GEOCHEMICAL STUDIES OF URANIUM

IN SOUTH-CENTRAL OKLAHOMA

By

RICHARD WARREN OLMSTED

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Thesis Approved:

Zuhair al-Shaieb
Thesis Adviser

John D. Naff

Robert O. Fay

John E. Stone

N N Durham
Dean of the Graduate College

PREFACE

Hydrogeochemical prospecting methods, gamma ray logs and car-borne scintillometer surveys, are used in this study to delineate zones of radioactive mineralization in south-central Oklahoma. Ore controls responsible for these radioactive deposits are discussed and a hypothesis, dealing with the formation of ore deposits found in the study area, is proposed. Petrographic analyses of potential host rocks are used to illustrate the relationship between radioactive occurrences and host rock lithologies. Other uranium occurrences throughout the state also are described and a discussion of potential sources of radioactive minerals in Oklahoma is presented.

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TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

TABLE OF CONTENTS (Continued)

LIST OF FIGURES

CHAPTER I

ABSTRACT

Hydrogeochemical anomalies were used to delineate areas of potential uranium mineralization in south-central and southwestern Oklahoma. Many of the anomalies were localized along or near the axes of major oil-producing structural trends which displayed bleaching of Permian red beds. This bleaching was caused by vertically migrating hydrocarbons which reduced ferric iron to the more soluble ferrous state, resulting in its removal by ground waters. The alteration was restricted mainly to the sandstone intervals of the overlying formations. Over one leaking reservoir altered rocks were found to a depth of 2,500 feet.

Structural, stratigraphic, and petrographic studies were conducted in areas where geochemical anomalies were found associated with red-bed alteration. At Cement, Oklahoma reduction of sulfates (gypsums) and associated uraniferous solutions by migrating hydrocarbons resulted in the precipitation of uranium and calcium carbonate. The uranium mineralization was associated with a zone characterized by diagenetic carbonate (normal carbon and oxygen isotopes), indicating that the uranium was transported into the ore zone by ground water moving upward along the flanks of the structure.

Radioactivity was indicated by a study of gamma ray logs of the Rush Springs and Chickasha Formations at Cement and of the Duncan Sandstone at Cox City, Oklahoma. At Cox City the subsurface anomalies

coincided with a fault which is thought to have been a major conduit for migrating hydrocarbons.

The mineralized zones in south-central Oklahoma occur in fine- to very fine-grained subarkoses. Petrographic analyses of the host rocks indicate that the sources of the uranium were granites and rhyolites in the Arbuckle and Wichita Mountains.

Geochemical studies of surface and subsurface mineralization along the oil-producing structures at Cox City, Cement and along the Red River, indicate that other areas in south-central Oklahoma should be investigated for radioactive mineralization. Oil-producing structures in southern Oklahoma having red-bed alteration such as West Cement, Chickasha, Velma-Cruce, Eola, and Healdton should be studied for future uranium exploration. In addition, arkosic materials in the western part of the study area which were derived from the Wichita Mountains, should be evaluated where the arkoses overlie oil reservoirs or subsurface structural features.

CHAPTER II

INTRODUCTION

Recent shortages of oil and natural gas have made us aware of the need for additional sources of energy. Of the numerous possible alteratives, nuclear energy is being considered as one of the principal fuel sources of the future. As a result, the demand for uranium has climbed steadily and, if present trends continue, our nation's future uranium requirements probably will not be met by merely finding new ore bodies in previously discovered mining districts. The necessity of discovering new uranium deposits and new mining districts will, therefore, be imperative.

Exploration programs conducted during the mid-nineteen fifties resulted in the discovery of numerous radioactive deposits in the Permian red beds of central and western Oklahoma. Although most of these deposits did not contain uranium in sufficient concentrations to be of economic value, a discovery in the town of Cement did have limited commercial success. These radioactive occurrences are a reason that extensive exploration efforts should be initiated for the purpose of evaluating the uranium potential of Oklahoma.

Purpose and Methodology

This study was undertaken for the purpose of locating and evaluating new areas of uranium mineralization using certain geologic and geochemi-

cal parameters. Data obtained from ground-water and radiometric investigations was used to delineate areas where additional exploration might be initiated.

The uranium potential of a portion of south-central and southwestern Oklahoma was evaluated by means of a study consisting of three sequential phases. The first phase consisted of ground-water sampling on a regional scale for reconnaissance purposes. Although most of the ground water was collected from private wells, stock and municipal wells also were tested. Samples were collected in 8 ounce polyethylene containers. Concentrated nitric acid was then added to each sample until a pH of 2 was obtained for the solution. The samples were shipped to a geochemical laboratory in Denver, Colorado where the uranium content of each sample was determined fluorometrically. The fluorometric method is capable of detecting uranium concentrations as low as 2 ppb. Forty-eight untreated samples were collected during the reconnaissance phase for the purpose of measuring the redox potential (Eh) and the pH of the solutions.

