URANIUM POTENTIAL IN THE ANTLERS FORMATION
SOUTH OF THE BELTON-TISHOMINGO UPLIFT,
SOUTHERN OKLAHOMA

By

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PREFACE

Carborne and airborne radiometric surveys, hydrogeochemical analyses and detailed investigation of reported anomalies and asphalt deposits were used to try and locate areas of uranium mineralization in the Antlers Formation, south of the outcrop area of the Eastern Arbuckle province granites. Although no uranium mineralization has been found on outcrop, the origin of certain asphalt deposits is discussed leading to a hypothesis as to the formation of related uranium deposits in the subsurface. Petrographic and clay-mineralogy studies have also been used to determine the lithologic characteristics of the host rock.

The writer is sincerely grateful for the assistance of his thesis adviser, Dr. Zuhair Al-Shaieb, who first suggested the study and always made himself available for constructive comments and criticism. The comments and suggestions of the advisory committee members, Dr. Gary F. Stewart and Dr. Hobart E. Stocking, are also appreciated. Don Hart of the U.S. Geological Survey contributed his time and allowed the writer access to unpublished maps and data relevant to this study. The author wishes to express his appreciation to the Geology Department of Oklahoma State University for their financial support and to ERDA for partial research support through contract BFEC-GJO REP 0005.

The cooperation and assistance of all the landowners, who gave permission to sample wells, permitted access to their lands, and showed the writer areas of interest, is gratefully acknowledged. Indirectly many of the faculty members and graduate students in the Department of Geology have contributed their ideas to this study.

My parents, Mr. and Mrs. Donald J. White, have always supported my educational goals by their active encouragement. Finally, I would like to express my sincere gratitude to my wife, Mary Teresa, who has been an inestimable help and ably served as manuscript typist and proofreader.

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INTRODUCTION

Location

The study area is located in southeastern Oklahoma, primarily in Atoka and Johnston Counties (see Figure 1). It includes the outcrop area of the Antlers Formation between the Tishomingo Granite outcrop to the north and the overlying Goodland-Walnut Formation to the south, an area 4 to 10 miles wide and approximately 36 miles long in the dissected coastal plain province. The granitic area to the north exhibits a rolling hummocky topography with sparse outcrops and relatively deep soil development. The Antlers outcrop is characterized by steep-sided gullies and poor drainage. The best outcrops of the Antlers are observed in gullies, along streams, in some roadcuts and in quarries. The overlying Goodland-Walnut Formation forms a distinct limestone cuesta which is easily recognized in the field.

Purpose and Methods of Investigation

The purpose of this study is to evaluate the Antlers Formation as a possible host for uranium mineralization. Several lines of evidence suggest that the Antlers might be a favorable host unit:

1. The availability of uranium leached from the Tishomingo and Troy Granites to the north;

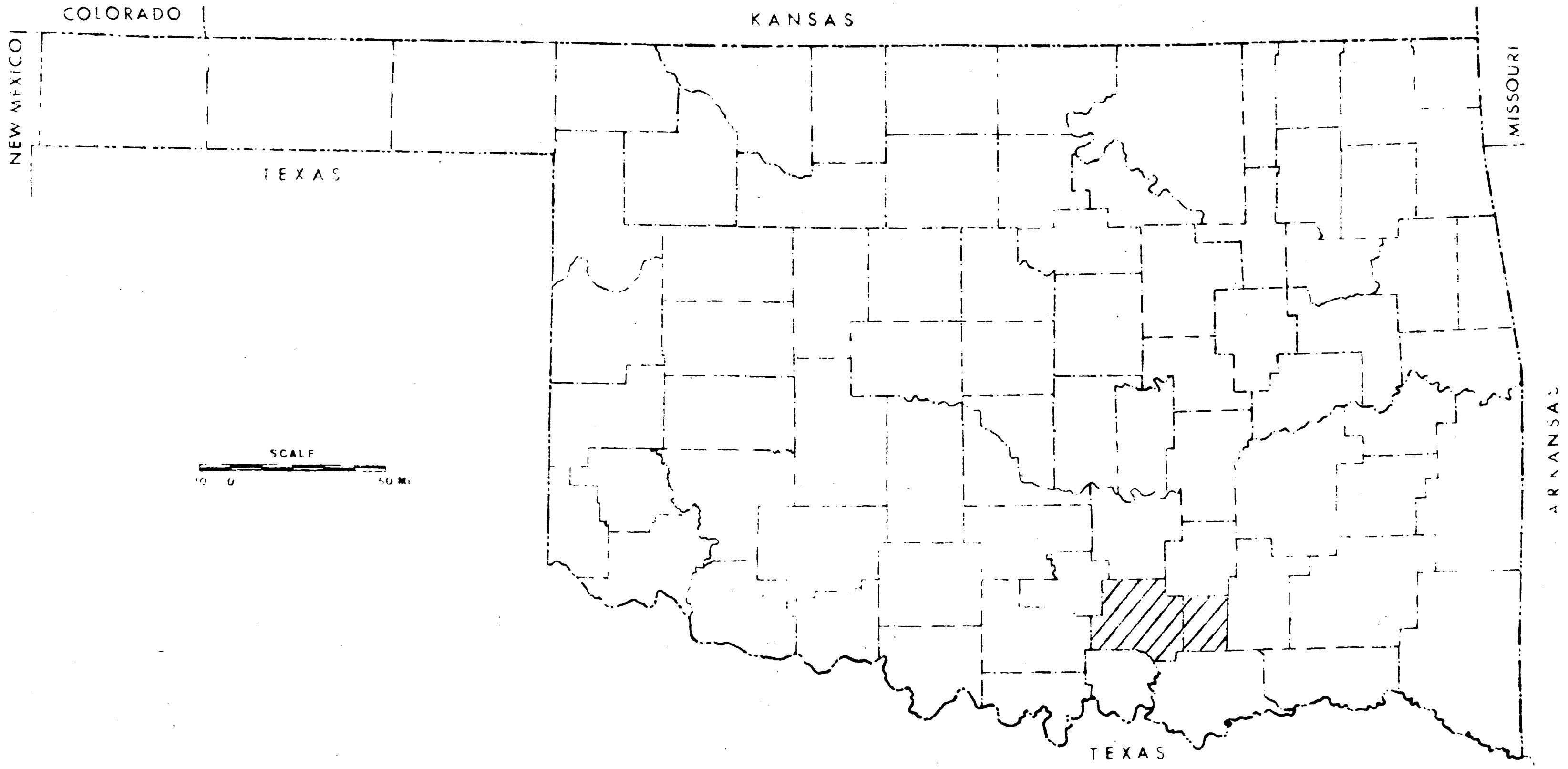

Figure 1. Index Map of Study Area (hachured)

2. Previously reported uranium anomalies associated with carbonized wood;
3. The reported presence of asphalt deposits plus pyrite nodules;
4. The ferruginous staining of the outcrop and its bleached character in some areas; and
5. The marginal marine depositional environment.

These criteria and other sedimentologic characteristics are only a few drawn from a number of sources including Gabelman (1971). One of the other factors which led to the study of the Antlers sandstone as a possible uranium host is its nonconformable relationship with the Tishomingo Granite in Johnston and Atoka Counties where the aquifer is recharged. This results in an essentially perched water table above the peneplaned granite bedrock, dipping south at 50-100 ft per mile. Predominant drainage is southward to the Red River and the piezometric surface dips south also. Thus surface and ground water from the granite outcrop flow into the more permeable Antlers, moving down-dip to be confined by the Goodland-Walnut Formation resulting in artesian conditions.

Harriss (1965) studied two weathering profiles of the Tishomingo Granite and his data indicate that 50 per cent of the uranium (1.7 ppm ave. U content) is released when the granite is weathered. The thorium appears to be in resistates since it is not released during pedogenesis. The movement of the surface and ground water from the granite to the Antlers suggests that uranium released to the soil by weathering would be transported into the Antlers aquifer.

In order to investigate this hypothesis a detailed hydrogeochemical study of the Antlers was carried out to determine: 1) if the conditions in the aquifer are favorable for transporting U^{6+} ions in solution; and 2) if anomalous concentrations of uranium are present in the ground water. To this end samples were collected from wells in the Antlers aquifer and analyzed for Eh, pH, uranium, and major cations and anions.

Several methods were integrated to locate areas of uranium mineralization. The preliminary investigation was a carborne radiometric survey of the entire study area using both a scintillometer and gamma-ray spectrometer. Every mile of section road and highway were traversed to determine background radiation, locate anomalies, and relate changes in lithology to changes in background. Later, when airborne radiometric data became available (ERDA, 1977), detailed investigations were made of those areas indicated as anomalies or possible anomalies.

Thorough investigations were also made in areas of previously reported anomalies, known asphalt deposits, and along the Antlers--Goodland-Walnut contact. Samples of both sandstone and claystone were collected for petrographic and x-ray diffraction analysis. Measured sections were compiled in order to correlate the various units of the Antlers sandstone. Virtually no subsurface data was found pertaining to the Antlers in the area covered by this study.

Previous Investigations

Most of the work done prior to this study was of a regional nature, concerned with the Trinity Group as a whole or the entire Cretaceous sequence. The first workers in the area were Hill (1887, 1891, 1901) and Taff (1902, 1903, 1904). Later studies make reference to Hill's work in Arkansas and Texas, in equivalent units, as the first study of Comanchean Lower Cretaceous rocks. Taff (1902, 1903) compiled maps of both the Tishomingo and Atoka quadrangles in what was then still Indian Territory. Taylor (1915) and Uhl (1932) worked on the igneous rocks in these areas and more recently Ham and others (1964) completed a study on the basement rocks of the Eastern Arbuckle province. Harriss (1965) and Harriss and Adams (1966) studied the geochemistry of the Tishomingo Granite, including its uranium content, and behavior during weathering and soil formation.

Miser's paper (1927) includes all of the Lower Cretaceous (Comanchean) rocks in southeastern Oklahoma and southwestern Arkansas and he first recognized the onlapping relationships of these units. In 1928 Vanderpool published a paper on the Trinity Group but he also included outcrops in north Texas. Melton and McGuigan (1928) studied the depth and present attitude of the Jurassic peneplane and hypothesize that this surface may have extended further north.

In a series of related papers Forgotson (1957a, 1957b, 1963) discussed the stratigraphy, paleotectonics, and depositional history of the Trinity Group in the Gulf Coast area. In his study he notes the discrepancy in the meaning of the term "Paluxy" between Oklahoma and Texas geologists and proposes the name Antlers Formation for the basal Cretaceous Comanchean rocks in Oklahoma. This nomenclature is followed by the U.S.G.S. and Oklahoma Geological Survey on Hart's (1974) map, which supercedes Miser's (1954) map.

In his thesis Prewit (1961) mapped the subsurface geology of the Cretaceous coastal plain and made a structural contour map of the base of the Cretaceous as well as an isopachous map of the Trinity Group in

Oklahoma. Manley's dissertation (1965) on the clay mineralogy of the Trinity Group tried to determine the provenance of the clays and the various clay-mineral suites present. Tanner (1965) used structural and depositional patterns to determine the orientation of the Cretaceous shoreline. He believes that there is evidence to indicate that the shoreline in Oklahoma may have been oriented north-south, west of the Ouachitas, extending up into Kansas. Other authors, however, believe that the shoreline was oriented east-west somewhere north of the present erosional edge.

Wayland (1954) and Wayland and Ham (1955) discuss the Baum limestone member of the Antlers near Ravia, immediately west of the study area. The Baum is a basal limestone conglomerate on top of the Paleozoic rocks. Blau (1961) studied the petrology and environment of deposition of the Goodland Limestone in Oklahoma. Hart (1970) mapped that part of Bryan County which was included in the present study. Currently Don Hart of the U.S.G.S. (personal communication, 1977) is studying the Antlers in Oklahoma to determine the chemical and physical characteristics of the aquifer.

CHAPTER II

GEOLOGIC SETTING

Precambrian igneous rocks and Lower Cretaceous sedimentary rocks form the major outcrops within the area of investigation (see Figure 2). Paleozoic rocks are exposed in two isolated down-faulted blocks within the Belton-Tishomingo uplift. The granites outcrop in a west-northwest trending horst which was exposed during the Belton-Tishomingo uplift. In the subsurface the Precambrian Eastern Arbuckle granite is the basement rock northeast of the Washita Valley fault-complex zone (see Figure 3) and the Cambrian Carlton Rhyolite is the basement rock southeast of this fault. Primarily Cretaceous sediments overlie the granite basement whereas the rhyolite is overlain by Paleozoic and Cretaceous rocks.

The Cretaceous sediments onlap the basement rocks which were eroded to a peneplane during the Triassic and Jurassic. A Cretaceous sea transgressed west and northwest to deposit rocks which generally strike east-west in the study area and dip 50-100 ft per mile to the south. Several radioactive anomalies have been reported in these Lower Cretaceous sedimentary rocks.

