M. B.
Oklahoma Water Resources Research Inst., Stillwater.
Available from the National Technical Information Service,
Springfield, VA 22161 as PB81-143661. Price codes: A03 in
paper copy, A01 in microfiche. Project Completion Report,
1980. 40 p, 4 Append. DWRT-B-045-OKLA(1), 14-34-0001-9129..

135697 W79-05590
Hydrologic Data for the Antlers Aquifer, Southeastern
Oklahoma

Davis, R. E.; Hart, D. L. Jr
Geological Survey, Oklahoma City, OK. Water Resources Div.
Geological Survey open-file report 78-1038, November 1978.
24 p, 5 tab, 3 ref..

132668 W79-02561
Oklahoma Water Resources Board v. City of Lawton
(Springwater Heated as Stream Water for Appropriation Permit
Application)

580 P. 2d 510-14 (Okla. 1978)..

130779 W79-00672
Flood Plain Information: Chikaskia River, Blackwell,
Oklahoma

Army Engineer District, Tulsa, OK.
Prepared for City of Blackwell, OK, June 1976, 26 p, 7 fig,
11 plates, 5 tab..

130778 W79-00671
Flood Plain Information: Wolf Creek, Lawton, Oklahoma
Army Engineer District, Tulsa, OK.
Prepared for City of Lawton, OK, June 1972, 34 p, 9 fig, 33
plates, 5 tab..

130570 W79-00463
Arcadia Lake Water-Quality Evaluation
Hall, R. W. Jr; Plumb, R. H.; Thornton, K. W.; Eley, R. L.;
Lessem, A. S.
Army Engineer Waterways Experiment Station, Vicksburg, MS.
Environmental Effects Lab.

Available from the National Technical Information Service,
Springfield, VA 22161 as AD-A039 492, Price codes: A14 in
paper copy, A01 in microfiche. 315 p 11 fig, 48 tab, 133 ref,
4 append. D01. 740015..

127163 W78-10056
Ground-Water Records for Eastern Oklahoma, Part 2 -
Water-Quality Records for Wells, Test-Holes, and Springs

Havens, J. S.
Geological Survey, Oklahoma City, OK. Water Resources Div.
Open-file report 78-357, May 1978. 139 p..

114100 W77-09998
Selected Water-Level Records for Western Oklahoma, 1975-1978

Goemaat, R. L.
Geological Survey, Oklahoma City, Okla. Water Resources Div.
Open-file report 77-239, 1977. 50 p, 1 fig, 1 tab..

113475 W77-09375
Flood Plain Information, Adams Creek and Tributaries, Tulsa
and Wagoner Counties, OK

Army Engineer District, Tulsa, Okla.
Prepared for the City of Broken Arrow, OK, December 1976. 28
p, 5 tab, 4 fig, 18 plates..

112272 W77-08163
Selected Water-Level Records for Western Oklahoma, 1950-1975

Goemaat, R. L.
Geological Survey, Oklahoma City, Okla. Water Resources Div.
Open-File report 77-73, January 1977. 94 p, 1 fig, 1 tab..

106106 W77-02024
Ground-Water Records for Southeastern Oklahoma: Part
1--Records for Wells, Test-Holes, and Springs

Havens, J. S.; Bergman, D. L.
Geological Survey, Oklahoma City, Okla.
Open-file report, June 1976. 59 p, 26 ref..

101814 W76-11412
GROUND-WATER RECORDS FOR NORTHEASTERN OKLAHOMA: PART
1--RECORDS OF WELLS, TEST-HOLES, AND SPRINGS

HAVENS, J. S.; BERGMAN, D. L.
GEOLOGICAL SURVEY, OKLAHOMA CITY, OKLA.
OPEN-FILE REPORT, MARCH 1976. 100 P, 33 REF..

095299 W76-05017
EFFECTS OF ARTIFICIAL DESTRATIFICATION ON POPULATIONS OF
BENTHIC MACROINVERTEBRATES AND ZOOPLANKTON IN HAM'S LAKE AND
ARBUCKLE RESERVOIR

WILHM, J.
OKLAHOMA STATE UNIV., STILLWATER, SCHOOL OF BIOLOGICAL
SCIENCES.

AVAILABLE FROM THE NATIONAL TECHNICAL INFORMATION SERVICE,
SPRINGFIELD, VA 22161, AS PB-250 125, \$5.00 IN PAPER COPY, \$2.25
IN MICROFICHE. OKLAHOMA WATER RESOURCES RESEARCH INSTITUTE,
STILLWATER, COMPLETION REPORT, (1976). 92 P, 2 FIG, 50 TAB, 42
REF, APPEND. DWRT A-059-OKLA(1).