The second phase involved detailed water sampling in those areas which contained geochemical anomalies. Radiometric surveys in the anomalous areas were also conducted at this time. A Precision Model 118 Royal Scintillator, with a 1 3/4 x 1 inch sodium iodide crystal was used for the radiometric studies.

The third and final phase involved a detailed structural and stratigraphic evaluation of the radioactive deposits. Petrographic studies of the host rocks augmented these evaluations. Parameters established during this phase were used to formulate models of the primary ore controls.

Area of Investigation

The study area (Fig. 1) covers all or parts of 11 counties in south-central and southwestern Oklahoma. Included are Carter, Comanche, Cotton, Jefferson, Stephens, and Tillman Counties, along with parts of Caddo, Garvin, Grady, Love, and Murray Counties. The area extends from near the Washita River on the north to the Red River on the south and from the northwest end of the Arbuckle Mountains westward to the western end of the Wichita Mountains. The Anadarko-Ardmore basin and the Wichita-Criner Hills uplift trend west-northwestward through the central part of the study area.

Two major highway systems connect with numerous state and local highways throughout southern Oklahoma. The H. E. Bailey Turnpike extends diagonally through the western half of the study area and from it the cities of Lawton, Chickasha, and Duncan are readily accessible. Interstate Highway 35 stretches along the eastern boundary of the study area, passing near the city of Ardmore, which is located just outside the area of investigation.

The mean annual temperature in southern Oklahoma is in the middle to lower sixties, with winter extremes in the upper teens and twenties and summer highs of over 100°F. Annual precipitation varies from an average of 34 inches per year in the eastern portion of the study area to 26 inches per year in the extreme southwestern part of the area of investigation.

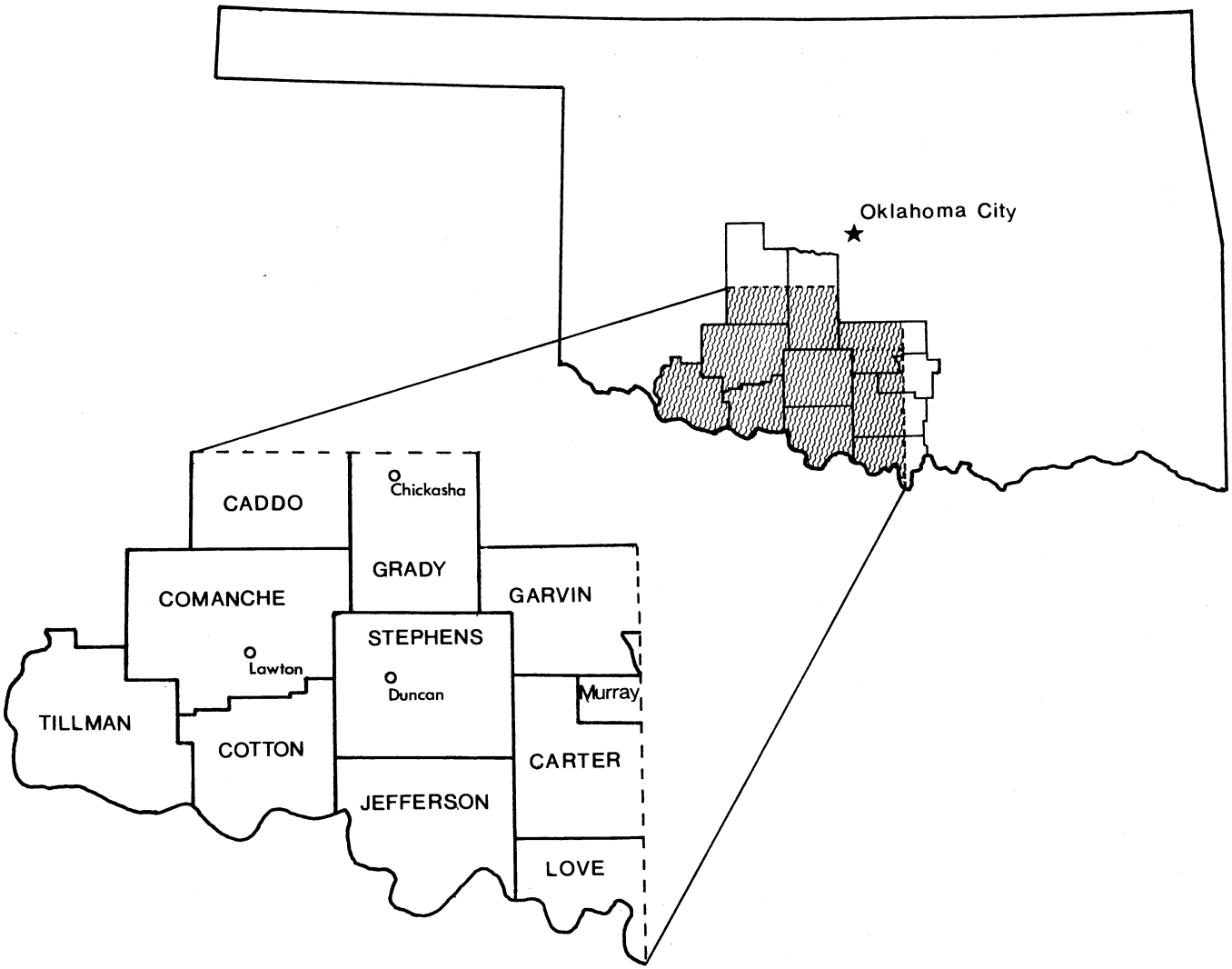

Fig. 1.-Index map of the study area

CHAPTER III

URANIUM GEOLOGY

Most of the uranium production in the United States is from ore deposits in sandstone and related sedimentary rocks. This chapter summarizes information concerning the general characteristics of these deposits and includes descriptions of the numerous deposits found throughout Oklahoma.