Stratigraphy

The sedimentary rocks in the study area are Lower Cretaceous Comanchean rocks of the Trinity and Fredricksburg Groups. The Antlers

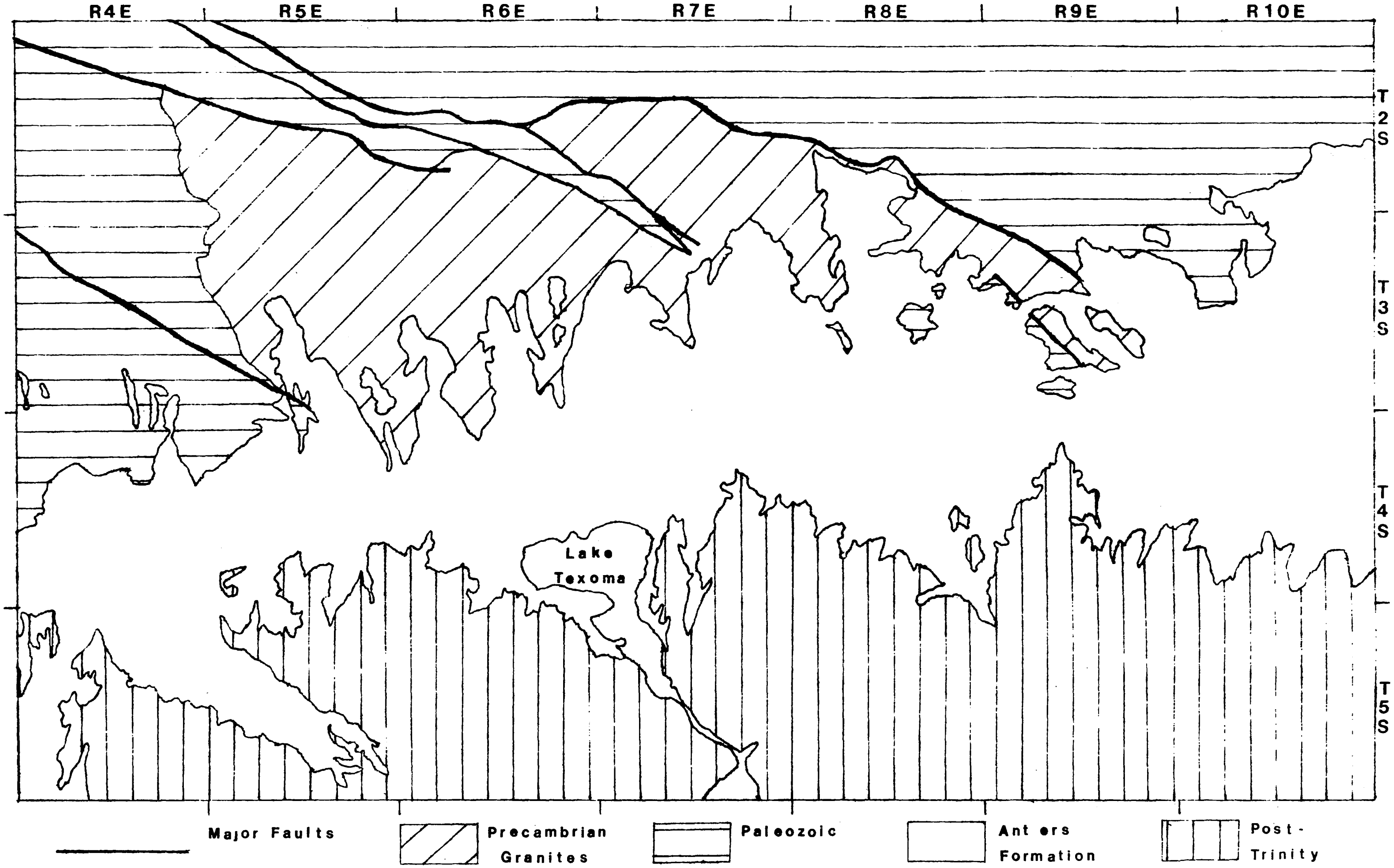

Figure 2. Generalized Geologic Map of Study Area. Geology Modified From Hart (1974).

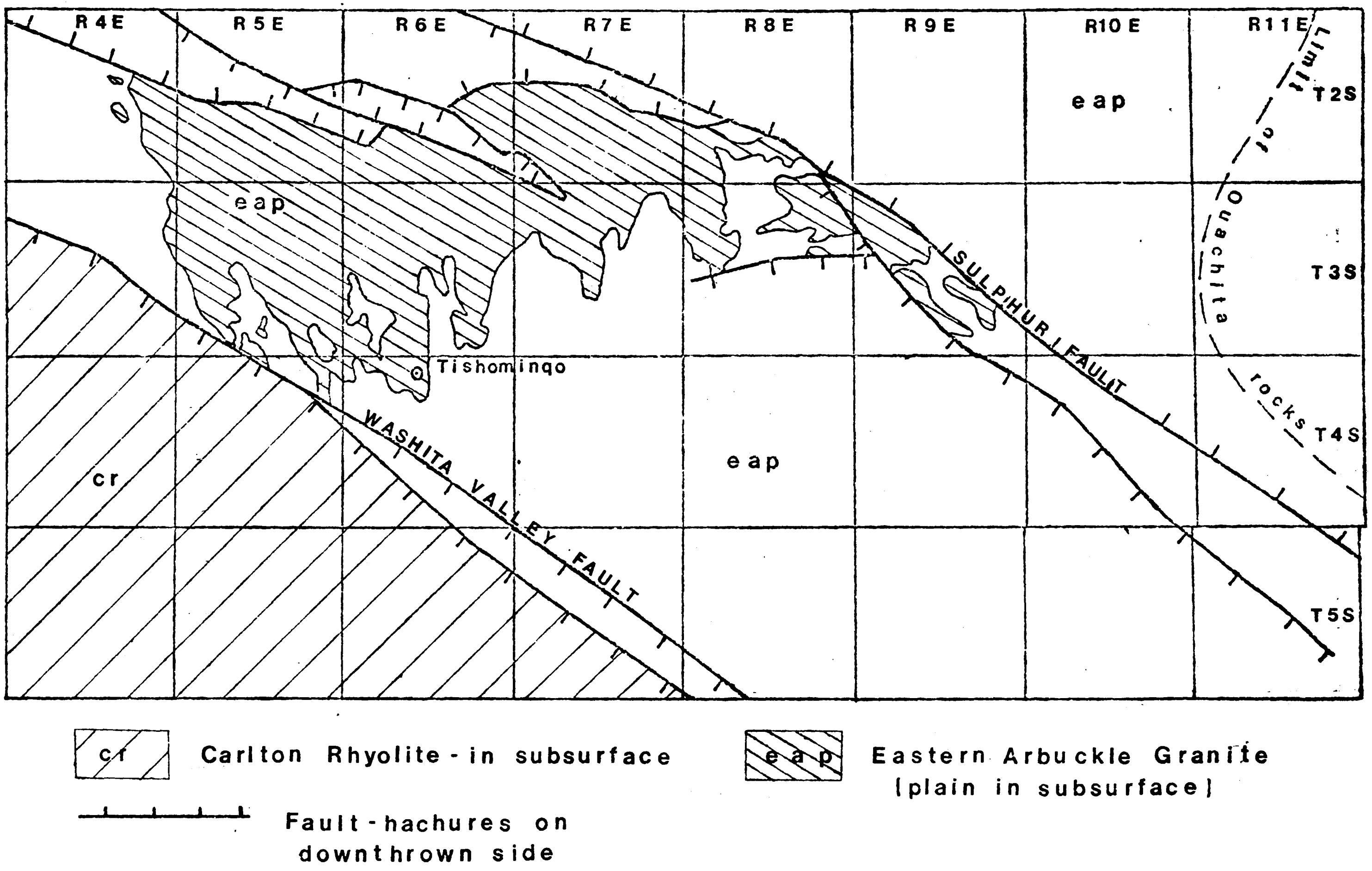

Figure 3. Map of Basement Rock in Study Area. Geology Modified From Ham and others (1964).

sandstones generally lie nonconformably on Precambrian granites and in a few areas on Paleozoic rocks. The Antlers is conformably overlain by the Goodland-Walnut Formation of the Fredricksburg Group. A traverse from north to south crosses the granites, the eroded onlap of the Antlers and the cuesta formed by the Goodland-Walnut caprock.

Basement Rocks

The basement rocks in the study area are primarily Precambrian Troy and Tishomingo Granites. In Atoka County lower Paleozoic rocks crop out in the area of the Belton-Tishomingo uplift in isolated downfaulted blocks. The granites were transgressed by a Cretaceous sea. Prewit (1961) shows that the base of the Cretaceous (the nonconformity between the Antlers and the Tishomingo Granite) is generally planar, dipping uniformly to the south. To the west and the east of the study area are local highs and lows which may be related to paleotopography or, as in the Madill area, to structure.

The granites of the Eastern Arbuckle province were mapped and described by Taylor (1915) and Uhl (1932). The mineral composition of the two granites is very similar. The Troy Granite is distinguished from the Tishomingo by texture; the former has medium-grained equigranular texture while the latter is coarser and commonly contains pink microcline phenocrysts (Ham and others, 1964). Table II (see Appendix) lists analyses of the granite showing that the uranium content varies from 2-4 ppm in ten wells penetrating basement rocks. Two analyses by Harriss (1965) indicated an average uranium value of 1.7 ppm.

Trinity Group

The Trinity Group is the basal division of the Cretaceous in southeastern Oklahoma and was defined in Texas by Hill (1901) to be those beds of the Lower Cretaceous below the Walnut Clay. The Trinity is divided into three formations which, in ascending order, are the Holly Creek Formation, the DeQueen Limestone, and the Antlers Formation. The lower two formations are not present in the study area; the Holly Creek is overlapped by the DeQueen, which is subsequently overlapped by the Antlers, east of the study area in McCurtain County.

Antlers Formation. The nomenclature and stratigraphic position of Oklahoma's basal Cretaceous rocks as reported in the literature has changed several times since Hill's first work in 1887. The unit, or parts of it, has been called Paluxy, Trinity and most recently Antlers. Part of the confusion results from the northward extension of Texas stratigraphic units to include rocks in Oklahoma which may have been deposited in different environments (Hart, 1970).

Another source of confusion lies in the petrologic similarities of the Paluxy in Texas and the basal Cretaceous sands in Oklahoma. The Paluxy of Texas was assigned by Hill and others (Hart, 1970) to both the Fredericksburg and Trinity Groups at various times. Now Paluxy is restricted in use to the sandstone of Fredericksburg age which overlies the Glen Rose Limestone. Forgotson (1957a) has shown that the Paluxy overlaps the Antlers in the subsurface of Texas. This relationship can be seen more clearly in the stratigraphic section in Figure 4.

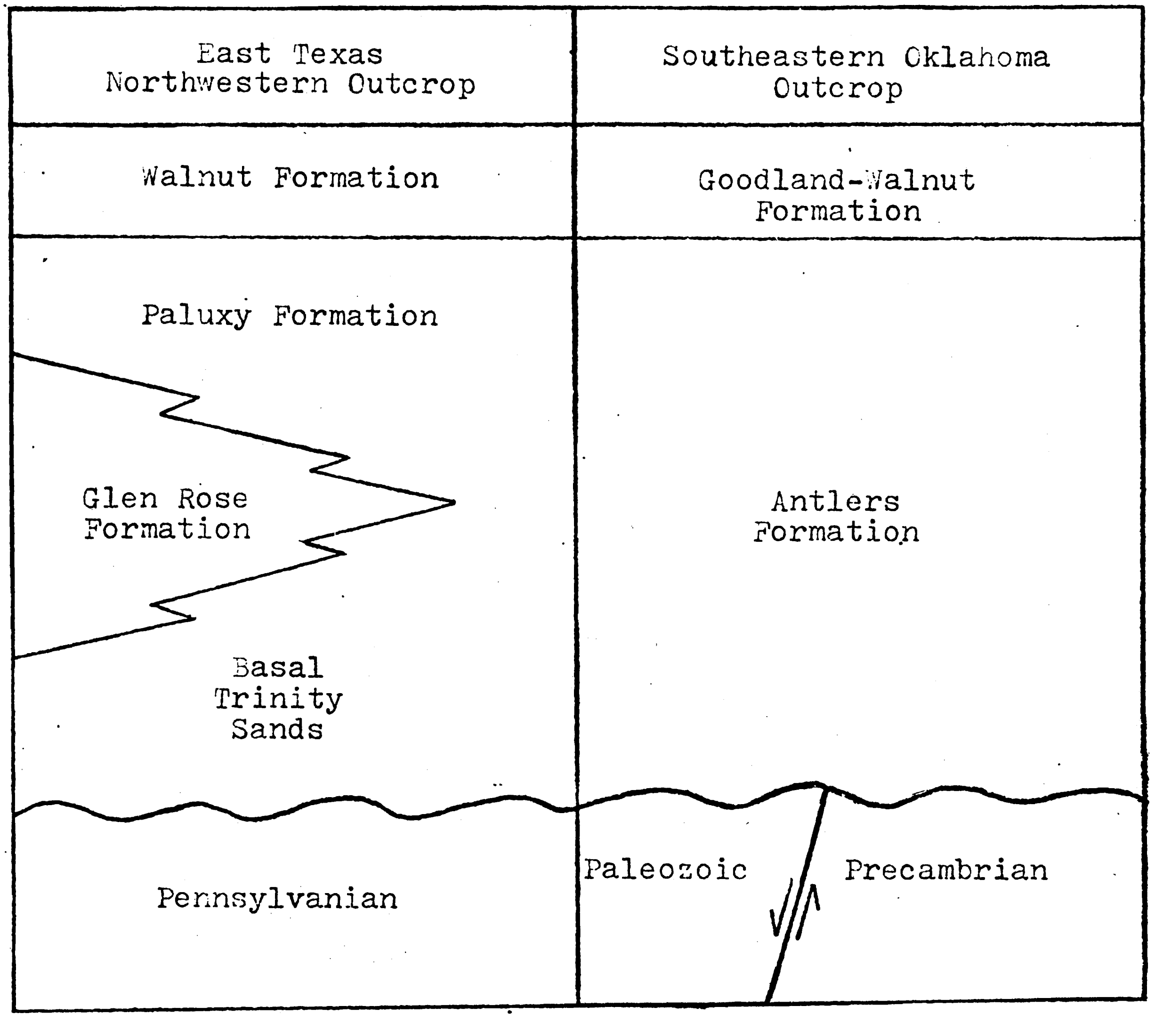

Figure 4. Stratigraphic Section Showing the Relationship of the Lower Cretaceous in Oklahoma With the Equivalent Units in Texas. Modified From Forgotson (1957a; 1957b).

In Oklahoma the basal Cretaceous was called "basement sands" and Trinity sand in the early part of this century; in the 1950's the term Paluxy came into use and that is the name applied to the unit on Miser's (1954) Geologic Map of Oklahoma. Forgotson (1957a, 1963) deciphered the stratigraphic relationship and proposed that Hill's earlier term of Antlers be used after the town of Antlers, Oklahoma where the sandstone crops out. The entire Antlers, however, may not be of Comanchean age. The upper part of these undifferentiated sands may be time equivalent to the Glen Rose and Paluxy of Texas, i.e. of Fredericksburg age. The most recent map by Hart (1974), a joint effort of the U.S. Geological Survey and the Oklahoma Geological Survey, uses the term Antlers for the basal Cretaceous of Oklahoma and that nomenclature will be followed in this study.

The Antlers crops out in the study area in T3S-T4S from R5E to R9E in a belt approximately 6 to 8 miles wide. There are erosional outliers of the Antlers on the granite north of the main outcrop. These outliers are evidence that the Antlers outcrop extended at least several miles north of its present position. Melton and McGuigan (1928) projected the present peneplane surface and showed that the Cretaceous outcrop may have extended farther north. Their data indicate that an imaginary plane thus extended would clear the highest topography in southeast Oklahoma.

The strike of the Antlers is generally east-west with a gentle dip to the south of approximately 50-100 ft per mile (Prewit, 1961). The basal contact, where exposed, shows a conglomerate on top of weathered granite which fines upward to a medium and fine-grained sand with occasional 3-6 in. thick layers of claystone.