092042 W76-01019
PHOSPHORUS IN OUR ENVIRONMENT

CAIN, J. M.; KERRIGAN, J. E.
WISCONSIN DEPT. OF NATURAL RESOURCES, MADISON.
IN: PROCEEDINGS OF CONFERENCE ON FARM ANIMAL WASTES,
NITRATES AND PHOSPHATES, IN RURAL WISCONSIN ECOSYSTEMS,
MADISON, GREEN BAY, AND EAU CLAIRE, WISCONSIN, FEBRUARY 1-5,
1971, P 134-137, 5 REF..

091840 W76-01036
THEY'RE GETTING THE JUMP ON POLLUTION CONTROLS

GRAVES, R.; HARTMAN, C.
HOARD'S DAIRYMAN, VOL 119, NO 12, P 768, JUNE 25, 1974. 1
FIG..

091833 W76-01023
ENVIRONMENTAL, ECONOMIC, AND PHYSICAL CONSIDERATIONS IN
LIQUID HANDLING OF DAIRY CATTLE MANURE

CASLER, G. L.; LADUE, E. L.
NEW YORK STATE COLL. OF AGRICULTURE AND LIFE SCIENCES,
ITHACA, DEPT. OF AGRICULTURAL ECONOMICS.
NEW YORK'S FOOD AND LIFE SCIENCES BULLETIN (SOCIAL SCIENCES:
AGRICULTURAL ECONOMICS, NO 1), NO 20, 23 P, OCTOBER, 1972. 10
TAB, 42 REF..

080159 W75-02058
THE DUST CAME AT NOON

JUDD, B. I.
THE CATTLEMAN, P 64, 66, 74, MAY 1974..

079532 W75-01176
RECONNAISSANCE OF THE WATER RESOURCES OF THE ARDMORE AND
SHERMAN QUADRANGLES, SOUTHERN OKLAHOMA

HART, D. L. JR
GEOLOGICAL SURVEY, OKLAHOMA CITY, OKLA.

OKLAHOMA GEOLOGICAL SURVEY, NORMAN, HYDROLOGIC ATLAS 3,
1974. 4 SHEETS, 7 REF..

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IN LAKE CARL BLACKWELL, OKLAHOMA

FAUST, A. R.
OKLAHOMA STATE UNIV., STILLWATER.
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APPENDIX B

CHEMICAL PROCEDURES

ALKALINITY

INTERFERENCE:

None

REAGENTS:

Distilled-deionized water

0.1 N HCl - Should be obtained commercially (N/10 standard)

APPARATUS:

Conductivity Meter

Conductivity cell

Magnetic stirrer with stir bar

50 ml Buret

200 ml Beaker

SAMPLING:

Sample should be stored in plastic

Sample should be stored at 4°C

Sample volume should be greater than 250 ml

Sample should be analyzed within 24 HOURS

PRECISION AND ACCURACY:

If proper laboratory procedures are followed than precisison should be within 1% If > 1 meq/l or 5% IF < 1 meq/l

PROCEDURE

** Let conductivity meter warm up for > 15 minutes or longer.

- 1) Transfer 100 ml of sample (or diluted to 100 ml) in a beaker. Add stir bar and place on magnetic stirrer. Allow sample to equilibrate to room temperature.
- 2) Rinse the buret with 0.1 N HCl three times, then fill and place over beaker. The tip of the buret should be 3-5 mm above the surface of the sample.
- 3) Place the conductivity cell in the sample and mount it so that the cell is **not** touching the stir bar.
- 4) Check conductivity of the sample. If it is greater than 20 micromhos, dilute with distilled-deionized water until conductivity is below 20 micromhos.
- 5) Record initial conductivity. Then add 0.1-0.3 ml of HCl. Record volume and conductivity, read the buret to 0.02 ml. Repeat **four times**.

- 6) Add 3-5 ml of HCl. Record volume and conductivity. Add 0.5-1.0 ml of HCl. REcord volume and conductivity. Repeat additions of 0.5-1.0 ml **four times**.
- 7) Determine volume added at each conductivity reading and record.
- 8) Enter data into HCO₃ program. Conductivity on y-axis and volume added on x axis. The results generated are in mg/l HCO₃. Use the first and last three data points only.