United States

Over 90 per cent of the uranium reserves of the United States are located in four western states. New Mexico has 49.50 per cent of our total reserves, Wyoming accounts for 35.03 per cent, Colorado has 3.05 per cent, and Utah has 2.94 per cent (Guccione, 1974). Much of the remaining reserves are in deposits located along the Texas Gulf Coast, in the Black Hills region of South Dakota, and in northeastern Arizona.

Although a small amount of uranium is produced from igneous and metamorphic rocks, virtually all the major uranium deposits occur in sandstone beds or lenses interbedded with siltstones and shales. The sandstone "host" formed either in intermontane basins, on broad alluvial fans, or on coastal plains. Typically it is a fine- to coarse-grained sandstone. Feldspars are a common constituent of many hosts and in some beds they are so abundant that the rock can be classified as an arkose (Finch, 1967). Volcanic ash occurs commonly within the host, but it

mostly is found in the sediments which immediately overlie the deposit. Coalified plant material is associated with almost all the deposits, perhaps causing reducing conditions within the sand body (Fischer, 1974).

In addition to the above characteristics, the geologic age of the host also is an important feature. Uranium minerals occur throughout the United States in rocks of every geologic system except Silurian (Finch, 1967). However, most of the large ore bodies occur in sandstones which range in age from Late Triassic (Colorado Plateau) through Eocene (Texas Gulf Coast).

The geochemistry of uranium plays a significant part in the formation of an ore deposit. In high silica granitic and volcanic rocks uranium occurs as the tetravalent uranous ion (U^{+4}). It may substitute for other tetravalent cations in the accessory minerals of the rock or it may occur as a film upon the surfaces of the major minerals in the form of the insoluble oxide uraninite (UO_2) (McKelvey, Everhart, and Garrels, 1955).

Upon exposure of the granitic materials to surface conditions, the U^{+4} ion is oxidized to the uranyl ion $(U^{+6}O_2)^{++}$. The oxidized cation is capable of forming both soluble complexes and insoluble compounds, depending upon the nature of the circulating solutions. Elements commonly not found in natural waters, such as phosphorus, vanadium, and arsenic, will combine with the ion to form slightly soluble uranium minerals, the most prominent being carnotite $[K_2(UO_2)_2(VO_4)_2 \cdot 1\text{-}3H_2O]$. However, the two primary dissolved constituents of natural waters, carbonate and sulfate, readily form soluble uranium complexes which may be carried away in solution. Under normal oxidizing conditions, therefore, uranium quickly enters circulating ground water and the uranium

solubility will be dependent upon the sulfate and total carbonate content of the system (McKelvey, Everhart, and Garrels, 1955).

It is believed that the primary source of uranium may have been the volcanic ash associated with the host or a nearby granitic body which has undergone extensive weathering. The uranium which has been leached by meteoric waters moves down-dip along more permeable sandstone beds. It has been precipitated from solution in places where adequate reducing conditions prevail. The uranium occurs primarily as pore fillings but also may be found replacing individual sand grains.

Reducing agents responsible for the localization of uranium include fossil plants, humic materials, unstable sulphur compounds, and H_2S generated by bacteria (Fischer, 1974).

In addition to the above reducing agents, H_2S seeping from subsurface oil pools is believed to have aided in the deposition of uranium in some Gulf Coast deposits. Sour gas from subsurface reservoirs is believed to have migrated vertically along normal faults located near the oil pools and, upon entering water-saturated sandstones, to have precipitated uranium from solution. This mechanism, however, has come under recent criticism (Bunker and MacKallor, 1973).

A conspicuous feature of many ore deposits is the coloration change which occurs in and around areas of uranium mineralization. In many instances beds which normally display a reddish coloration are altered in the mineralized area to lighter shades of brown, yellow, gray, or white. The coloration changes are significant because they outline zones of oxidation and reduction.

Uranium ore bodies exist in a variety of shapes and sizes. They may occur as peneconcordant deposits, having their long dimensions near-

ly parallel to the stratification of the host (Finch, 1959), or they may occur as vein-type deposits, forming along faults and fractures which cut across bedding planes (Finch, 1967).