Excellent exposures of the carbonate cemented, arkosic conglomerate and the overlying sand are seen west of Pennington Creek, near Tishomingo. The entire thickness of the Antlers outcrop is quite variable due to erosion. The maximum thickness attained is 300 ft in the outcrop area, but the Antlers thickens considerably to the south in the subsurface.

There is a general fining-upward trend in the Antlers. The claystones may be more than 30-40% of the total thickness of the Antlers in the study area and the per cent sand decreases down-dip (Prewit, 1961, and D. Hart, 1977, personal communication).

Goodland-Walnut Formation

Hill first used two terms, the Goodland Limestone and the Walnut Clay, for this unit but Taff (1902, 1903) combined the two. Hart's (1974) map uses the Goodland-Walnut Formation, but they are mapped as separate units in Texas. The Goodland-Walnut Formation is conformable with the underlying Antlers sandstone. The contact between the two is marked regionally by a distinct cuesta and, where the Walnut facies is present, the contact is at the base of the Exogyra agglomerate. In several localities in Oklahoma the contact between the Goodland and the Antlers is the site of asphalt mineralization. The extent and genesis of these deposits is discussed more fully in Chapter IV. There are several erosional outliers of the Goodland-Walnut north of the main contact suggesting that the Goodland-Walnut extended several miles north of its present outcrop. The strike and dip of the Goodland-Walnut is essentially the same as the Antlers.

Blau (1961) studied the petrology of the Goodland limestone and classified it as a sparse biomicrite. He concluded that the probable environment of deposition was offshore at a depth of less than 120 ft, possibly exposed at low tide. Within the area of investigation the Goodland-Walnut is approximately 25 ft thick. It is a hard dense white limestone in which there are several quarries. Below the limestone are clay beds, referred to as the Walnut clay, but this unit is not always present.

Structure

The base of the Cretaceous unconformably overlies Paleozoic and/or Precambrian rocks in southern Oklahoma. Forgotson (1963) states that the Lower Cretaceous Trinity sediments were deposited on a broad unstable shelf between the craton to the north and the Gulf Coast geosyncline to the south. In Oklahoma the Antlers was deposited on a stable shelf, 10 to 70 miles wide, separated from the unstable shelf by a hinge line, forming a homoclinal surface which dips to the south.

At this time the Belton-Tishomingo horst was a stable element. The horst is bounded on the northeast by the Sulphur fault and on the southwest by the Washita Valley fault-complex zone (see Figure 3); these faults were first activated prior to Late Cambrian deposition (Harlton, 1966). The fault zones were rejuvenated repeatedly during the Paleozoic and the boundary faults can be seen to have had more than 11,000 ft of vertical displacement by the time the area was affected by Pennsylvanian Arbuckle diastrophism (Harlton, 1966).

To the immediate west and southwest of this area are several southeast plunging structures; the Cumberland anticline and syncline, Madill anticline, Preston anticline, etc., which parallel the Arbuckle structural elements. Prewit (1961) proposes that these structures were formed by the draping of sediments over Paleozoic topography. There are two problems with his hypothesis: 1) the entire area was subject to peneplanation during Triassic and Jurassic time which reduced all surrounding areas to a uniform flat surface dipping south, and 2) Hart (1970) shows that Prewit's data on thickness and elevation in this area do not correlate with his conclusions. Hart's explanation is that there was Cretaceous deformation, some of it penecontemporaneous, as a result of tectonic adjustment along the same trends as the Arbuckle deformation. In the study area and to the east there is too little subsurface control to reveal structure and one must rely on Prewit's (1961) generalized structural contour map on the base of the Cretaceous for data.

CHAPTER III

SAMPLING METHODS AND ANALYTICAL PROCEDURES

A variety of methods and procedures, which were used in collecting and analyzing the water and clay samples, are outlined below.

Ground-Water Samples

A total of 39 water samples were collected from wells in the Antlers aquifer. Uniform coverage of the outcrop area was the goal of the sampling program, but the actual choice of sites was dictated by the availability of wells and the permission of landowners. Two 500 ml samples were collected at each site; one was stored in an ice chest and the other was treated with nitric acid and stored separately.

The wells were allowed to run for a few minutes to obtain fresh samples. All bottles were completely filled to minimize the reaction of the water with air.

In order to minimize changes in the redox potential (Eh) and pH, the samples were analyzed as soon as possible after collection. The samples were stored on ice until the readings were obtained.

Atomic Absorption Spectrophotometry

The samples were analyzed for calcium, magnesium, potassium, sodium and silica content using a Perkins-Elmer 403 double-beam atomic absorption spectrophotometer. The manufacturer's instructions were followed as to wavelength, flame-type, and sensitivity range. For the calcium analysis 1% lanthanum oxide was added to each sample to suppress interference by other elements which could lead to decreased sensitivity and falsely low readings. No special treatment was necessary for the other cation analyses.

Anion Analyses

The samples were also analyzed for $SO_4^=$, $CO_3^=$, HCO_3^- and Cl^- by titrimetric methods. All samples were stored on ice until the analyses were completed. For the chloride analysis, the pH of the sample was adjusted with the addition of $NaHCO_3$ until alkaline to methyl orange, but acid to phenolphthalein. K_2CrO_4 indicator was added and then the solution was titrated with $AgNO_3$ until a red or reddish-brown precipitate formed.

The sulfate concentration was determined by reading the optical density of the sample on a colorimeter at a wavelength of 700 millimicrons. A 25 ml sample was first treated with 25 ml of 4.8 pH acetate buffer, 0.5 ml of gum arabic and excess $BaCl_2$ which formed a white precipitate. The readings from the samples were compared with the values of a standard curve (absorption vs. concentration).

For the carbonate analysis a 5 ml sample was treated with phenolphthalein; the lack of reaction in all samples indicated that there was no $CO_3^=$ present. To this aliquot methyl orange was added, and the sample was titrated with dilute H_2SO_4 until the end point to determine the concentration of HCO_3^-.

Uranium Analyses

All of the samples for uranium analysis were treated with 2-3 ml of concentrated nitric acid when they were collected in the field. The samples were then sent to Skyline Labs, Inc., of Denver to be analyzed for U content. A Galvanek-Morrison-type flourometer was used in the analysis. The lower limit of detection is 2 ppb and the reported accuracy of the method is ±10%.

Clay-Mineralogy Sample Preparations

Clay samples were collected from several locations in the study area. The sample distribution was designed to detect any vertical (stratigraphic) change or any horizontal (facies) changes by the changes in the clay content. Additional samples were collected at measured sections and other points of interest. All of the samples were stored in plastic bags to prevent contamination.

The samples from claystones were disaggregated by hand and placed in a container with 25 ml distilled water. After the samples were thoroughly mixed, the clay fraction was pipetted onto a clean porcelain slide and allowed to air dry. Clay from the sandstones was similarly extracted, except the clay fraction was decanted several times in order to separate out the coarse fraction and reduce interference from quartz.

X-ray Diffraction

The samples were analyzed using a Philips-Norelco x-ray diffractometer at a rate of $2\theta°/2$ min. Those samples with peaks in the 14-18 angstrom range were treated with ethylene glycol in a dessicator to determine the presence of expandable-layer clays. Another set of slides was heated to 450°C for one hour in a muffled oven to determine whether chlorite was present in any of the samples.

CHAPTER IV

PETROLOGY AND PETROGRAPHY OF THE ANTLERS FORMATION

There are several lithologies present in the Antlers Formation including: limestone conglomerate, arkosic conglomerate, fine-to very fine-grained sandstones, siltstones and claystones. Generally the sandstones are poorly cemented whereas the arkosic conglomerate is carbonate cemented. The fresh sandstones are yellow to white on outcrop and weather to varying shades of orange and red-orange. The sandstones are extremely friable and the only cementing agent is the hematite rimming the quartz grains or authigenic clays. The color of the claystones varies from olive green, gray or a mottled red due to iron-rich zones.

Several horizons within the sandstone contain iron nodules. Most are hematitic, but there are pyrite nodules with oxidized rims, indicating that some of the nodules originally were pyritic. The Antlers crops out in an area of low relief (150-200 ft) and the topography combined with the heavy vegetative cover result in poor exposures, except along the banks of streams, in a few road cuts and in quarries.

The base of the Antlers, where exposed, usually is marked by a conglomerate which reflects the lithology of the underlying rocks. In the Mannsville area the Baum limestone member of the Antlers reflects the contributions of the underlying Arbuckle limestones while in the Tishomingo area the basal conglomerate is arkosic reflecting the underlying Tishomingo Granite. A measured section (see Figure 5) shows the complete succession from the weathered granite, to the arkosic conglomerate, upward to fine-grained sandstones with interbedded claystones.

There are two conglomeratic units in this measured section, in an exposure just west of Pennington Creek and the town of Tishomingo (see Figure 6). Both are carbonate cemented arkosic conglomerates which form slight benches on outcrop as seen in Figure 6. The basal conglomerate contains coarser fragments, some up to 2-3 inches in diameter. This unit also contains more feldspar, predominantly microcline, than the upper conglomerate. The contact between the two is marked by a break in slope as well as a change in vegetative cover. The upper conglomerate is also carbonate cemented and in thin section (see Figure 7) the carbonate can be seen to replace the microcline.

The sequence fines upward, and the upper 30 ft of the section are fine-to very fine-grained quartzarenites with interbedded claystones. Medium-scale crossbedding, oxidized pyrite nodules, and zones of hematite staining are observed in this interval exposed in a quarry (see Figure 8) 100-150 yards west of the conglomerate outcrop. Figure 9 shows a typical thin section of this quartzarenite with authigenic kaolinite surrounding the quartz grains.

Because there are no persistent marker beds or diagnostic fossils in the Antlers, it is impossible to correlate the various measured sections in the study area. There is an overall fining-upward trend in the Antlers, although there are some coarser units in the upper

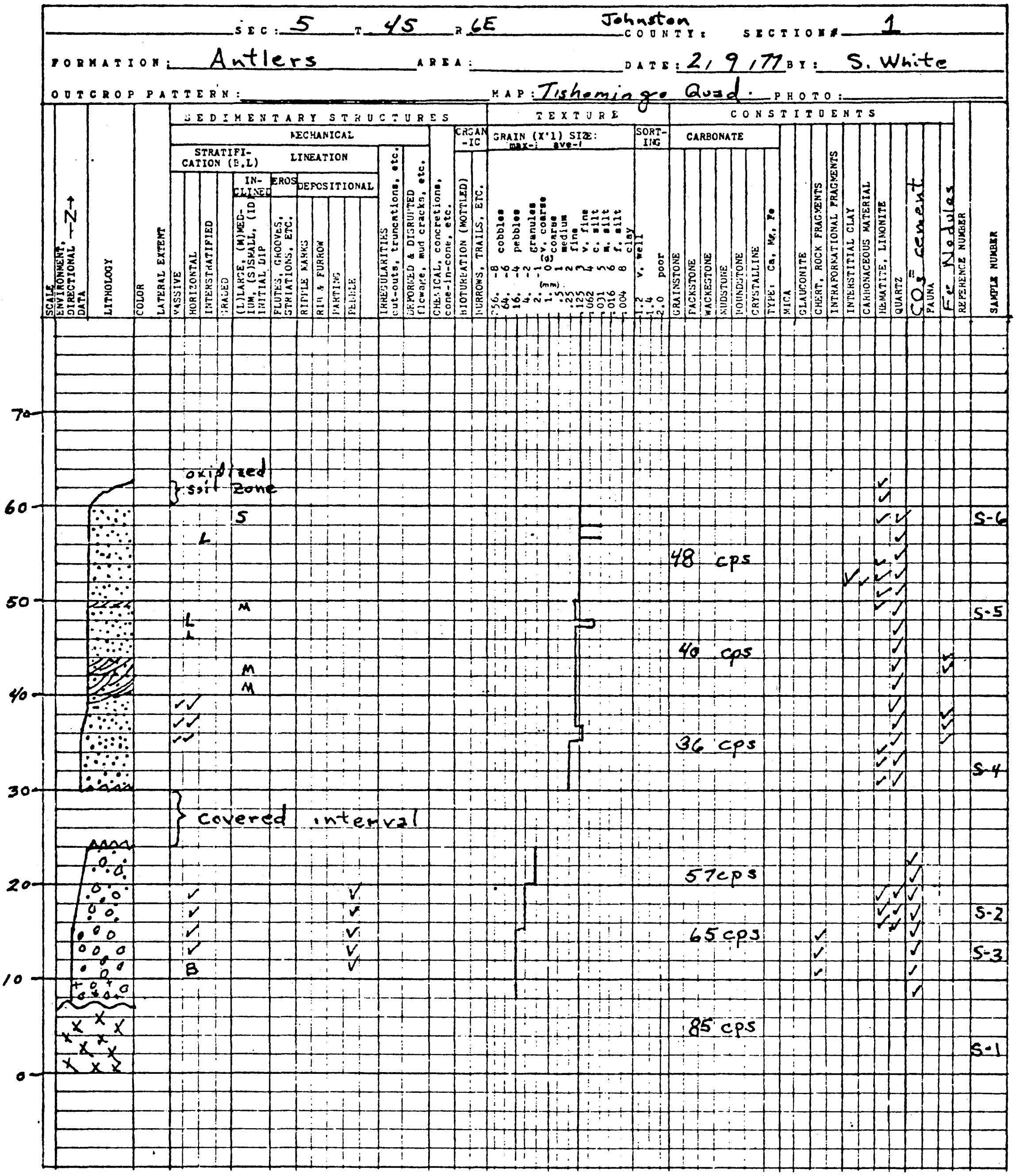

Figure 5. Measured Section at the Base of the Antlers, Near Tishomingo. Along Highway 22 in Sec. 5, T4S, R6E.

Figure 6. Outcrop of Arkosic Conglomerate. Arrow Indicates Boundary of Upper and Lower Conglomerate Units.