CHLORIDE

Method 325.3 (Titrimetric, Mercuric Nitrate)

STORET NO. 00940

1. Scope and Application
 - 1.1 This method is applicable to drinking, surface, and saline waters, domestic and industrial wastes.
 - 1.2 The method is suitable for all concentration ranges of chloride content; however, in order to avoid large titration volume, a sample aliquot containing not more than 10 to 20 mg Cl per 50 ml is used.
 - 1.3 Automated titration may be used.
2. Summary of Method
 - 2.1 An acidified sample is titrated with mercuric nitrate in the presence of mixed diphenylcarbazone-bromophenol blue indicator. The end point of the titration is the formation of the blue-violet mercury diphenylcarbazone complex.
3. Comments
 - 3.1 Anions and cations at concentrations normally found in surface waters do not interfere.
 - 3.2 Sulfite interference can be eliminated by oxidizing the 50 ml of sample solution with 0.5 to 1 ml of H_2O_2 .
4. Apparatus
 - 4.1 Standard laboratory titrimetric equipment including a 1 ml or 5 ml microburet with 0.01 ml graduations.
5. Reagents
 - 5.1 Standard sodium chloride, 0.025 N: Dissolve 1.4613 \pm 0.0002 g (dried at 600°C for 1 hour) in chloride-free water in a 1 liter volumetric flask and dilute to the mark.
 - 5.2 Nitric acid, HNO_3 solution (3 + 997)
 - 5.3 Sodium hydroxide solution, NaOH, (10 g/l)
 - 5.4 Hydrogen peroxide (30%), H_2O_2
 - 5.5 Hydroquinone solution (10 g/liter): Dissolve 1 g of purified hydroquinone in water in a 100 ml volumetric and dilute to the mark.
 - 5.6 Mercuric nitrate titrant (0.141 N): Dissolve 25 g $Hg(NO_3)_2 \cdot H_2O$ in 900 ml of distilled water acidified with 5.0 ml conc. HNO_3 in a 1 liter volumetric flask and dilute to the mark with distilled water. Filter if necessary. Standardize against standard sodium chloride solution (5.1) using procedure 6. Adjust to exactly 0.141 N and check. Store in a dark bottle. A 1.00 ml aliquot is equivalent to 5.00 mg of chloride.
 - 5.7 Mercuric nitrate titrant (0.025 N): Dissolve 4.2830 g $Hg(NO_3)_2 \cdot H_2O$ in 50 ml of distilled water acidified with 0.5 ml conc. HNO_3 (sp. gr. 1.42) in a 1 liter volumetric flask and dilute to the mark with distilled water. Filter if necessary. Standardize against standard

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Issued 1971
Editorial revision 1978

sodium chloride solution (5.1) using procedure 6. Adjust to exactly 0.025 N and check. Store in a dark bottle.

- 5.8 Mercuric nitrate titrant (0.0141 N): Dissolve 2.4200 g $\text{Hg}(\text{NO}_3)_2 \cdot \text{H}_2\text{O}$ in 25 ml of distilled water acidified with 0.25 ml of conc. HNO_3 (sp. gr. 1.42) in a 1 liter volumetric flask and dilute to the mark with distilled water. Filter if necessary. Standardize against standard sodium chloride solution (5.1) using procedure 6. Adjust to exactly 0.0141 N and check. Store in a dark bottle. A 1 ml aliquot is equivalent to 500 μg of chloride.
- 5.9 Mixed indicator reagent: Dissolve 0.5 g crystalline diphenylcarbazone and 0.05 g bromophenol blue powder in 75 ml 95% ethanol in a 100 ml volumetric flask and dilute to the mark with 95% ethanol. Store in brown bottle and discard after 6 months.
- 5.10 Alphazurine indicator solution: Dissolve 0.005 g of alphazurine blue-green dye in 95% ethanol or isopropanol in a 100 ml volumetric and dilute to the mark with 95% ethanol or isopropanol.