Most of the uranium produced in the United States is mined from tabular and pod-like "roll" ore bodies. The roll-type deposit accounts for most of the ore currently being mined in the Tertiary basins of Wyoming, the Black Hills region, and the Texas Gulf Coast. The rolls are crescent shaped in cross section with their axial plane lying nearly parallel to the bedding of the host. The concave side of the roll is generally sharp, contains the highest concentration of ore and is on the up-dip side of the ore body. The rolls occur along crescent shaped interfaces between altered or oxidized sandstone on the concave side and unaltered or unoxidized sandstone on the convex side.

Most of the uranium production in the Colorado Plateau region has come from tabular ore deposits. The ore is concentrated into masses which lie nearly parallel to the host sandstone bedding, but do not follow the beds in detail. The deposits average a few feet in thickness and range up to hundreds of feet across. The tabular deposits are irregular in plan view, but have a tendency to be elongate in the direction of the long axis of the host (Fischer, 1974).

Oklahoma

Although this paper deals primarily with sandstone-type uranium deposits, radioactive anomalies have been reported throughout Oklahoma in numerous other geologic environments. Uranium has been discovered in marine black shales, asphaltic sandstones, carbonaceous nodules, and Cambrian igneous rocks. In addition, the presence of helium and radon

in some oil and gas wells (Pierce, Mytton, and Gott, 1956; Pierce, Gott, and Mytton, 1964) and the high uranium content of some petroleum ashes (Hyden, 1956; Hyden and Danilchik, 1962) are further indications of possible mineralization. Anomalous uranium concentrations also have been reported for ground and surface waters at several localities throughout the state (Landis, 1960; Scott and Barker, 1962).

Marine Shales

Middle Paleozoic marine black shales containing anomalous concentrations of uranium have been found in parts of eastern Oklahoma. Landis (1958) and Swanson (1960) examined several radioactive samples from the Devonian Chattanooga Shale in northeastern Oklahoma. Uranium values for the shale ranged from 0.001 to 0.007 per cent, with one locality in Cherokee County having 0.005 per cent uranium in an interval 10 feet thick.

In the Arbuckle Mountains region of southern Oklahoma the Woodford Shale, a correlative of the Chattanooga Shale, and the Mississippian Delaware Creek Shale* were found to be anomalously radioactive. The uranium content of several Woodford samples ranged from 0.001 to 0.014 per cent, with a modal value of 0.001 per cent uranium (Landis, 1958). Samples collected from the Delaware Creek Shale ranged from less than 0.001 to over 0.002 per cent uranium (Patrick and Ham, 1969).

Hyden and Danilchik (1962) sampled several Pennsylvanian black shales in the Krebs, Cabaniss, and Marmaton Groups of northeastern Oklahoma. Most of the carbonaceous shales contained 0.001 per cent

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*Formerly Caney Shale. See Hart (1974).

uranium or less, with phosphatic shales having a higher concentration of uranium. The phosphatic shales averaged approximately 0.003 per cent U_3O_8. The Excello Member of the Senora Formation, a phosphatic shale, was sampled in detail and results show an equivalent uranium content of 0.003 to 0.004 per cent.

Asphaltic Sandstones

Asphalt deposits in sandstones of Ordovician, Pennsylvanian, and Permian ages crop out in southern Oklahoma. Although most of these asphaltic sandstones do not have anomalous concentrations of uranium, selected samples from the Sulphur, Cameron (T.2N., R.12W.), and Ada areas did contain between 0.002 and 0.22 per cent uranium in the ash of the extracted oil (Hail, 1957).

Carbonaceous Nodules

Carbonaceous nodules discovered along the northern flanks of the Wichita uplift (Hill, 1957) were found to contain above normal concentrations of uranium. Three nodules collected in the NE¼, Sec. 30, T.6N., R.14W. contained 2.36, 9.38 and 3.58 per cent uranium in the ash of the extracted oil. Five other samples collected from nearby areas, however, did not have a uranium content in excess of 0.002 per cent. Most of the uraniferous nodules ranged from one to five millimeters in diameter and were associated with petroliferous rocks of Permian age.

Granitic Vein Deposits

A two-to three-inch wide vein containing traces of uranium and thorium was discovered on the north side of Osage Lake in the SE¼, Sec.

22, T.3N., R.14W. (Dale and Beach, 1951; United States Atomic Energy Commission, 1968). The vein, which occurs in a Cambrian granite, contains 0.002 per cent uranium with 0.17 per cent thorium. The radioactive minerals are associated with zircon crystals.

Sandstone Deposits

Uranium deposits in sandstone have been known in the Upper Paleozoic red beds of western Oklahoma since the late nineteen-forties. According to Beroni (1956) uranium was first discovered in a sandstone lens on the Staneart property (Lee D. Uto prospect) in Sec. 8, T.22N., R.4E. in Pawnee County. The uranium bearing materials were found in a channel deposit in the Upper Pennsylvanian Oscar Group*. The radioactive minerals were associated with carbonaceous materials including wood fragments and logs. The sulfide minerals pyrite, chalcopyrite, and chalcocite, in association with calcite, fluorite, and dolomite, were also found in the carbonaceous materials. Secondary uranium minerals in the deposit included uranophane $[Ca(UO_2)_2Si_2O_7 \cdot 6H_2O]$ and carnotite $[K_2(UO_2)_2(VO_4)_2 \cdot 1\text{-}3H_2O]$, along with the copper minerals malachite, and azurite. Selected samples from the deposit had a uranium content of 0.002 to over 1.00 per cent U_3O_8 (Beroni, 1956).