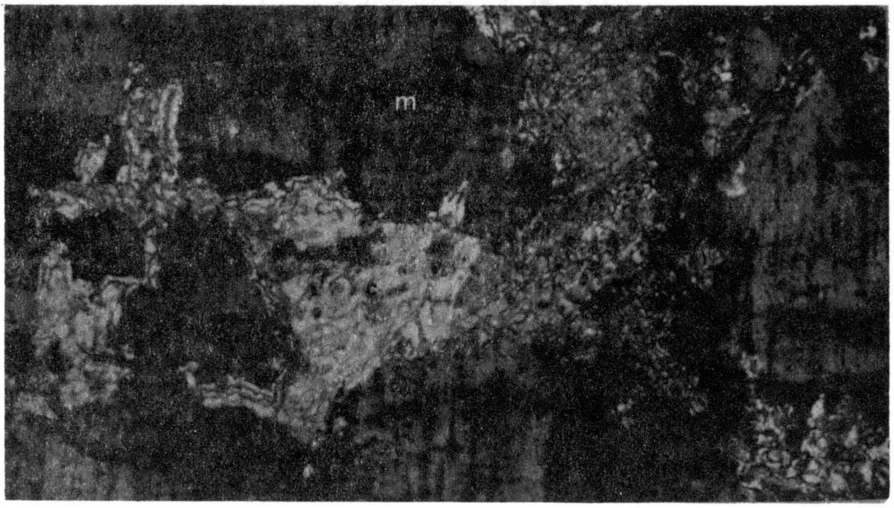

Figure 7. Photomicrograph of Arkosic Conglomerate. Note That Microcline (m) Grains Are Being Replaced by the Carbonate (c) Cement. X50, X-nicols.

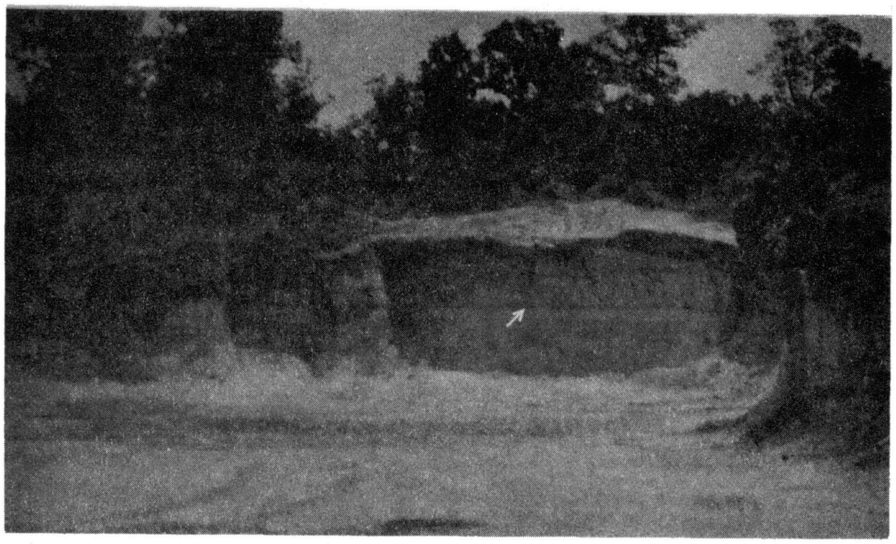

Figure 8. Outcrop of Antlers Formation Exposed in a Quarry Near Tishomingo. The Arrow Indicates a Claystone Bed.

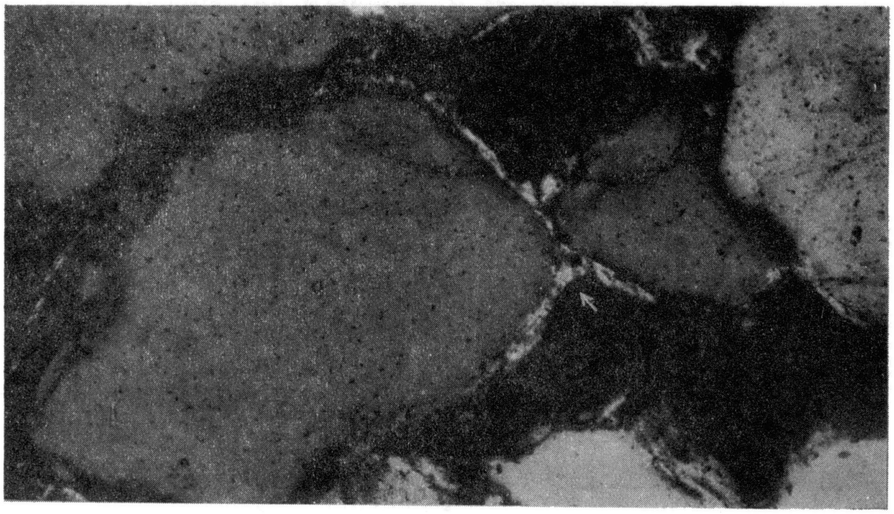

Figure 9. Photomicrograph of Quartzarenite With Authigenic Kaolinite (k) Between Quartz (q) Grains. X128, X-nicols.

Antlers, including the fine-to medium-grained unit below the Goodland-Walnut Formation which at some sites contains asphalt (see Figure 10). Thin sections of these sandstones reveal that the pore spaces of the quartzarenite are completely filled with asphaltic residue (see Figure 11). The asphalt and the sand unit in which it is found are not always present at the Goodland-Walnut contact. Figure 12 shows the contact in Sec. 14, T4S, R7E where the limestone is underlain by the Walnut clay above a claystone in the Antlers and no asphalt is present.

Thirteen thin sections of the Antlers Formation were made. All of the thin sections were impregnated with epoxy because of the extremely friable nature of the sandstone. More than one thin section was made in those localities where there is a change in lithology in the vertical section. The clay minerals were identified both by x-ray diffraction and optically, using the methods of Carrigy and Mellon (1964) and Grim (1968).

In thin section the Antlers is remarkably uniform. It is characteristically a fine-to very fine-grained quartzarenite which is subangular to subrounded, moderate to well sorted, with a porosity of 10-20%. Many of the quartz grains exhibit undulatory extinction and some are highly fractured. On outcrop the Antlers is a clean white sand but more commonly the quartz grains are coated with a rim of hematite which may also permeate the clay minerals. The clay minerals present are basically montmorillonite, kaolinite, illite, and rarely a well crystalline illite-mica. Some of the clays, mostly kaolinite and some illite, appear to be authigenic, lining the pore spaces in a highly permeable sand (see Figure 9).

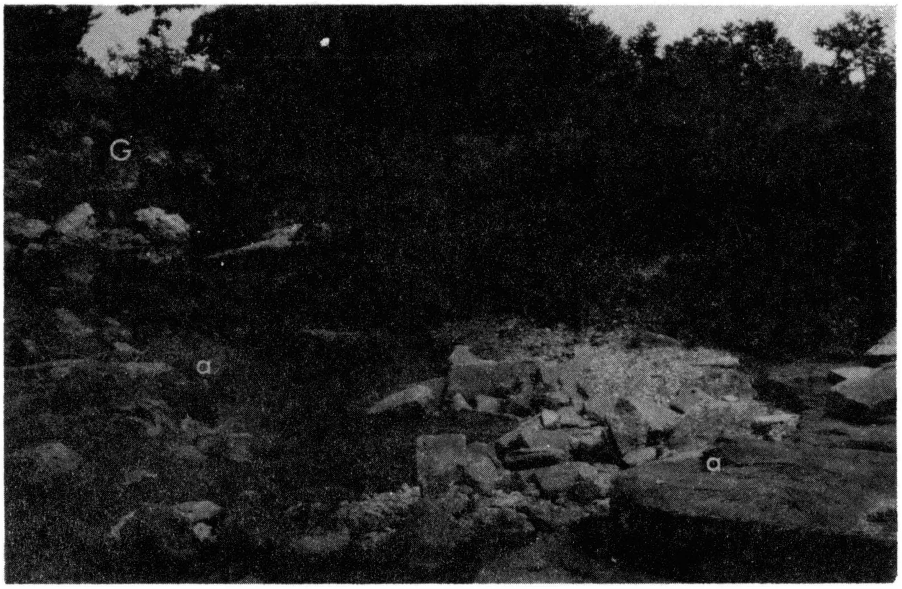

Figure 10. Asphaltic Sandstone Exposed in the Bed of Horse Creek Below the Contact With the Goodland-Walnut (G) NW NW Sec. 3, T5S, R8E.

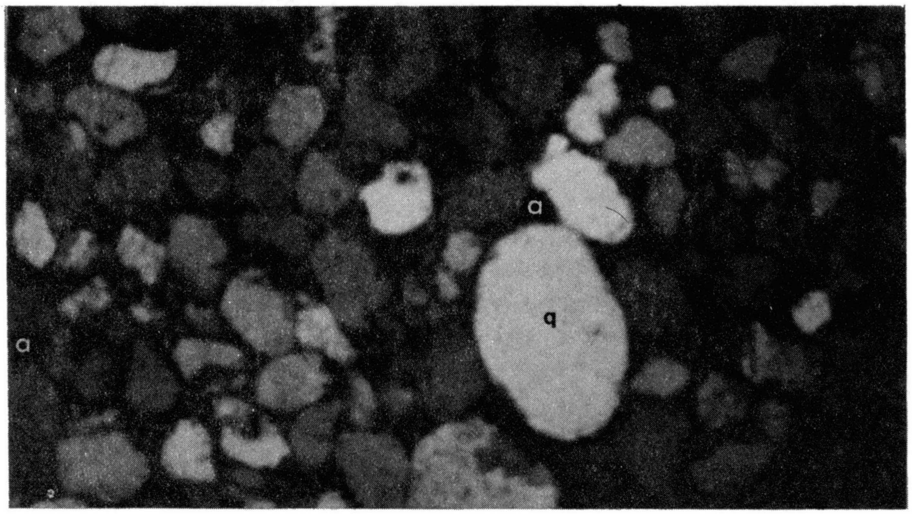

Figure 11. Photomicrograph of Asphalt-Impregnated Quartzarenite. The Pores Surrounding the Quartz (q) Grains contain Asphaltite (a). X50, X-nicols.

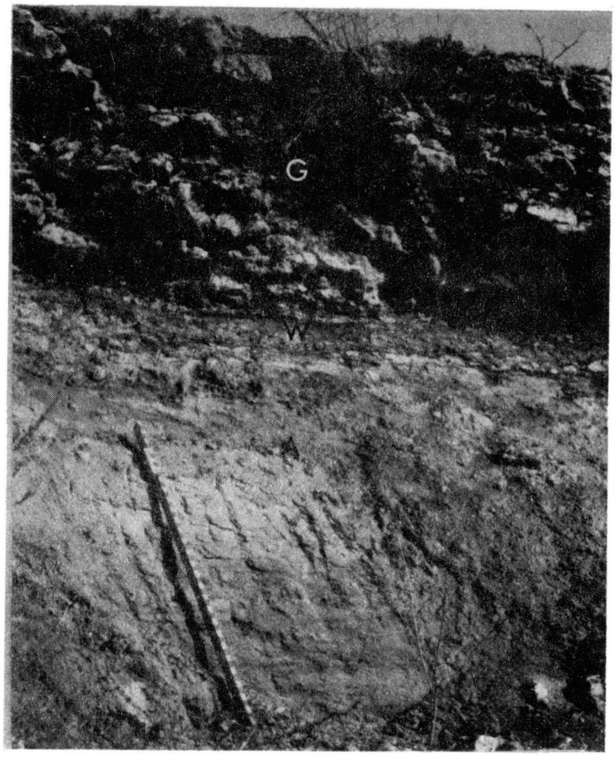

Figure 12. Contact Between Goodland-Walnut and Antlers Formations. Sec. 14, T4S, R7E Goodland Limestone (G) Overlies Walnut Clay (W) Facies Which Overlies a Claystone in the Upper Antlers (A). Note That There Is no Asphalt or Quartzarenite Seen at the Contact in This Location.

Of the thin sections classified as sandstone, several contain a few percent feldspar, but not enough to be classified as a subarkose. The minerals staurolite, epidote and zircon are also seen, but only in trace amounts. Manley (1965) and others believe that several thousand feet of Jackfork Sandstone eroded from the Ouachitas provided a source for the Antlers sandstone. The texture of the Antlers does not seem to bear this out since one would expect better sorting and more rounded grains from a reworked sand, but textural evidence is far from conclusive. This relatively "immature" texture could also be the result of highly fractured quartz grains breaking down during transportation. The occasional microcline and plagioclase seen in the thin sections indicate that some of the constituents have been contributed by the granites to the north.

The conglomerates contain quartz, plagioclase, chert and microcline grains from 0.2 mm up to several centimeters in diameter. The corrosion of the feldspars by the iron-rich carbonate cement has markedly decreased their size (see Figure 7). In the measured section it is clear that the basal conglomerate unit is derived from the granite upon which it rests nonconformably.

The asphaltite sands in the study area were found in a porous fine-to medium-grained sandstone immediately below the Goodland-Walnut contact (see Figure 10). Manley (1965) noted the existence of a clean white sand in this stratigraphic position but he did not mention the asphalt. The thin sections (see Figure 11) show that virtually all the pore space is filled with a yellow-brown resinous material, up to 10-15% of the volume. The sandstone impregnated with the asphaltite is remarkably clean with only quartz and a few grains of chert or clay in evidence. One can see micro-bedding planes of coarse- and fine-grained sands in thin section.

The two siltstones sectioned (see Figure 13) have much lower porosity and at least 50% of the contacts of quartz grains are of the floating or point variety. Iron oxide stains coat fractures in the rock but, because of the low permeability, rarely penetrate more than several millimeters. There also appear to be relict feldspar grains which have altered almost entirely to clay.

Asphlatic Sandstones

There are several localities where asphaltic sandstones are reported to crop out in the study area (see Table III in Appendix). Most of these sites were catalogued by Jordan (1964), but outcrops were found during this study which had not previously been reported. The asphalt mineralization is in a one to three foot thick zone, impregnating a fine-grained quartzarenite immediately below the Goodland-Walnut contact.