6. Procedure

- 6.1 Place 50 ml of sample in a vessel for titration. If the concentration is greater than 20 mg/l chloride, use 0.141 N mercuric nitrate titrant (5.6) in step 6.6 or dilute. If the concentration is less than 2.5 mg/l of chloride, use 0.0141 N mercuric nitrate titrant (5.8) in step 6.6, a 1 ml or 5 ml microburet, and determine an indicator blank on 50 ml chloride-free water using procedure 6.6. If the concentration is less than 0.1 mg/l of chloride concentrate an appropriate volume to 50 ml.
- 6.2 Add 5 to 10 drops of mixed indicator reagent (5.9), shake or swirl solution.
- 6.3 If a blue-violet or red color appears add HNO_3 solution (5.2) dropwise until the color changes to yellow.
- 6.4 If a yellow or orange color forms immediately on addition of the mixed indicator, add NaOH solution (5.3) dropwise until the color changes to blue-violet; then add HNO_3 solution (5.2) dropwise until the color changes to yellow.
- 6.5 Add 1 ml excess HNO_3 solution (5.2).
- 6.6 Titrate with 0.025 N mercuric nitrate titrant (5.7) until a blue-violet color persists throughout the solution. See 6.1 for choice of titrant normality. Alphazurine indicator solution (5.10) may be added with the indicator to sharpen the end point. This will change color shades. Practice runs should be made.
- 6.7 Additional steps to eliminate particular interferences:
 - 6.7.1 If chromate is present at < 100 mg/l and iron is not present, add some alphazurine indicator solution (5.10) and acidify to pH 3 (indicating paper). End point will then be an olive-purple color.
 - 6.7.2 If chromate is present at > 100 mg/l and iron is not present, add 2 ml of fresh hydroquinone solution (5.5).
 - 6.7.3 If ferric ion is present use volume containing no more than 2.5 mg of ferric ion or ferric ion plus chromate ion. Add 2 ml fresh hydroquinone solution (5.5).
 - 6.7.4 If sulfite ion is present, add 0.5 ml of H_2O_2 solution (5.4) to 50 ml sample and mix for 1 minute.

7. Calculation

$$\text{mg chloride/l} = \frac{(A - B)N \times 35.450}{\text{ml of sample}}$$

where:

A = ml titrant for sample

B = ml titrant for blank

N = normality mercuric nitrate titrant

$$\text{mg NaCl/l} = \text{mg chloride/l} \times 1.65$$

8. Precision and Accuracy

8.1 Forty two analysts in eighteen laboratories analyzed synthetic water samples containing exact increments of chloride, with the following results:

Increment as Chloride mg/liter	Precision as Standard Deviation mg/liter	Bias, %	Accuracy as Bias, mg/liter
17	1.54	+2.16	+0.4
18	1.32	+3.50	+0.6
91	2.92	+0.11	+0.1
97	3.16	-0.51	-0.5
382	11.70	-0.61	-2.3
398	11.80	-1.19	-4.7

(FWPCA Method Study I, Mineral and Physical Analyses)

- 8.2 In a single laboratory (EMSL), using surface water samples at an average concentration of 34 mg Cl/l, the standard deviation was ± 1.0 .
- 8.3 A synthetic unknown sample containing 241 mg/l chloride, 108 mg/l Ca, 82 mg/l Mg, 3.1 mg/l K, 19.9 mg/l Na, 1.1 mg/l nitrate N, 0.25 mg/l nitrite N, 259 mg/l sulfate and 42.5 mg/l total alkalinity (contributed by NaHCO_3) in distilled water was analyzed in 10 laboratories by the mercurimetric method, with a relative standard deviation of 3.3% and a relative error of 2.9%.

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SULFATE

Method 375.4 (Turbidimetric)

STORET NO. Total 00945

1. Scope and Application
 - 1.1 This method is applicable to drinking and surface waters, domestic and industrial wastes.
 - 1.2 The method is suitable for all concentration ranges of sulfate; however, in order to obtain reliable readings, use a sample aliquot containing not more than 40 mg SO_4/l .
 - 1.3 The minimum detectable limit is approximately 1 mg/l sulfate.
2. Summary of Method
 - 2.1 Sulfate ion is converted to a barium sulfate suspension under controlled conditions. The resulting turbidity is determined by a nephelometer, filter photometer or spectrophotometer and compared to a curve prepared from standard sulfate solutions.
 - 2.2 Suspended matter and color interfere. Correct by running blanks from which the barium chloride has been omitted.
 - 2.3 Silica in concentrations over 500 mg/l will interfere.
3. Comments
 - 3.1 Proprietary reagents, such as Hach Sulfaver or equivalent, are acceptable.
 - 3.2 Preserve by refrigeration at 4°C.
4. Apparatus
 - 4.1 Magnetic stirrer, variable speed so that it can be held constant just below splashing. Use identical shape and size magnetic stirring bars.
 - 4.2 Photometer: one of the following which are given in order of preference.
 - 4.2.1 Nephelometer
 - 4.2.2 Spectrophotometer for use at 420 nm with light path of 4 to 5 cm.
 - 4.2.3 Filter photometer with a violet filter having a maximum near 420 nm and a light path of 4 to 5 cm.
 - 4.3 Stopwatch, if the magnetic stirrer is not equipped with an accurate timer.
 - 4.4 Measuring spoon, capacity 0.2 to 0.3 ml.
5. Reagents
 - 5.1 Conditioning reagent: Place 30 ml conc. HCl, 300 ml distilled water, 100 ml 95% ethanol or isopropanol and 75 g NaCl in solution in a container. Add 50 ml glycerol and mix.
 - 5.2 Barium chloride, BaCl_2 , crystals, 20 to 30 mesh.
 - 5.3 Sodium carbonate solution (approximately 0.05N): Dry 3 to 5 g primary standard Na_2CO_3 at 250°C for 4 hours and cool in a desiccator. Weigh 2.5 \pm 0.2 g (to the nearest mg), transfer to a 1 liter volumetric flask and fill to the mark with distilled water.