During the nineteen-fifties several radioactive deposits were discovered in the Red River area of southwestern Oklahoma. The largest deposit was found in Cotton County south of Randlett, Oklahoma in the SW¼, Sec. 30, T.5S., R.12W. (Chase, 1954). Small amounts of uraninite

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*The Oscar Group is here considered as Upper Pennsylvanian in age in accordance with the classification of the Oklahoma Geological Survey.

(UO_2), galena, pyrite, and chalcopyrite were found associated with woody fragments in the lower two to four feet of a channel sandstone 25 feet thick. The deposit, which is in the Permian Garber Sandstone, also contained torbernite, [$Cu(UO_2)_2(PO_4)_2 \cdot 8\text{-}12H_2O$] autunite [$Ca(UO_2)_2(PO_4)_2 \cdot 10\text{-}12H_2O$], uranophane, carnotite, and bayleyite [$Mg_2(UO_2)(CO_3)_3 \cdot 18H_2O$], along with malachite, and azurite. Analyses of selected samples from the deposit revealed a uranium content of from 0.014 to 2.140 per cent eU (United States Atomic Energy Commission, 1968).

In western Jefferson County in the SE¼, Sec. 7, T.5S., R.8W. anomalous radioactivity was reported on a 0.5- to 1.5-foot reddish-brown sandstone lens (Chase, 1954). No radioactive readings were recorded for the deposit, but anomalous radioactivity was reported a short distance away, on ferruginous sandstone "float" resting upon blue-gray shales (United States Atomic Energy Commission, 1968). A 0.5-pound sample of the fine-grained, well cemented sandstone contained 0.052 per cent eU_3O_8. A similar report of anomalous radioactivity on sandstone "float" material was made in the NE¼, Sec. 1, T.5S., R.9W.

Several other minor anomalies have been reported in Cotton and Jefferson Counties (Plate 1). The deposits generally are found in sandstone lenses interbedded with red shales and siltstones. No visible uranium minerals have been described in these areas where the radioactivity is generally three to four times a normal background of 0.025 MR/HR. The anomalies are frequently associated with carbonaceous materials or bituminous residue and secondary copper minerals are a frequent constituent of the deposits (United States Atomic Energy Commission, 1968).

Two radioactive anomalies were reported in the Post Oak Conglomer-

ate east of Manitou in Sec. 34, T.1N., R.15W. and Sec. 1, T.1S., R.16W. (United States Atomic Energy Commission, 1968). The host rock is a coarse-grained arkosic sandstone five to ten feet thick, stained with iron, manganese, and asphalt (Beroni, 1954). Samples taken from the deposit contained up to 0.010 per cent eU_3O_8.

The only uranium occurrence in Oklahoma to have been of commercial value was the deposit found behind the old school gymnasium in the town of Cement. From July to September, 1956, approximately 26 tons of ore were extracted from the deposit. Two truckloads of ore averaging 2.66 and 0.16 per cent U_3O_8 were taken from the deposit and shipped to Grants, New Mexico. All of the ore was produced from a trench 50 feet long, three feet wide and four to five feet deep. The mining operations depleted the ore body which was located in the SW¼, NE¼, Sec. 3, T.5N., R.9W. In the deposit, carnotite $[K_2(UO_2)_2(VO_4)_2 \cdot 1\text{-}3H_2O]$ and tyuyamunite $[Ca(UO_2)_2(VO_4)_2 \cdot nH_2O]$ were found disseminated in sandstone parallel to a N70°W-trending joint which dipped 80° to the southwest. The fracture is situated near the axis of the Cement anticline.

A second radioactive anomaly was reported in the Cement area shortly after the initial uranium discovery. The deposit, which is located in the NE¼, SE¼, Sec. 2, T.5N., R.9W., occurs in interbedded sandstones and siltstones of the Rush Springs Formation. No visible uranium minerals were recognized, however, radioactive readings of 0.2 to 0.5 MR/HR were recorded along a 100-foot sandstone outcrop (United States Atomic Energy Commission, 1968).

The secondary uranium minerals carnotite and tyuyamunite have been reported in the Upper Permian red beds of western Oklahoma (United States Atomic Energy Commission, 1968). In Roger Mills, Custer, and

Washita Counties these uranium minerals were reported uniformly distributed throughout some one-to five-foot sandstone and siltstone lenses in the lower Doxy Formation. Copper minerals are lacking in these deposits and some of the uranium occurs on the flanks of minor folds produced by the slumping of sedimentary rocks into solution cavities which developed in the underlying formations (Beroni, 1956).