The asphalt layer crops out along the strike of the Goodland-Walnut--Antlers contact for several miles. One outcrop, in the bed of Horse Creek (see Figure 10), is one to 1.5 mi south of the main cuesta of the Goodland-Walnut, indicating that the mineralized zone may extend into the subsurface for at least that distance. Water wells south of the outcropping contact reportedly penetrate the asphaltite zone in the same stratigraphic position. There are 6 sections in which asphalt mineralization has been reported, striking east-west parallel to the Goodland-Walnut outcrop. Therefore, it is possible that as much as 10 to 15 square miles of the asphaltic sands

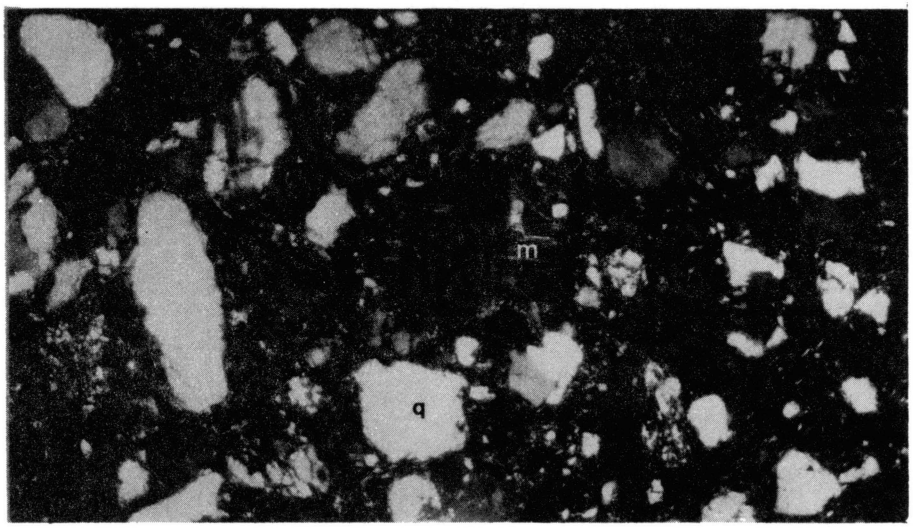

Figure 13. Photomicrograph of a Siltstone in the Antlers Formation; Primarily Quartz (q) and Microcline (m) With Interstitial Clay Minerals. Note the Poor Sorting and Alteration of the Microcline. X50, X-nicols.

underlie the Goodland-Walnut continuing down-dip to a depth of no more than 50-100 ft. These deposits might become economic if petroleum prices continue to rise; there are several quarries in the Goodland limestone and, if these were deepened, the asphaltic sands could also be extracted. However, the asphalt deposits have not been mined to any extent since the early 1900's.

Both Honess and Melton (1930) note the presence of asphalt in the Antlers throughout its outcrop in Oklahoma. They conclude that the lack of source material within the Antlers indicates that the petroleum must have migrated from the Paleozoic rocks which underlie the Antlers, inclined to the unconformity surface. This hypothesis adequately explains petroleum and asphalt deposits near the base of the Antlers, but because of the numerous and extensive claystone beds in the Antlers, it is difficult to see how petroleum migrated to the upper Antlers to be trapped by the limestone.

In addition Ham's (1964) basement rock map shows that there are no Paleozoic rocks in contact with the Antlers north of the Washita Valley fault. Therefore any explanation of the origin of the asphalt deposits in the study area must provide a means for petroleum to migrate through the entire thickness of the Antlers from an underlying source rock south of the Washita Valley fault or demonstrate that down-dip the Antlers contains hydrocarbons which migrated to their present position. Both of these hypotheses do not adequately explain the deposits because of the lack of primary vertical permeability in the Antlers and, even though the equivalent Trinity rocks in Texas contain oil, Prewit (1961) and Hart (1977, personal communication) show that the sand to shale ratio decreases southward thus decreasing permeability down-dip.

The major drainages in the study area line up with the Paleozoic faults even though several hundred feet of Cretaceous rocks overlie the faults. Renewed movement along old fracture systems is not uncommon and there is evidence that west of here the Preston and Madill anticlines reflect renewed movement during the Cretaceous along Arbuckle structural elements (Hart, 1970).

An alternative explanation for the origin of the asphalt, for which no direct evidence exists, is that there has been penecontemporaneous faulting of the Antlers associated with the Washita Valley fault-complex zone creating a zone of secondary permeability along which petroleum migrated through the Antlers from underlying Paleozoic rocks. The objections to this explanation are that no marker beds can be found in the Antlers and one cannot clearly show the fault movement. Also there is no evidence of displacement in the overlying Goodland-Walnut.

South of Durant more than 600 ft of Antlers sands overlie the Paleozoic rocks and this accumulation of sediment might have caused small scale penecontemporaneous fault movement along the dormant fracture zone. Such movement would not necessarily have to be reflected in the overlying Goodland-Walnut Formation because the fault could have ceased moving when the amount of sediment deposited along this zone decreased. If the fault was propagated through the limestone there are hundreds of feet of impermeable shales and marls above it to trap the petroleum in the Antlers.

Therefore renewed movement along the Washita Valley fault-complex zone could allow migration of petroleum from the subjacent Paleozoic rocks through the Antlers where it would be trapped by the overlying impermeable strata (see Figure 14). Once in this horizon the petroleum would migrate up-dip in a normal fashion and the lighter fraction of the oil would evaporate leaving behind the asphaltic residue.

Since there is no evidence of faulting in the Goodland, the fault probably formed in Comanchean time; the petroleum, however, could not be trapped until after the limestone had been deposited in Fredericksburg time. The exact location and extent of this inferred fault is not known but probably runs from T6S-R9E to T5S-R7E parallel to the Washita Valley fault-complex zone. It could extend further southeast but this is the minimum length necessary to account for the up-dip migration of petroleum to the site of the asphalt deposits.

A simple test of this hypothesis would be to compare the thickness of the Antlers on either side of the fault. Prewit's isopachous map (1961) uses a contour interval of 200 ft and well control is insufficient to demonstrate the presence or absence of an increased thickness southwest of the fault. However, Prewit's map does indicate an increase in the thickness of the Antlers in T7S, R10E near Durant, south of the fault.

Many asphalt deposits contain small percentages of uranium; however, a detailed survey of the outcrops with a scintillometer and gamma-ray spectrometer revealed no uranium or thorium enrichment. The migration of hydrocarbons along the fault zone presents the possibility of uranium deposits forming in the subsurface. Uranium, carried in solution by the ground water and moving down-dip which encountered the fault zone and the associated reducing conditions, would be

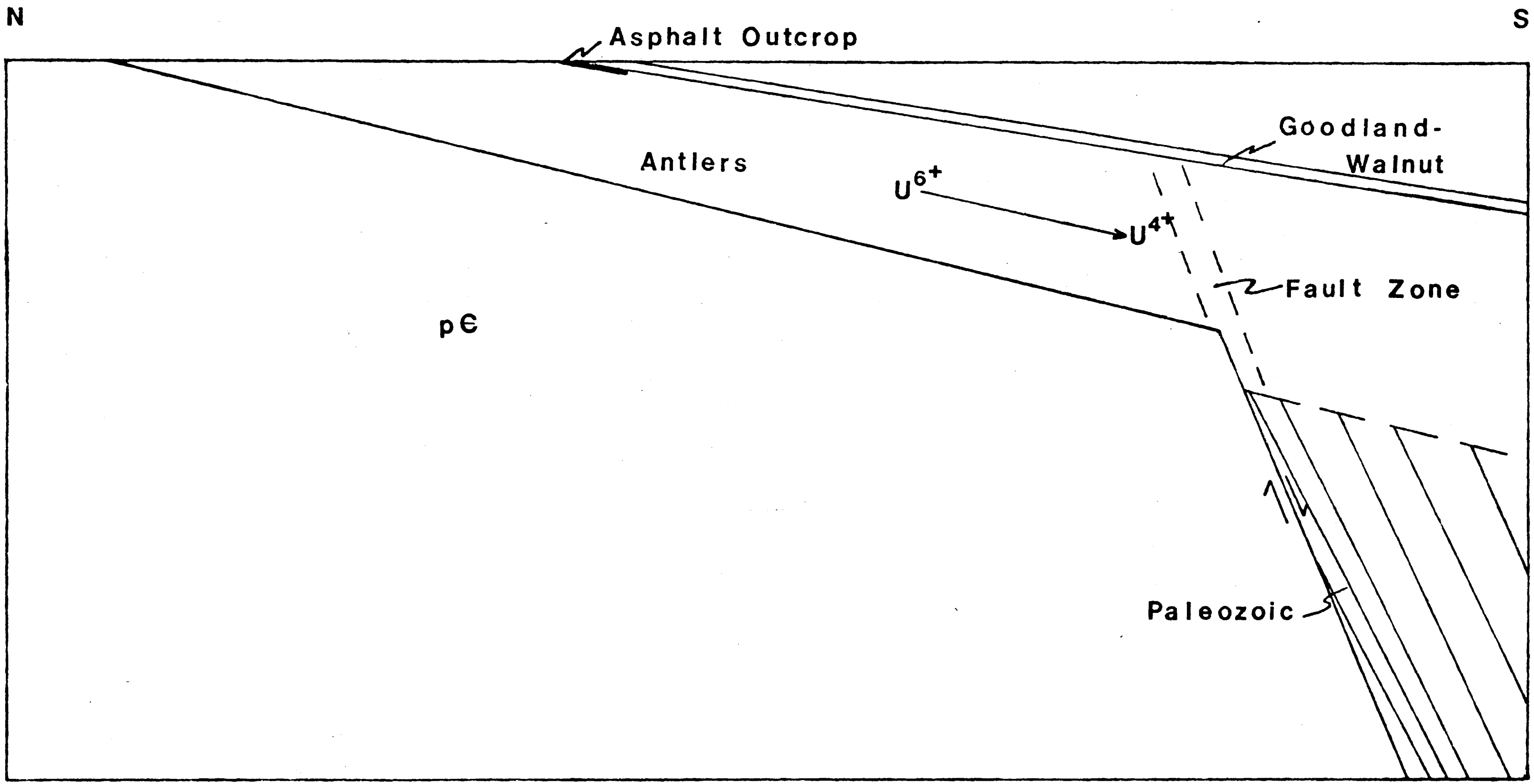

Figure 14. Diagrammatic Cross Section Showing the Origin of the Asphaltic Sandstone and Associated Uranium Mineralization. Note That the Dips and Thicknesses are not True to Scale.

precipitated as tetravalent minerals. With sufficient time and uranium concentrations in the ground-water system an economic uranium deposit could have formed in this area.

Clay Mineralogy

The clay mineralogy of the Trinity Group in southern Oklahoma was the topic of Manley's (1965) dissertation. He attempted to find a reliable way of deciphering the stratigraphy of the Antlers Formation since there are no reliable marker beds or diagnostic fossils. Manley collected 600 samples in his study, approximately 35 of them in the present area of investigation. He showed that the clay mineralogy did not vary in the differing lithologies (sandstones, claystones, etc.) of the Antlers.

In this study 35 clay samples were collected and analyzed using a Philips-Norelco diffractometer at a rate of $2\theta^\circ/2$ min. All of the slides were subsequently treated with ethylene glycol to facilitate the identification of any expandable-layer clays. The slides were then heated to 450° C for one hour and analyzed again. Eleven of the clays were extracted from the same samples as the thin sections to aid petrographic identification. The methods used to determine the mineralogy of the clays were largely taken from Grim (1968) and Carroll (1970). The three predominate clays in this area are montmorillonite, kaolinite and illite in order of decreasing abundance.

The montmorillonite expanded from about 15 Å to 17 Å after glycolation. When heated to 450° C for one hour, the resulting loss of the inter-layer water, caused the montmorillonite to collapse to 10 Å. The montmotillonite peaks were sharp indicating a well-crystalline clay.

The illite peak when present was at 10 Å (001) and sometimes a reflection was seen at 5 Å (002). The kaolinite was recognized by a sharp peak at 7.15 Å (001). No chlorite was detected. The presence of glauconite was suspected but none was detected. This may be due to the oxidizing conditions in the sandstones.

There were at least two, perhaps three, suites of clay minerals identified. The Antlers in the northern part of the area contains primarily montmorillonite-illite-kaolinite (see Figure 15) while the southern (stratigraphically higher) section contains montmorillonite-kaolinite (see Figure 16). Although the control is not as good, a few samples indicated a transitional zone of montmorillonite-illite in a central zone (see Figure 17). The distribution of these zones coincides somewhat with similar suites mapped in Manley's 1965 study (see Figure 18).

In his study Manley identified four clay-mineral suites in the Trinity Group and concluded that the four suites were each the result of a different source area as the Cretaceous sea transgressed northwestward. Some of the clays, as seen in thin section, are probably authigenic (see Figure 9) and Manley's study assumed that all clays were detrital. Some clays in thin section appear to line the pore space and this is one of the criteria that Wilson and Pittman (1977) used to recognize authigenic clays.

Manley assumed that the clay minerals were detrital in origin; reflected the composition of the source area; and that the dissimilarity in clay minerals reflected contributions of various source areas. The zonation of clay minerals is possibly a stratigraphic relationship produced as the sediments transgressed northwestward onlapping the

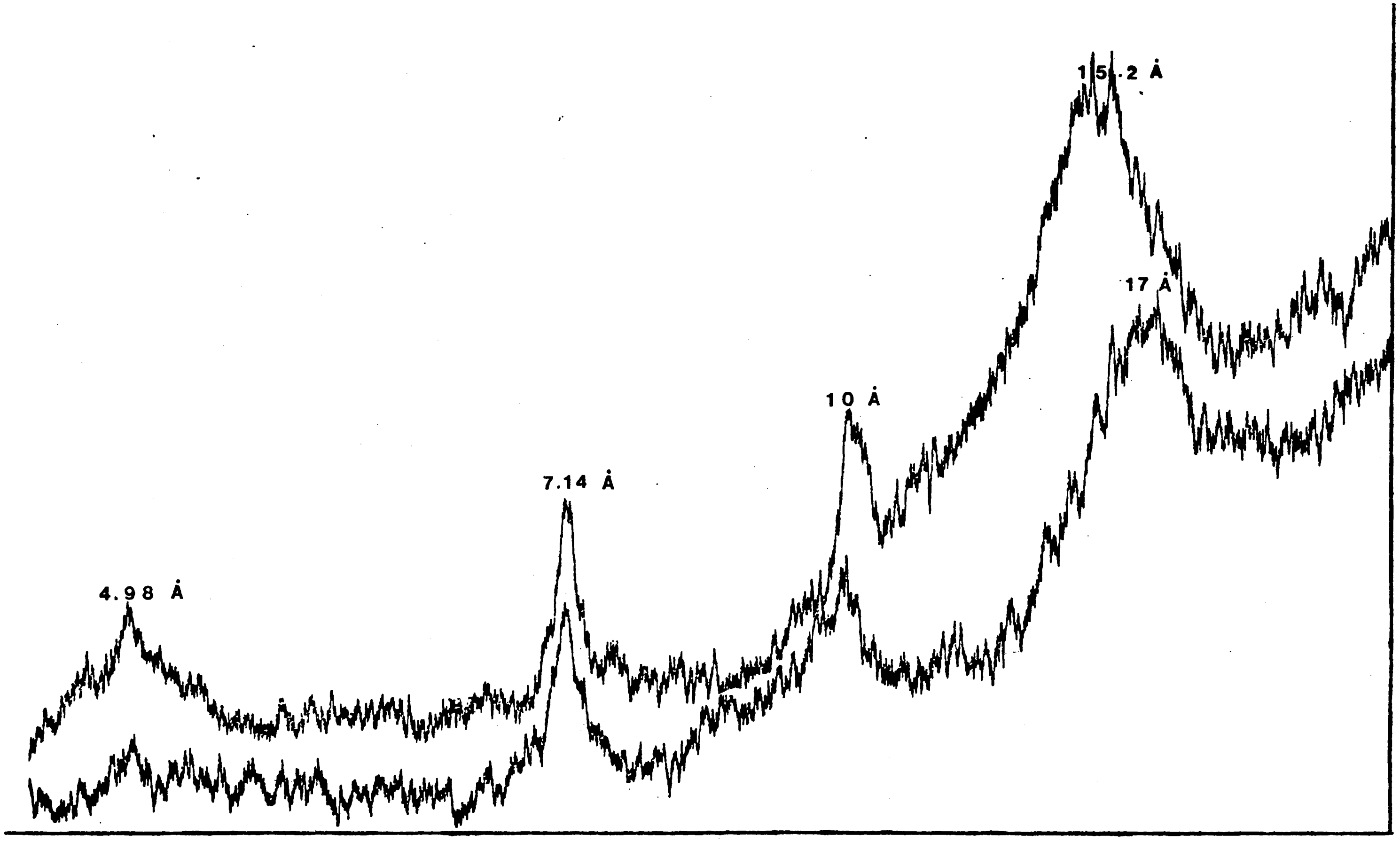

Figure 15. X-ray Diffractogram Showing Montmorillonite (M)-Illite (I)-Kaolinite (K) Suite. In the Lower Trace the Montmorillonite Peak Shifts From 15.2 to 17 Å After Glycolation.