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5.4 Standard sulfate solution (1.00 ml = 100 μ g SO_4): Prepare by either 5.4.1 or 5.4.2.

5.4.1 Standard sulfate solution from H_2SO_4

5.4.1.1 Standard sulfuric acid, 0.1N: dilute 3.0 ml conc. H_2SO_4 to 1 liter with distilled water. Standardize versus 40.00 ml of 0.05 N Na_2CO_3 solution (5.3) with about 60 ml distilled water by titrating potentiometrically to pH about 5. Lift electrodes and rinse into beaker. Boil gently for 3–5 minutes under a watch glass cover. Cool to room temperature. Rinse cover glass into beaker. Continue titration to the pH inflection point. Calculate normality using

$$N = \frac{A \times B}{53.00 \times C}$$

where:

A = g Na_2CO_3 weighed into 1 liter

B = ml Na_2CO_3 solution

C = ml acid used to inflection point

5.4.1.2 Standard acid, 0.02 N: Dilute appropriate amount of standard acid, 0.1 N (5.4.1.1) to 1 liter (200.00 ml if 0.1000 N). Check by standardization versus 15 ml of 0.05 N Na_2CO_3 solution (5.3).

5.4.1.3 Place 10.41 ml standard sulfuric acid, 0.02 N (5.4.1.2) in a 100 ml volumetric and dilute to the mark.

5.4.2 Standard sulfate solution from Na_2SO_4 : Dissolve 147.9 mg anhydrous Na_2SO_4 in distilled water in a 1 liter volumetric flask and dilute to the mark with distilled water.

6. Procedure

6.1 Formation of barium sulfate turbidity

6.1.1 Place 100 ml sample, or a suitable portion diluted to 100 ml, into a 250 Erlenmeyer flask.

6.1.2 Add exactly 5.0 ml conditioning reagent (5.1).

6.1.3 Mix in the stirring apparatus.

6.1.4 While the solution is being stirred, add a measuring spoonful of BaCl_2 crystals (5.2) and begin timing immediately.

6.1.5 Stir exactly 1.0 minutes at constant speed.

6.2 Measurement of barium sulfate turbidity

6.2.1 Immediately after the stirring period has ended, pour solution into absorbance cell.

6.2.2 Measure turbidity at 30 second intervals for 4 minutes.

6.2.3 Record the maximum reading obtained in the 4 minute period.

6.3 Preparation of calibration curve.

6.3.1 Prepare calibration curve using standard sulfate solution (5.4).

6.3.2 Space standards at 5 mg/l increments in the 0–40 mg/l sulfate range.

6.3.3 Above 50 mg/l the accuracy decreases and the suspensions lose stability.

6.3.4 Check reliability of calibration curve by running a standard with every 3 or 4 samples.

6.4 Correction for sample color and turbidity.

6.4.1 Run a sample blank using the procedure 6.1 and 6.2 without the addition of barium chloride (6.1.4).

7. Calculations

7.1 Read mg SO₄ from calibration curve

$$\text{mg SO}_4/\text{l} = \frac{\text{mg SO}_4 \times 1,000}{\text{ml sample}}$$

8. Precision and Accuracy

8.1 Thirty-four analysts in 16 laboratories analyzed six synthetic water samples containing exact increments of inorganic sulfate with the following results:

Increment as Sulfate mg/liter	Precision as Standard Deviation mg/liter	Accuracy as	
		Bias, %	Bias mg/liter
8.6	2.30	-3.72	-0.3
9.2	1.78	-8.26	-0.8
110	7.86	-3.01	-3.3
122	7.50	-3.37	-4.1
188	9.58	+0.04	+0.1
199	11.8	-1.70	-3.4

(FWPCA Method Study 1, Mineral and Physical Analyses).