CHAPTER IV

GEOLOGIC SETTING

Igneous and sedimentary rocks of Cambrian through Lower Cretaceous age crop out within the area of investigation. However, excluding a report of radioactivity in a Cambrian pegmatite dike, virtually all of the radioactive deposits in southern Oklahoma have been found in rocks of Upper Pennsylvanian and Permian ages.

Stratigraphy

The succession of mineralized sedimentary rocks in the study area extends from the Upper Pennsylvanian Oscar Group through the Permian Rush Springs Formation. The numerous radioactive occurrences within this interval are favorable for future exploration. In this study, emphasis will, therefore, be placed upon the Upper Pennsylvanian and Permian sedimentary rocks found in southern Oklahoma. The Late Paleozoic stratigraphic column used in this study (Fig. 2) is after Hart (1974), Havens (1975), and Bingham and Moore (1975).

Cambrian Through Upper Pennsylvanian (Lower Part of Gearyan)

Undifferentiated Paleozoic Rocks. Cambrian granitic rocks which crop out in the Wichita and Arbuckle Mountains are of interest because of their potential as a source for uranium. Granitic rocks exposed in

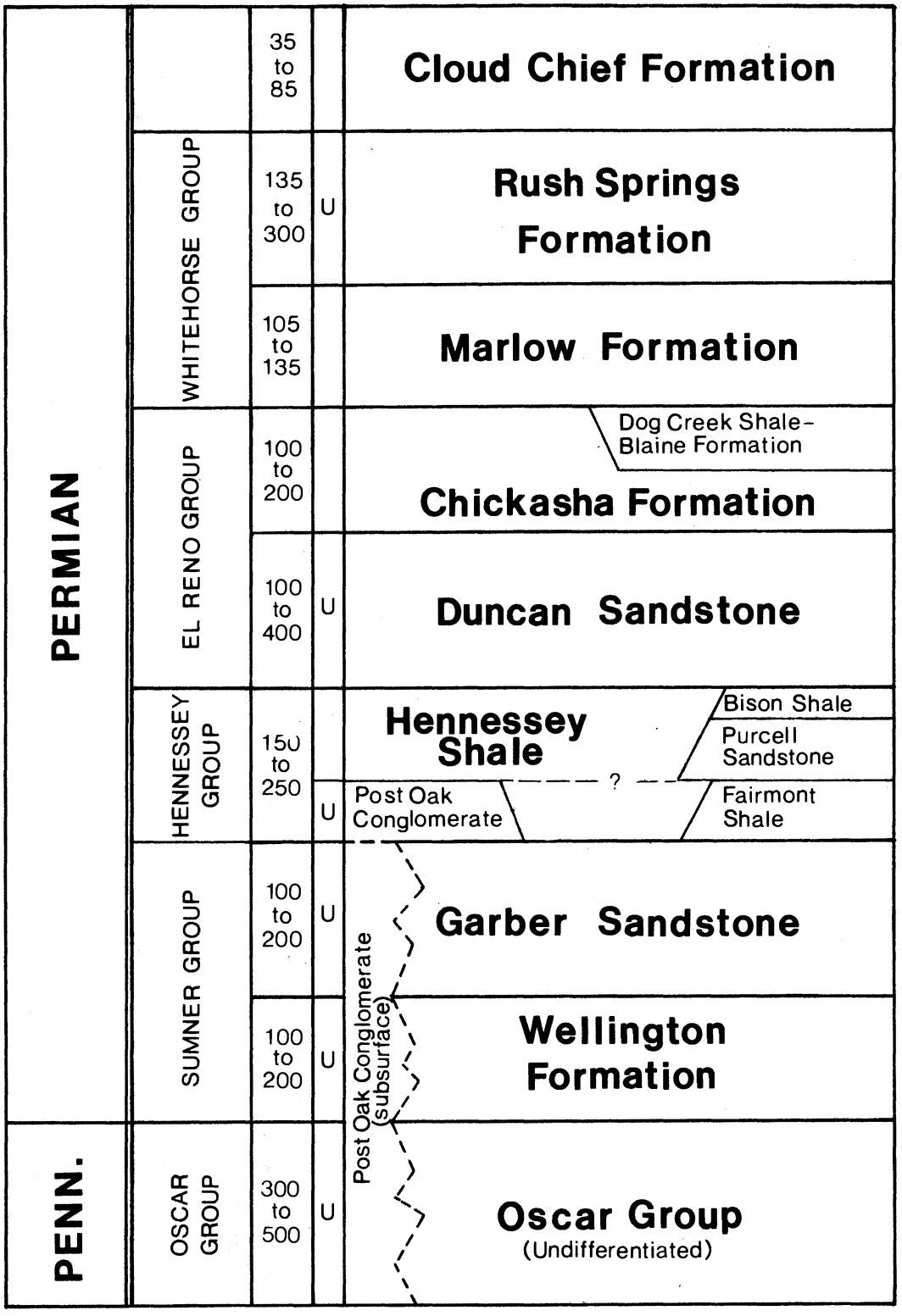

Fig. 2.-Columnar section of the study area showing thicknesses of units in feet and radioactive occurrences (U)

the Wichita Mountains are of three principal types. A layered gabbroic sequence cropping out on the north and west flanks of the mountains is covered by a series of rhyolitic tuffs and porphyries. The rhyolite and gabbro sequence has subsequently been intruded by fine- to medium-grained granites and granite porphyries which form the northwest-trending core and principal part of the mountains (Ham, Denison, and Merritt, 1964).