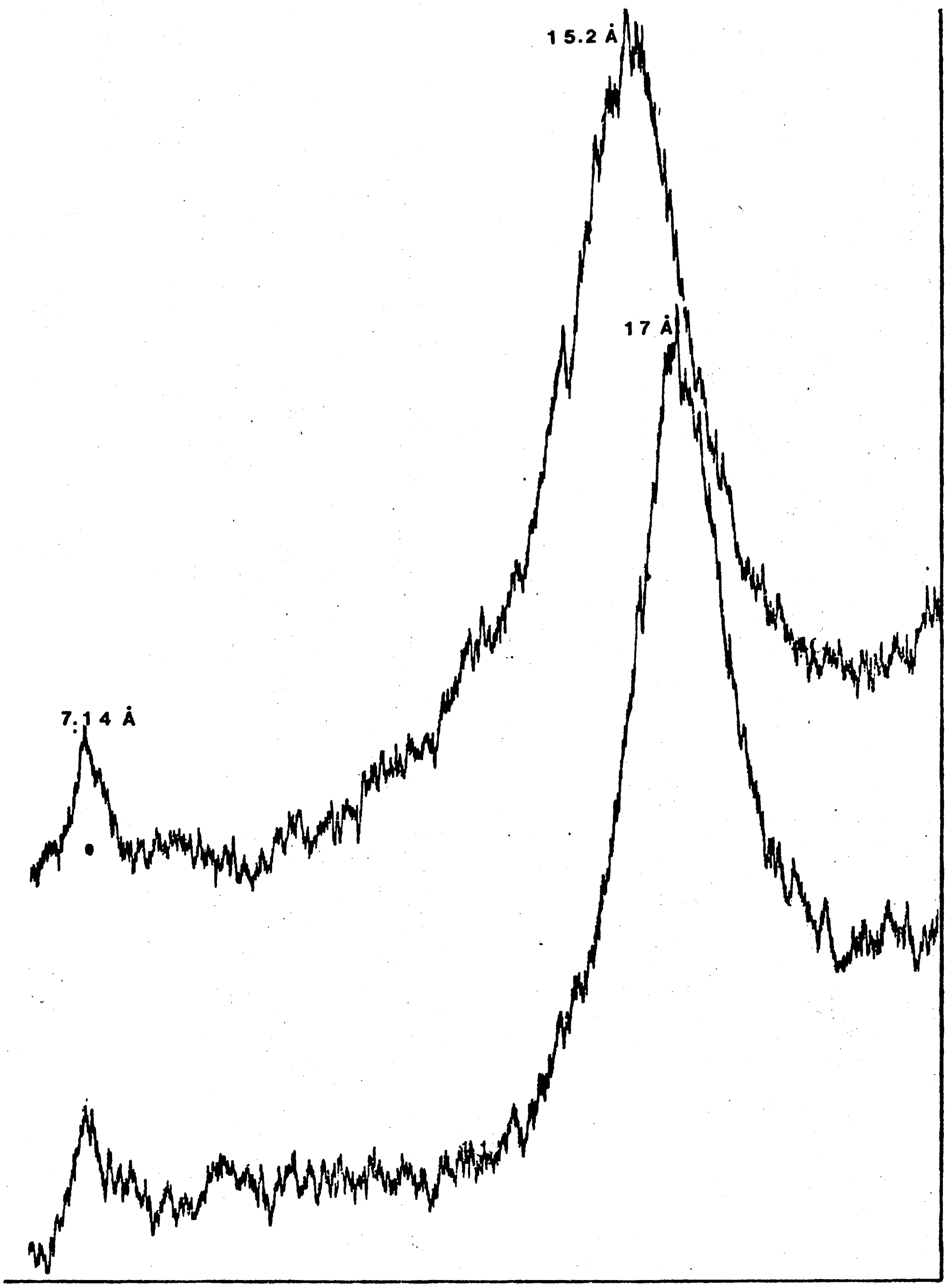

Figure 16. X-ray Diffractogram Showing Montmorillonite (M)-Kaolinite (K) Suite. In the Lower Trace the Montmorillonite Peak Shifts From 15.2 to 17 Å After Glycolation.

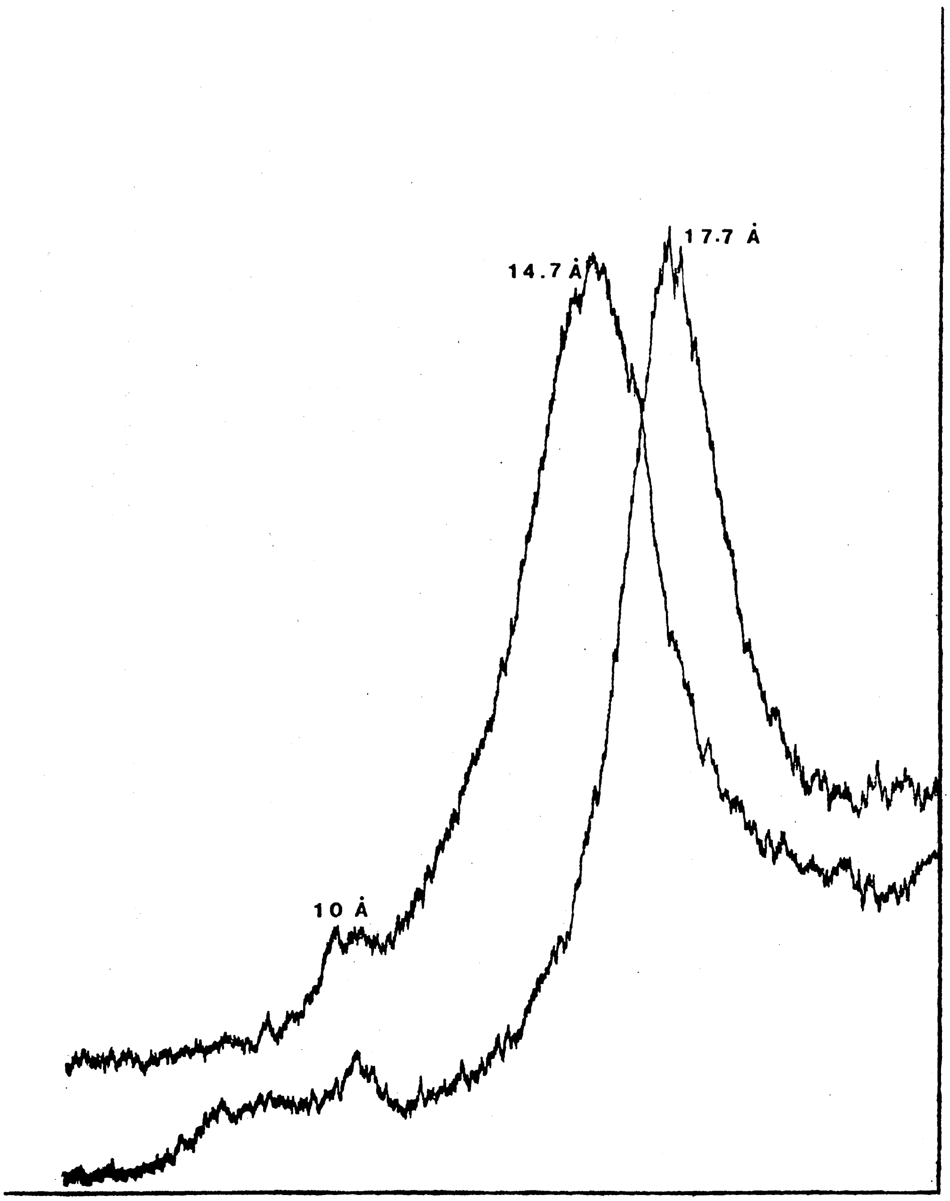

Figure 17. X-ray Diffractogram Showing Montmorillonite (M)-Illite (I) Suite. In the Lower Trace the Montmorillonite Peak Shifts From 14.7 to 17.7 Å. After Glycolation.

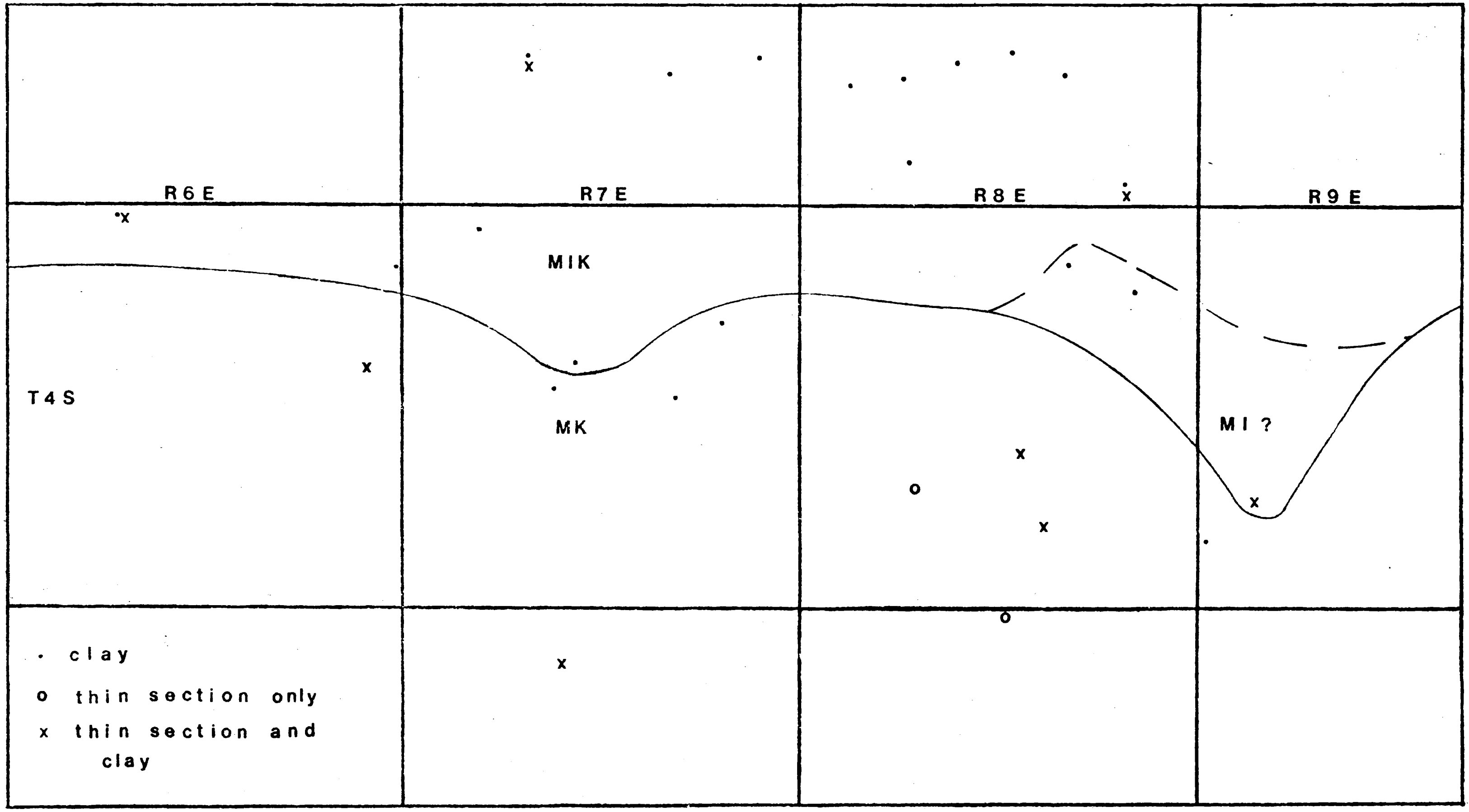

Figure 18. Map Showing the Distribution of Clay-Mineral Suites. Also Shown are the Thin Section and Clay Sample Sites.

older sediments. Manley (1965) proposes that a great thickness of Jackfork Sandstone eroded from the Ouachitas provided the quartz sands for the Antlers. The same longshore current that transported the sand to the west could also have carried the clay sediments in suspension from a Ouachita source.

An alternate hypothesis of a single source for the first three suites is suggested by Gibb's (1977) work in the Amazon basin. He states that there are three mechanisms to explain lateral variation in marine bottom sediments: chemical alteration, differential flocculation, and size segregation. It has been observed that illite and then kaolinite are deposited first as the suspended load is carried away from the source while montmorillonite is deposited in a range which extends considerably further. Gibbs proposes that the smaller size of the montmorillonite grains causes them to be carried in suspension a greater distance. He states that chemical alteration of clays is a very slow process, as shown in several experiments, and that the natural organic and metallic coatings on all clays give them similar properties during flocculation.

Gibbs (1977) postulates that the relative percentages of illite and kaolinite decrease away from the source region, whereas montmorillonite increases; not that all the illite and kaolinite are deposited at or near the source. Manley's (1965) data, although not a perfect fit, could be interpreted in this manner. His data show a relative decrease in illite and kaolinite westward away from the Ouachitas in three successive zones. Only the fourth clay zone, discordantly overlying the others, must be explained by another mechanism or a change in source region.