8.2 A synthetic unknown sample containing 259 mg/l sulfate, 108 mg/l Ca, 82 mg/l Mg, 3.1 mg/l K, 19.9 mg/l Na, 241 mg/l chloride, 0.250 mg/l nitrite N, 1.1 mg/l nitrate N, and 42.5 mg/l total alkalinity (contributed by NaHCO₃) was analyzed in 19 laboratories by the turbidimetric method, with a relative standard deviation of 9.1% and a relative error of 1.2%.

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APPENDIX C

X-RAY FLUORESCENT ANALYSIS

FLUO RESCENT
X RAY
SPEC TROGRAPHIC
Analytical Laboratory

718 Sherman Street (rear)
Denver, Colorado 80203
Phone (303) 837-1396
Merlyn L. Salmon, Manager

XXXX QUALITATIVE
XXXX SEMI-QUANTITATIVE
— QUANTITATIVE

ANALYTICAL REPORT

TO: Oklahoma State Univ A. Hounsflow

Job Number 31780
Page 1 of 10 Pages
Date 6 Nov 1984

SAMPLE: BKCR1

Copper 37	Iron 1800	Lanthanum
Silver	Cobalt	Cerium
Gold	Nickel	Praseodymium
Zinc 46	Cesium	Neodymium
Cadmium	Rubidium	Samarium
Mercury	Barium 95	Europium
Gallium	Strontium 140	Gadolinium
Indium	Titanium	Terbium
Thallium	Zirconium 150	Dysprosium
Germanium	Hafnium	Holmium
Tin	Thorium	Erbium
Lead 200	Vanadium	Thulium
Arsenic	Columbium	Ytterbium
Antimony	Tantalum	Lutetium
Bismuth	Chromium	Yttrium
Selenium	Molybdenum	
Tellurium	Tungsten	
Bromine	Uranium	
Iodine	Manganese 110	

The values above are estimated elemental concentrations in:

per cent XXXX parts per million grams per liter

No check was made for elements with atomic numbers less than 22.

By *Merlyn L. Salmon*

NOTE: A PORTION OF THE REPORTED SAMPLES WILL BE RETAINED FOR A PERIOD OF TWO YEARS FROM THE ABOVE DATE. THE REMAINDER OF THE SAMPLE WILL BE RETAINED FOR THIRTY DAYS FOLLOWING RECEIPT OF WRITTEN INSTRUCTIONS FOR DISPOSAL FROM THE ADDRESSEE ABOVE.

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— QUANTITATIVE

ANALYTICAL REPORT

TO: Oklahoma State Univ

Job Number 31780
Page 2 of 10 Pages
Date 6 Nov 1984

SAMPLE: DABR or UABR (indistinct marking)

Copper	33	Iron	9400	Lanthanum	
Silver		Cobalt		Cerium	
Gold		Nickel	150	Praseodymium	
Zinc	36	Cesium		Neodymium	
Cadmium		Rubidium	160	Samarium	
Mercury		Barium	900	Europium	
Gallium		Strontium	170	Gadolinium	
Indium		Titanium		Terbium	
Thallium		Zirconium		Dysprosium	
Germanium		Hafnium		Holmium	
Tin		Thorium		Erbium	
Lead		Vanadium		Thulium	
Arsenic		Columbium		Ytterbium	
Antimony		Tantalum		Lutetium	
Bismuth		Chromium		Yttrium	50
Selenium		Molybdenum			
Tellurium		Tungsten			
Bromine		Uranium			
Iodine		Manganese	160		

The values above are estimated elemental concentrations in:

_____ per cent XXXX parts per million _____ grams per liter

No check was made for elements with atomic numbers less than 22.