On the north and east flanks of the Wichitas early Paleozoic sedimentary rocks are eroded into isolated hills and ridges. The outcrops are remnants of thick-bedded, shallow-water carbonates deposited on the granitic basement.

In the western Arbuckle Mountains a thick sequence of Paleozoic sedimentary rocks is found resting upon a Cambrian rhyolitic basement which is equivalent to the rhyolite exposed in the Wichita Mountains. This rock is locally named the Colbert Rhyolite Porphyry and consists of thick rhyolitic flows and tuffs. The largest exposure of the porphyry is in T.1S., Rs.1E.-1W. In the eastern Arbuckle Mountains, the Pre-Cambrian Tishomingo and Troy Granites, and Blue River Gneiss form the basement.

The Paleozoic sedimentary rocks exposed in the Arbuckle Mountains and in the Criner Hills to the south, consist mainly of marine black shales and carbonates with several intervening sandstones and conglomerates.

Upper Pennsylvanian (Upper Part of Gearyan)

Oscar Group, Undifferentiated. In the southern part of the study area, the Upper Pennsylvanian Oscar Group consists of light-gray to brown, lenticular sandstones interbedded with brown and gray shales

(Bunn, 1930). The fine- to medium-grained, friable sandstones are cross-bedded and mostly weather into thin plates. Conglomerate lenses composed mostly of chert, granite and rhyolite fragments, and carbonate pebbles occur in the upper 100 feet of the section. The shales, which are generally massive or blocky, contain occasional thin, light-colored, sandy lenses. The conglomerates which occur in the upper part of the section are helpful in distinguishing the Oscar Group from the overlying Wellington Formation.

Around the Arbuckle Mountains and extending northward away from the uplift the sandstones of the Oscar Group are commonly arkosic. In that area the base of the Group is the Hart Limestone which Dott (1930) described as a series of gray to white limestones interbedded with red shales and gray arkosic sandstones. Red shales, with interbedded gray to brown arkosic sandstones and a few limestone conglomerates, comprise the remainder of the section.

The Oscar Group is approximately 500 feet thick in the area adjacent to the Arbuckle Mountains. The interbedded sandstones and shales thin toward the south, resulting in a thickness of approximately 300 feet in the southern part of the study area.

Several radioactive anomalies were detected on the Oscar Group in the southern part of the study area (Plate 1). The anomalies, which generally are recorded on sandy shales and siltstones, are mostly in the upper part of the section associated with sandstone lenses.

Permian System

Sumner Group. The Sumner Group consists of the Wellington Formation and overlying Garber Sandstone.

(a.) Wellington Formation. The Ryan Sandstone is at the base of the Wellington Formation throughout the study area. Around the northwest end of the Arbuckle Mountains the Ryan consists of two massive sandstones separated by a thick shale interval. Dott (1930) described the basal sandstone as massive, of medium hardness, and black to brown in color. It is overlain by red shales which contain several light-colored sandstone lenses. The upper sandstone is thin-bedded, well cemented and yellow, gray, or black in color. It is manganese stained and according to Dott (1930), copper and silver have been produced from the sandstone in Sec. 4, T.4N., R.2E. (Byars deposit).

An approximately equal thickness of shales overlies the lower sandstone members. The interval is composed largely of red shales with some thin and a few locally massive sandstone lenses.

In the southern part of the study area the Ryan is recognized by the large, dark-gray to reddish-brown, calcareous concretions which weather out of the sandstone. In many places the sandstone contains concentrations of bituminous material and may be locally asphaltic. The Ryan consists of lenticular, gray to buff or yellow, medium- to fine-grained, friable sandstones. The sandstones are locally thin-bedded and calcareous, measuring from 20 to over 60 feet in thickness. On weathered surfaces the sandstones are dark in color due to concentrations of iron and manganese oxide (Flood, 1969).

The remainder of the Wellington Formation in the southern part of the study area consists of over 100 feet of reddish-brown to gray, blocky shales and siltstones. Sandstone lenses composed of buff to gray friable sandstone are common in this upper sequence.

Radioactive anomalies have been reported from readings on the sand-

stone members of the Wellington Formation at several places in southern Oklahoma (Plate 1). Copper occurrences in the Wellington have also been reported at several locations in this area (Munn, 1914; Branson, Burwell, and Chase, 1955; Flood, 1969).

(b.) Garber Sandstone. The sandstones of the Garber Sandstone are generally distinguished from those of the underlying Wellington Formation and Oscar Group by their reddish-brown color. The basal Garber sequence consists of the Asphaltum Sandstone (Bunn, 1930), a buff to gray, calcareous sandstone which is locally asphaltic. Bunn described the Asphaltum as massive- to thin-bedded and ranging from 20 to over 50 feet in thickness. It consists of one or more members separated by shale beds and contains lenses of a carbonate, clay-pebble conglomerate. The conglomerate was mapped in southwestern Oklahoma by Munn (1914) as the Auger Lentil. He observed that toward the east in eastern Cotton County the conglomerate was more sandy and in many places had the appearance of a calcareous sandstone.