Variations in the above hypothetical pattern could be due to two factors: 1) there were local streams which contributed clays to the depositional system changing the sequence of clays locally, or 2) the formation of authigenic clay minerals in situ altered the original suites. Insufficient study has been made to determine which clays are detrital or authigenic, but the present study indicates that at least some of the clay minerals present are authigenic. From these observations, it is possible that the illite and kaolinite are diagenetic or alteration products. If this is so, one might explain the decreasing diagenetic changes to the west based on the younger age of the sediments in the west.

CHAPTER V

URANIUM IN THE ANTLERS FORMATION

There are several extant reports which indicate uranium mineralization exists in the Antlers Formation in Johnston County. Radiometric surveys and radiochemical analysis of the ground water furnish additional data on the uranium content of the Antlers. Asphaltite deposits in the study area indicate that there may be nearby reducing zones where uranium in solution could be precipitated.

Known Anomalies

Several references record the fact that there are uranium anomalies in the Antlers Formation in Johnston County. The earliest mention is by Branson and others (1955) and Curtis and others (1956) in Oklahoma Geological Survey publications. A U.S.G.S. map (Butler et al., 1962) and Finch's (1967) report on epigenetic uranium deposits in sandstone list a deposit in the Paluxy (Antlers). An A.E.C. and U.S.G.S. (1968) document gives a very general location for a claim of a Mr. J. W. Angel from Coleman, Oklahoma. All of these reports are concerned with two localities where Mr. Angel reportedly located coalified logs enriched in uranium. A test pit may have been dug in the area, but no large scale mining has ever been carried out.

The newest source of anomaly locations is contained in a 1977 ERDA contracted aerial gamma-ray survey of the Ardmore (1:250,000) quadrangle including the present study area. The locations of possible anomalies and prospects were listed in the report. All of these areas were field checked with a hand-carried scintillometer and gamma-ray spectrometer and no anomalies were located. It was noted that many of these anomalies were associated with the contact between the Antlers and the Goodland-Walnut Formation. The background readings increase from 45-50 cps to 75-80 cps as one passes from the Antlers to the Goodland-Walnut reflecting, perhaps, the organic content of the latter. No anomalies, readings 2-2½ times background, were located in the study area.

Radiometric Surveys

In the initial phases of the study a carborne radiometric survey was carried out to determine background and locate possible anomalies. A scintillometer, and later a gamma-ray spectrometer, were positioned in the window of a car traveling at 25-30 mph. All section roads and major highways were traversed in this manner. This did not result in a perfect grid survey with a one-mile spacing but gave a representative survey of the outcrop where population areas, refuges and lakes did not intervene.

In 1976 Texas Instruments, Inc. of Dallas flew an airborne gamma-ray and magnetic survey of the Ardmore quadrangle at an altitude of 1000 ft. Several statistically significant uranium anomalies were reported. The assignment of an anomaly in their study is predicated on knowledge of the bedrock and surficial geology and Hart's (1974) maps were used to delineate the geologic boundaries. A slight change in the boundaries at this scale could result in the use of incorrect background data which would appear as an anomaly.

Many of the anomalies were found at the contact between the Antlers and the Goodland-Walnut and, as previously noted, the background associated with the Goodland-Walnut may be 1½-2 times that of the Antlers. Thus, if an area which was believed to be Antlers was in fact Goodland-Walnut, an anomaly might erroneously be assigned to that locality. All of the reported anomalies were reinvestigated in the field and no anomalous readings were observed.

Uranium in the Ground-Water System

Thirty-nine ground-water samples were collected and analyzed for uranium as well as major cations and anions. The sampling pattern was designed to cover the outcrop area as completely as possible, but the final distribution was determined by the availability of wells (several areas were serviced by reservoirs) and the permission of the landowners. The location and distribution of the samples are shown in Figure 19 and Table V. It can be seen from the data in Table I that the major cation in the ground water is calcium and the major anions are bicarbonate and sulfate.

Of the total 39 ground-water samples collected, 15 were sent to Skyline Labs, Inc. of Denver to be analyzed for uranium content. The majority of the samples contained less than 2 ppb U (the detection limit of the analysis). Two of the samples contain 4 ppb U and one other had 3 ppb U. No relationship could be inferred between the uranium content and Eh, pH or any chemical component of the water.

TABLE I

SUMMARY OF GROUND-WATER ANALYSES*

Analysis	Range	Average
Uranium**	2-4	--
Sodium	0.9-41	15.1
Silica	3-15	8.3
Pottassium	0.1-45.1	4.2
Calcium	4.1-253	86.8
Magnesium	0.4-45.1	12.3
Sulfate	6-650	89.2
Chloride	0-46.2	11.6
Bicarbonate	12-531	236.5
Carbonate	0	0

*Complete values in Tables VI and VII in Appendix.

**Uranium values are ppb; all others are in ppm.

The distribution of uranium in the aquifer does not show a pattern which could be related to a geochemical halo around an area of mineralization (see Figure 19). The Eh and pH of the samples plot in the field of uranyl dicarbonate (see Figure 20). The average concentration of carbonate in the ground water (assuming a closed system) is $5.9\text{x}10^{-3}$M. As the amount of carbon dioxide in the system increases, Hostetler and Garrels (1962) and Listitsin (1962) have shown that the solubility of uranium increases. Hostetler and Garrels (1962) have also shown that the uranly dicarbonate complex is the major ionic form when the total CO_2 content is less than $10^{-3.8}$M. The physical and chemical conditions in the ground water are favorable to the transportation of U^{6+} in the uranyl dicarbonate complex.

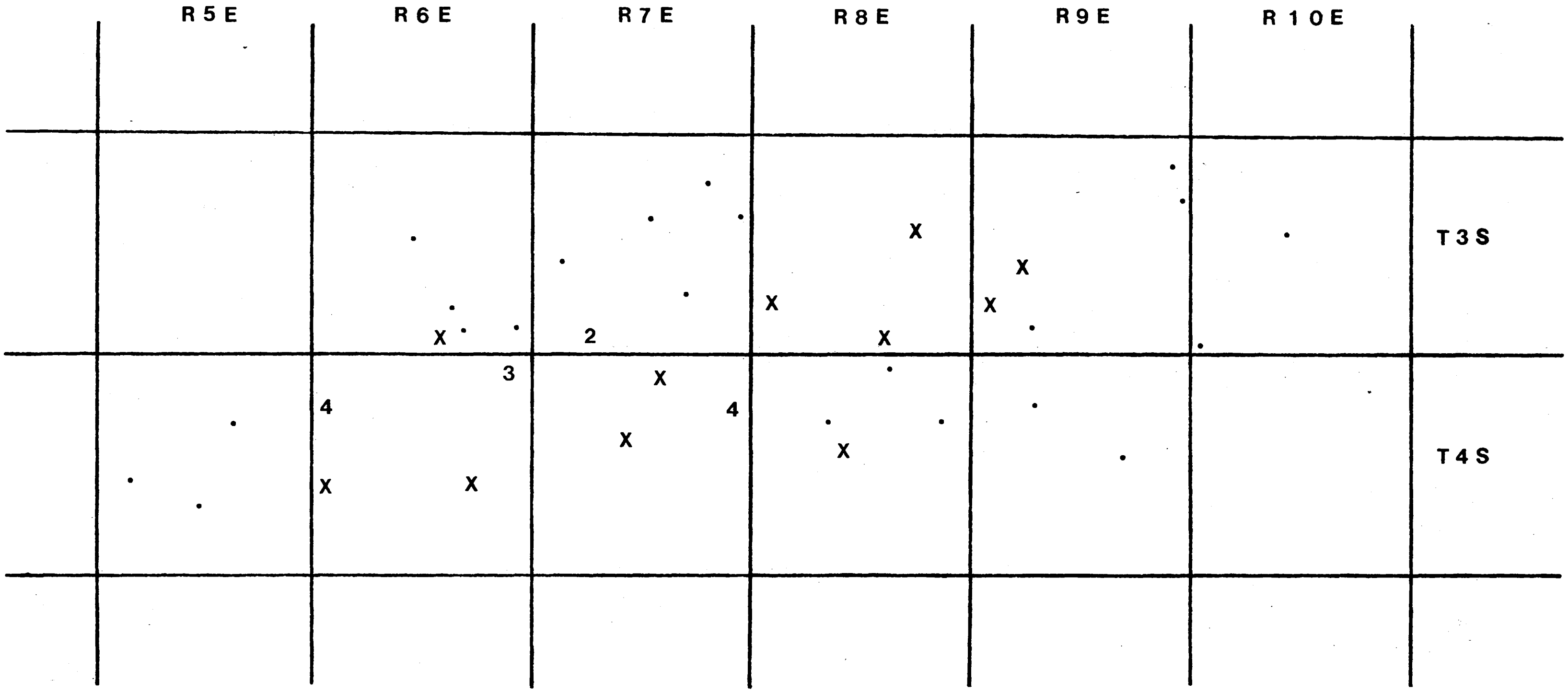

Figure 19. Map Showing Location of Wells Sampled for Hydrogeochemistry. X Marks Sites of Uranium Analyses Less Than 2 ppb Whereas Numbers Indicate Uranium Values in ppb.

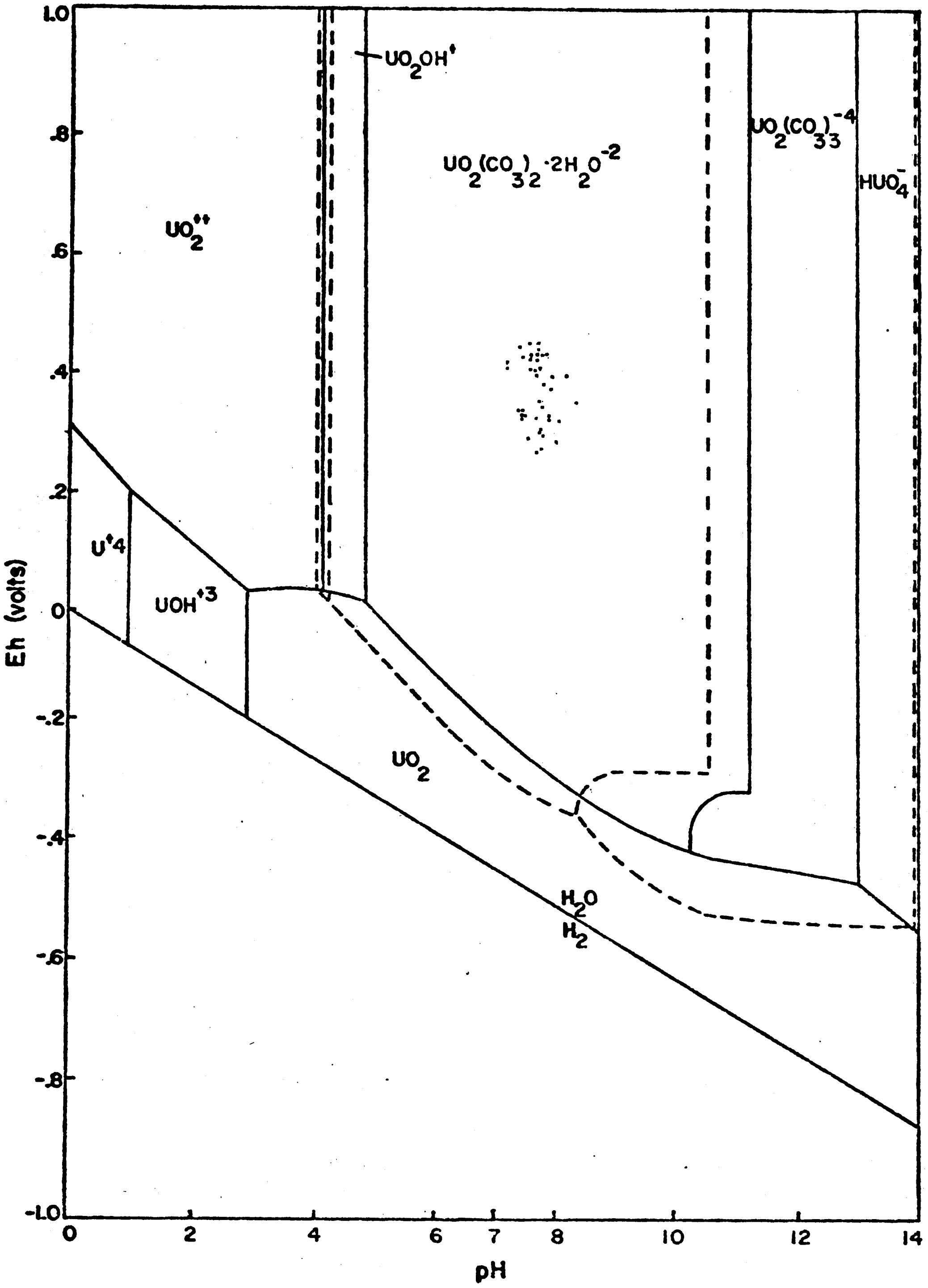

Figure 20. Aqueous Equilibrium Diagram for $U-O_2-H_2O-CO_2$ System With Total $CO_2 = 10^{-3}$ M. Dashed Lines Show Boundaries for the System With Total $CO_2 = 10^{-2}$ M. Modified From Hostetler and Garrels (1962).

CHAPTER VI

SUMMARY AND CONCLUSIONS

The study's principal objective was to locate areas of uranium mineralization in the Antlers sandstone south of the Belton-Tishomingo uplift. A survey of the literature revealed several lines of evidence to select this area as a possible host rock for uranium. The sandstone rests unconformably on a granite source area with an arkosic conglomerate at the contact; the granite, which contains 1.7-4 ppm uranium, has been shown to release 50% of the uranium during weathering (Harriss, 1965; Harriss and Adams, 1966). There are reports in the literature of uranium mineralization and anomalies in the study area. The predominant drainage and the dip of the piezometric surface is to the south from the recharge area, in the same direction as the dip of the Antlers the depositional environment of the Antlers as reported in the literature is marginal marine, similar to Tertiary deposits in south Texas where uranium is mined. Finally, the presence of asphalt deposits indicates the presence of a reducing environment to precipitate uranium minerals.