By *Merlyn L. Salmon*

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 QUANTITATIVE

ANALYTICAL REPORT

TO: Oklahoma State Univ

Job Number 31780
 Page 3 of 10 Pages
 Date 6 Nov 1984

SAMPLE: DJCR3

Copper <u>33</u>	Iron <u>3400</u>	Lanthanum <u> </u>
Silver <u> </u>	Cobalt <u> </u>	Cerium <u> </u>
Gold <u> </u>	Nickel <u>40</u>	Praseodymium <u> </u>
Zinc <u>36</u>	Cesium <u> </u>	Neodymium <u> </u>
Cadmium <u> </u>	Rubidium <u> </u>	Samarium <u> </u>
Mercury <u> </u>	Barium <u>560</u>	Europium <u> </u>
Gallium <u> </u>	Strontium <u>1800</u>	Gadolinium <u> </u>
Indium <u> </u>	Titanium <u> </u>	Terbium <u> </u>
Thallium <u> </u>	Zirconium <u>460</u>	Dysprosium <u> </u>
Germanium <u> </u>	Hafnium <u> </u>	Holmium <u> </u>
Tin <u> </u>	Thorium <u> </u>	Erbium <u> </u>
Lead <u>590</u>	Vanadium <u> </u>	Thulium <u> </u>
Arsenic <u> </u>	Columbium <u> </u>	Ytterbium <u> </u>
Antimony <u> </u>	Tantalum <u> </u>	Lutetium <u> </u>
Bismuth <u> </u>	Chromium <u> </u>	Yttrium <u> </u>
Selenium <u> </u>	Molybdenum <u> </u>	<u> </u>
Tellurium <u> </u>	Tungsten <u> </u>	<u> </u>
Bromine <u> </u>	Uranium <u> </u>	<u> </u>
Iodine <u> </u>	Manganese <u> </u>	<u> </u>

The values above are estimated elemental concentrations in:

 per cent XXXX parts per million grams per liter

No check was made for elements with atomic numbers less than 22.

By *Merlyn L. Salmon*

NOTE: A PORTION OF THE REPORTED SAMPLES WILL BE RETAINED IN FULL FOR A PERIOD OF TWO YEARS FROM THE ABOVE DATE. THE REMAINDER OF THE SAMPLE WILL BE RETAINED FOR THIRTY DAYS, PENDING RECEIPT OF WRITTEN INSTRUCTIONS FOR DISPOSAL FROM THE ABOVE SET ABOVE.

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SPEC TROGRAPHIC
Analytical Laboratory

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Phone (303) 837-1396
Merlyn L. Salmon, Manager

XXXX QUALITATIVE
XXXX SEMI-QUANTITATIVE
____ QUANTITATIVE

ANALYTICAL REPORT

TO: Oklahoma State Univ

Job Number 31780
Page 4 of 10 Pages
Date 6 Nov 1984

SAMPLE: DMR1

Copper 37	Iron 560	Lanthanum
Silver	Cobalt	Cerium
Gold	Nickel	Praseodymium
Zinc 36	Cesium	Neodymium
Cadmium	Rubidium	Samarium
Mercury	Barium 90	Europium
Gallium	Strontium 92	Gadolinium
Indium	Titanium	Terbium
Thallium	Zirconium	Dysprosium
Germanium	Hafnium	Holmium
Tin	Thorium	Erbium
Lead 200	Vanadium	Thulium
Arsenic	Columbium	Ytterbium
Antimony	Tantalum	Lutetium
Bismuth	Chromium	Yttrium 100
Selenium	Molybdenum	
Tellurium	Tungsten	
Bromine	Uranium	
Iodine	Manganese	

The values above are estimated elemental concentrations in:

_____ per cent XXXX parts per million _____ grams per liter

No check was made for elements with atomic numbers less than 22.

By *Merlyn L. Salmon*

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ANALYTICAL REPORT

TO: Oklahoma State Univ

Job Number 31780
Page 5 of 10 Pages
Date 6 Nov 1984

SAMPLE: DMR2

Copper <u>33</u>	Iron <u>1800</u>	Lanthanum <u> </u>
Silver <u> </u>	Cobalt <u> </u>	Cerium <u> </u>
Gold <u> </u>	Nickel <u>40</u>	Praseodymium <u> </u>
Zinc <u>36</u>	Cesium <u> </u>	Neodymium <u> </u>
Cadmium <u> </u>	Rubidium <u> </u>	Samarium <u> </u>
Mercury <u> </u>	Barium <u>950</u>	Europium <u> </u>
Gallium <u> </u>	Strontium <u>1600</u>	Gadolinium <u> </u>
Indium <u> </u>	Titanium <u>180</u>	Terbium <u> </u>
Thallium <u> </u>	Zirconium <u>510</u>	Dysprosium <u> </u>
Germanium <u> </u>	Hafnium <u> </u>	Holmium <u> </u>
Tin <u> </u>	Thorium <u>220</u>	Erbium <u> </u>
Lead <u> </u>	Vanadium <u> </u>	Thulium <u> </u>
Arsenic <u> </u>	Columbium <u>35</u>	Ytterbium <u> </u>
Antimony <u> </u>	Tantalum <u> </u>	Lutetium <u> </u>
Bismuth <u> </u>	Chromium <u> </u>	Yttrium <u>55</u>
Selenium <u> </u>	Molybdenum <u> </u>	<u> </u>
Tellurium <u> </u>	Tungsten <u> </u>	<u> </u>
Bromine <u> </u>	Uranium <u>95</u>	<u> </u>
Iodine <u> </u>	Manganese <u> </u>	<u> </u>

The values above are estimated elemental concentrations in:

 per cent XXXX parts per million grams per liter

No check was made for elements with atomic numbers less than 22.

By *Merlyn L. Salmon*

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ANALYTICAL REPORT

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SAMPLE: DTFR1

Copper <u>82</u>	Iron <u>1100</u>	Lanthanum _____
Silver _____	Cobalt _____	Cerium _____
Gold _____	Nickel _____	Praseodymium _____
Zinc <u>120</u>	Cesium _____	Neodymium _____
Cadmium _____	Rubidium _____	Samarium _____
Mercury _____	Barium <u>180</u>	Europium _____
Gallium _____	Strontium <u>550</u>	Gadolinium _____
Indium _____	Titanium _____	Terbium _____
Thallium _____	Zirconium <u>170</u>	Dysprosium _____
Germanium _____	Hafnium _____	Holmium _____
Tin _____	Thorium _____	Erbium _____
Lead _____	Vanadium _____	Thulium _____
Arsenic _____	Columbium _____	Ytterbium _____
Antimony _____	Tantalum _____	Lutetium _____
Bismuth _____	Chromium _____	Yttrium _____
Selenium _____	Molybdenum _____	_____
Tellurium _____	Tungsten _____	_____
Bromine _____	Uranium _____	_____
Iodine _____	Manganese _____	_____

The values above are estimated elemental concentrations in:

_____ per cent XXXX parts per million _____ grams per liter

No check was made for elements with atomic numbers less than 22.

By

Merlyn L. Salmon

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ANALYTICAL REPORT

TO: Oklahoma State Univ

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Date 6 Nov 1984

SAMPLE: DTFR2

Copper_____110	Iron_____6200	Lanthanum_____
Silver_____	Cobalt_____	Cerium_____
Gold_____	Nickel_____40	Praseodymium_____
Zinc_____33	Cesium_____140	Neodymium_____
Cadmium_____	Rubidium_____340	Samarium_____
Mercury_____	Barium_____880	Europium_____
Gallium_____	Strontium_____	Gadolinium_____
Indium_____	Titanium_____130	Terbium_____
Thallium_____	Zirconium_____	Dysprosium_____
Germanium_____	Hafnium_____	Holmium_____
Tin_____	Thorium_____	Erbium_____
Lead_____390	Vanadium_____	Thulium_____
Arsenic_____	Columbium_____66	Ytterbium_____
Antimony_____	Tantalum_____	Lutetium_____
Bismuth_____	Chromium_____	Yttrium_____50
Selenium_____	Molybdenum_____	_____
Tellurium_____	Tungsten_____	_____
Bromine_____	Uranium_____140	_____
Iodine_____	Manganese_____	_____

The values above are estimated elemental concentrations in:

_____ per cent XXXX parts per million _____ grams per liter

No check was made for elements with atomic numbers less than 22.

By

Merlyn L. Salmon

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VITA

Cindy Lynn Smith

Candidate for the Degree of
Master of Science

Thesis: NATURAL GROUND WATER SYSTEMS AND ASSOCIATED
FRESHWATER CARBONATE DEPOSITS IN SOUTHERN OKLAHOMA

Major Field: Geology

Biographical:

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Education: Graduated from Norwalk High School, Norwalk
Conneticut, in August, 1973; recieved Bachelor of
Arts degree in geology from Boston University,
Boston, Massechusetts, January, 1980; completed
requirements for the Master of Science degree with
a major in geology. at Oklahoma State University
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Professional Experience: Data Management Specialist,
Association of Oklahoma Governments, 1980-1981;
Geologist, US Army Corp of Engineers, Omaha
District, 1981-1983; research assistant, Oklahoma
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