Carborne and airborne radiometric surveys of the area were unable to locate any new areas of surface mineralization. The previously reported anomalies were carbonized wood and test pits in these areas did not locate any larger, economic mineralized zone. Geochemical analysis of the ground water showed that low level concentrations

(2-4 ppb) of uranium were present. The Eh-pH of the water samples indicated that the conditions in the water were favorable for transporting U^{6+} in solution in the form of uranyl dicarbonate. The oxidizing environment of the ground water is considered unfavorable for the formation of uranium mineralized zones and the low levels of uranium tend to minimize the possible existence of an older deposit which is currently being oxidized.

However, in measuring sections and investigating asphalt deposits for possible uranium association, a wide-spread zone of asphalt mineralization was located at the top of the Antlers section, just below the Goodland-Walnut contact. Several hypotheses for the origin of these deposits were investigated. The only reasonable explanation for the origin of these deposits is that there is a fault in the Antlers related to the Washita Valley fault-complex zone approximately ten miles south of the present Goodland-Walnut--Antlers contact. This penecontemporaneous fault formed a zone of secondary permeability, allowing hydrocarbons to seep through the Antlers, where it was confined by the overlying strata, then moved up-dip where the lighter fraction evaporated and escaped, leaving behind an asphaltite residue. The fault movement may have been a tectonic adjustment to the 600 to 700 ft thick sediments in this area and is not reflected in the Goodland-Walnut since the rate of sediment accumulation decreased by the time the limestone was deposited.

Sometime after this fault formed, uraniferous ground water moved down-dip to the fault zone and the reducing conditions associated with petroleum seeps. Here, the uranium would be reduced from U^{6+} to U^{4+} state and be deposited as uraninite, coffinite or similar minerals.

Uranium deposits and anomalies associated with petroleum seeps have been studied in south-central Oklahoma (Olmsted, 1971) and the only uranium mine in Oklahoma, near Cement, is associated with a seep along a fold-related fracture.

It is the conclusion of this report that there is a significant possibility that a uranium deposit exists in the subsurface, as yet undetected. Since the deposit would be at the most several hundred feet deep, a drilling exploration program in this area would be relatively inexpensive and has the potential of locating an economic deposit of uranium mineralization.

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APPENDIXES

TABLE II

URANIUM ANALYSIS OF SUBSURFACE EASTERN ARBUCKLE GRANITES

Location	Depth (ft)	Uranium (ppm)
19-2N-3E	6200-6290	4
25-1S-4E	344-3459	2
27-3N-5E	4795-4807	2
27-1N-5E	3224-3262	2
31-2N-7E	8740-8775	2
34-2S-8E	90-740	2
25-3S-9E	580-1178	2
1-7S-9E	6050-7730	2
9-7S-10E	4560-5430	2
9-7S-10E	6010-7730	2

After Al-Shaieb et al. (1977)

TABLE III

LOCATION OF ASPHALT DEPOSITS IN THE STUDY AREA

Location	Description*
S½-SE Sec. 36 T3S R4E	In Antlers sandstone and conglomerate
S½-SW Sec. 31 T3S R5E	" " " " "
SW-NW Sec. 1 T4S R4E NE " " " "	Quarried asphalt pit in Antlers; 75 x 100 ft, 5 samples-bitumen 7.8-11.9 %
NW Sec. 6 T4S R5E	Quarried asphalt pit in Antlers
E½-NE Sec. 14 " "	In Antlers conglomerate 4-5 % bitumen
SE Sec. 19 T4S R6E SW Sec. 20 " "	Prospected Antlers sandstone; 6-8 ft deep, 20 x 50 ft, 6.5-8.4 % bitumen
SW-SE Sec. 27 T4S R8E	At limestone contact in creek bed
SW " " " "	Antlers sandstone 250 x 105 yd. outcrop
NW-SE Sec. 29 " "	At limestone contact; quarried near farm pond
SW-NE " " " "	In creek bed below limestone contact
NE-SE Sec. 24 T4S R9E	At limestone contact, Maytubby Springs
SE Sec. 2 T5S R7E	Prospected Antlers sandstone and conglomerate
NE-NE Sec. 4 " "	Antlers sandstone outcrop 400 ft by 4.5 ft thick.
NW-NW Sec. 3 T5S R8E	In bed of Horse Creek below limestone contact

*Modified after Jordan (1964)

TABLE IV

CLAY MINERALOGY OF ANTLERS SAMPLES

Sample No.	Location	Smectite*	Illite (001)	Illite-Mica	Kaolinite	Illite (002)
C-1	NE Sec. 32 T3S R8E	15-17.3-10	10	9.1	7.14	--
5	SE Sec. 35 T3S R8E	14.7-?-10	10	--	7.14	5.0
6	NW Sec. 12 T4S R8E	15-17.3-10	10	8.67	--	5.6
7	" "	15.2-17.7-10	10	--	7.14	5.0
8	NW Sec. 31 T4S R9E	15.2-17-10	--	8.58	7.14	--
9	" "	15-16.4-10	--	--	--	4.5
10	SW Sec. 2 T4S R8E	14.7-17.7-10	10	--	--	--
11	NW Sec. 26 T3S R8E	14.7-17-10	--	8.4	7.14	--
12	SW Sec. 22 T3S R8E	14.7-16.5-10	10	8.4	7.14	5.0
13	SW Sec. 21 T3S R8E	14.7-17-10	10	--	7.14	--
14	NE Sec. 29 T3S R8E	14.7-17-10	10	--	7.14	--
15	NE Sec. 30 T3S R8E	14.7-17.7-10	10	--	7.14	--
16	SW Sec. 24 T3S R7E	14.2-16-10	10	--	7.14	--

TABLE IV (Continued)

Sample No.	Location	Smectite	Illite (001)	Illite-Mica	Kaolinite	Illite (002)
C-17	NW Sec. 26 T3S R7E	14.2-17-10	10	--	7.14	--
18	SE Sec. 20 T3S R7E	14.2-17-10	10	--	7.14	--
19	NW Sec. 5 T4S R7E	14.7-17-10	10	--	7.14	--
20	SE Sec. 1 T4S R6E	15-16.4-10	10	--	7.14	--
S-2	NE Sec. 5 T4S R6E	--	--	--	7.14	--
3	" "	?-17.7-10	10	--	7.14	--
4	" "	15.2-17.7-10	10	--	7.14	--
5	" "	15.2-17-10	10	--	7.14	--
6	" "	15-16.4-10	10	--	7.14	5.0
Ka-6	NW Sec. 14 T4S R7E	15.5-17.7-10	--	--	7.14	--
201	NE Sec. 16 T4S R7E	14.7-17-10	10	--	7.14	--
302	NE Sec. 15 T4S R6E	14.7-17-10	10	--	7.14	--
315	SW Sec. 16 T4S R7E	15.2-17-10	10	--	7.14	5.0
401	SW Sec. 22 T4S R8E	16.4-16.7-10	--	--	7.14	--

TABLE IV (Continued)

Sample No.	Location	Smectite	Illite (001)	Illite-Mica	Kaolinite	Illite (002)
Ka-403	SE Sec. 20 T3S R7E	MLC-?-10	--	--	--	--
612	NE Sec. 30 T4S R10E	15.2-17-10	--	8.5	--	--
616	NW Sec. 13 T4S R6E	--	10	--	7.14	--
620	SE Sec. 35 T3S R8E	15.2-17-10	10	--	7.14	--
X-5	NE Sec. 14 T4S R7E	15.2-17-10	--	--	7.14	--
X-6A	SW Sec. 4 T5S R7E	15.2-17-10	10	--	7.14	--
As-1	SW Sec. 14 T4S R7E	15.2-16.1-10	--	--	7.14	--

*All peaks are expressed in angstroms and the three values under smectite are respectively for the untreated sample, the glycolated sample and the heated sample.

TABLE V

WATER WELL SAMPLE LOCATIONS

Sample No.	Location	Aquifer
Jn- 2	NW NW Sec. 16 T4S R 7E	Antlers
3	SW NE Sec. 23 T4S R 6E	"
4	NW SE Sec. 3 T4S R 7E	"
5	SW NW Sec. 12 T4S R 7E	"
6	SW SE Sec. 32 T3S R 7E	"
7	SE SW Sec. 34 T3S R 6E	"
8	NW NE Sec. 7 T4S R 6E	"
9	NW SW Sec. 1 T4S R 6E	"
10	NE NE Sec. 19 T4S R 6E	"
11	SE SE Sec. 30 T3S R 8E	"
12	NE SE Sec. 14 T3S R 8E	"
13	NE NE Sec. 34 T3S R 8E	"
14	SW NW Sec. 16 T3S R 8E	"
15	SE SW Sec. 12 T4S R 8E	"
16	NE NE Sec. 3 T4S R 8E	"
17	SE SW Sec. 9 T4S R 8E	"
18	SE NE Sec. 11 T3S R 7E	"
19	SW NW Sec. 35 T3S R 5E	"
20	NE SE Sec. 10 T4S R 5E	"
21	NW NW Sec. 24 T4S R 4E	"
22	SW SE Sec. 15 T4S R 4E	"
23	SE NE Sec. 19 T4S R 5E	"
24	NW SE Sec. 21 T4S R 5E	"
25	SE SE Sec. 27 T3S R 6E	"
26	SE SE Sec. 16 T3S R 6E	"
27	NW NW Sec. 15 T3S R 7E	"

TABLE V (Continued)

Sample No.	Location					Aquifer
Jn-28	NE NE	Sec.	19	T3S	R 7E	Antlers
29	NE NE	Sec.	36	T3S	R 6E	"
30	SE NE	Sec.	13	T3S	R 7E	"
31	SW NW	Sec.	26	T3S	R 7E	"
At- 1	SW SE	Sec.	20	T3S	R 9E	(?)
2	NW NE	Sec.	30	T3S	R 9E	Antlers
3	SW SE	Sec.	1	T3S	R 9E	"
4	SE SE	Sec.	12	T3S	R 9E	"
5	NE NE	Sec.	32	T3S	R 9E	"
6	SW SW	Sec.	31	T3S	R10E	"
7	SW SE	Sec.	16	T4S	R10E	"
8	SW SW	Sec.	14	T4S	R 9E	"
9	SE NE	Sec.	8	T4S	R 9E	"

TABLE VI

URANIUM ANALYSES OF GROUND-WATER SAMPLES

Sample No.		Eh (mv)	pH	U (ppb)	Location
Jn	2	284	7.6	2	NW NW Sec. 16 T4S R7E
"	3	324	7.7	2	SW NE Sec. 23 T4S R6E
"	4	334	7.6	2	NW SE Sec. 3 T4S R7E
"	5	339	7.2	4	SW NW Sec. 12 T4S R7E
"	6	344	7.3	2	SW SE Sec. 32 T3S R7E
"	7	334	7.3	2	SE SW Sec. 34 T3S R6E
"	8	344	7.8	4	NW NE Sec. 7 T4S R6E
"	9	324	7.9	3	NW SW Sec. 1 T4S R6E
"	10	254	7.8	2	NE NE Sec. 19 T4S R6E
"	11	294	7.5	2	SE SE Sec. 30 T3S R8E
"	12	294	8.0	2	NE SE Sec. 14 T3S R8E
"	13	279	7.6	2	NE NE Sec. 34 T3S R8E
"	14	314	7.6	2	SW NW Sec. 16 T3S R8E
At	1	324	7.6	2	SW SE Sec. 20 T3S R9E
"	2	339	7.8	2	NW NE Sec. 30 T3S R9E

TABLE VII

CHEMICAL ANALYSES OF GROUND-WATER SAMPLES

Sample No.	Na	Si	K	Ca	Mg	$SO_4^{=}$	Cl^-	HCO_3^-	$CO_3^{=}$
Jn- 2	24.5	15	0.9	62.0	11.4	60	10.7	214	--
3	4.0	8	1.1	48.4	3.8	10	0	165	--
4	9.1	10	2.3	20.1	3.1	60	10.7	30	--
5	23.9	8	2.3	135.7	22.1	154	8.9	390	--
6	18.1	9	3.5	142.6	27.3	400	21.3	98	--
7	9.8	9	1.2	43.0	4.6	56	3.6	110	--
8	32.9	11	1.8	164.0	27.2	164	35.5	445	--
9	13.9	8	1.2	150.6	14.4	96	3.6	470	--
10	4.9	11	2.0	93.2	10.3	30	5.3	323	--
11	16.3	10	2.5	58.6	6.4	124	23.1	67	--
12	3.3	4	2.4	117.1	16.2	72	0	366	--
13	39.4	5	4.8	58.0	14.3	82	39.0	189	--
14	1.5	8	0.1	30.5	1.4	22	19.5	43	--
15	3.5	13	2.4	6.1	0.4	28	10.7	12	--
16	24.3	11	2.8	9.7	1.7	50	7.1	30	--
17	18.6	12	11.9	118.8	25.5	320	17.8	116	--
18	0.9	3	2.7	43.7	2.64	10	33.7	73	--
19	2.3	6	0.3	137.9	31.6	32	46.2	500	--
20	13.7	7	2.6	114.3	45.1	76	12.4	512	--
21	24.4	8	2.2	191.7	26.5	166	8.9	451	--
22	27.1	10	0.8	152.0	3.7	32	14.2	518	--

TABLE VII (Continued)

Sample No.	Na	Si	K	Ca	Mg	$SO_4^=$	Cl^-	HCO_3^-	$CO_3^=$
Jn-23	6.8	7	1.4	86.3	7.5	50	5.3	250	--
24	3.3	12	23.7	54.2	4.4	30	8.9	140	--
25	41.0	7	9.5	253.0	31.6	650	3.6	238	--
26	5.0	8	0.5	122.9	23.5	30	16.0	439	--
27	41.0	5	45.1	86.7	8.2	148	12.4	207	--
28	3.0	6	0.1	16.4	0.8	30	0	18	--
29	29.7	10	1.4	74.1	6.8	134	17.8	134	--
30	18.9	7	0.5	57.3	5.1	96	7.1	134	--
31	21.5	12	0.4	55.0	3.4	42	10.7	171	--
At- 1	7.0	5	0.8	119.4	12.9	12	0	445	--
2	8.6	4	1.7	22.7	1.5	10	7.1	73	--
3	22.6	7	3.4	85.4	3.1	46	7.1	262	--
4	24.5	4	2.1	123.6	13.6	60	3.6	445	--
5	9.7	9	18.1	119.4	29.3	18	3.6	531	--
6	9.1	10	0.7	4.1	0.6	6	3.6	18	--
7	1.4	5	1.6	82.9	4.8	10	0	274	--
8	6.3	10	2.0	42.3	31.7	46	7.1	274	--
9	4.3	8	1.0	32.7	5.6	18	7.1	55	--
Average values in ppm									
	15.1	8.3	4.2	86.8	12.3	89.2	11.6	236.5	0

VITA

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