Several locally massive sandstone lenses occur within the Garber section. Throughout the study area and especially in Garvin County, these massive beds cap many of the prominent escarpments. Elsewhere, the sandstone members are reddish-brown, gray, or black in color and are thin, hard, and cross-bedded (Dott, 1930). They occur as lenses in reddish-brown to gray siltstones and shales. In the study area the Garber Sandstone is 100 to 200 feet thick.

Flood (1969) conducted petrographic analyses on several sandstones in western Jefferson County. Members of the Oscar Group, Wellington Formation, and Garber Sandstone crop out in the area which was sampled. Flood observed that the sandstones in this area were similar, having a

modal grain size of approximately 0.2 millimeters with a maximum grain diameter of 0.4 millimeters. Sorting ranged from poor to moderately well sorted, with the detrital portion of the rocks composed of 95 per cent quartz and about 4 per cent rock fragments.

Hennessey Group. In south-central Oklahoma the Hennessey Group consists of the Hennessey Shale and its gradational equivalents, the Post Oak Conglomerate, Fairmont Shale, Purcell Sandstone, and Bison Shale.

(a.) Hennessey Shale. In central Garvin County the upper 40 to 80 feet of the Garber Sandstone grade into red, blocky shales which contain numerous red sandstone lenses. This sequence was mapped as the Fairmont Shale by Hart (1974) and is, therefore, considered as a member of the Hennessey Group, in accordance with the classification of Aurin, Officer and Gould (1926).

Overlying the Fairmont Shale are reddish-brown, fine- to coarse-grained, lenticular sandstones which mark topographic highs in much of western Garvin County. The sandstones, which are collectively referred to as the Purcell Sandstone, are cross-bedded and contain some shale and mudstone conglomerates (Hart, 1974). North of T.2N., R.3W. these sandstones are generally red in color, however, west and south of this area they are buff to gray (Dott, 1930).

The Purcell Sandstone is overlain by a series of gray to reddish-brown blocky calcareous shales. This sequence is named the Bison Shale.

West of Duncan, Oklahoma the Bison Shale and Purcell Sandstone are undifferentiated and the sequence is mapped as the Hennessey Shale. In Stephens County the Hennessey is gray, however, toward the west, in

Comanche County and around the Wichita Mountains it has a reddish-brown coloration. A few small, light-colored sandstone lenses occur intermittently throughout the section. The thickness of the Hennessey Shale ranges between 150 and 250 feet throughout the study area. In the vicinity of the Wichita Mountains the Hennessey Shale is gradational laterally into the Post Oak Conglomerate, which is several hundred feet thick at the surface.

(b.) Post Oak Conglomerate. Chase (1954) described four lithofacies of the Post Oak Conglomerate, three of which crop out in the study area. An unconsolidated granite-boulder conglomerate, composed of rounded granitic boulders embedded in a brownish-yellow clay, crops out from near the center of T.3N., R.16W. to the center of T.2N., R.13W., and crops out on the north side of the mountains in R.15W. In the subsurface the boulders are well cemented with calcite, limonite, and clay and are surrounded by an arkosic matrix. A short distance from the mountains the boulder conglomerate grades into a gravel facies containing a number of arkosic lenses. Chase observed that six to eight miles south of the mountains the conglomerate is a coarse-grained arkosic sandstone which in places is gradational into the Hennessey Shale. The interbedded arkose and shale is about 400 feet thick and occurs in the subsurface 20 to 30 miles south and north of the mountains.

Near the center of T.2N., R.13W. the granite boulder conglomerate grades eastward into a mixed granite-rhyolite porphyry, boulder conglomerate (Chase, 1954). The conglomerate crops out around the southeastern end of the mountains and consists of light-pink to yellow-brown, angular and subangular rhyolite pebbles and boulders with some limestone conglomerates.

The third conglomerate facies crops out around the northeast margin of the Wichitas. It is composed of limestone cobbles and boulders which change abruptly into calcareous sands and shales away from the mountains (Chase, 1954).

Although the Post Oak Conglomerate is gradational into the Hennessey Shale at the surface, in the subsurface it interfingers with the Garber Sandstone, Wellington Formation, and Oscar Group and with rocks to Lower Pennsylvanian (Morrowan) age. Close to the mountains, on the north, the conglomerates are many thousands of feet thick.

Radioactive anomalies have been reported from readings on the granite-boulder conglomerate facies of the Post Oak Conglomerate south of the Wichita Mountains. The radioactivity occurs in Sec. 34, T.1N., R.15W. and Sec. 1, T.1S., R.16W. and is associated with arkosic sandstone lenses (United States Atomic Energy Commission, 1968).

El Reno Group. In the study area the El Reno Group consists of the Duncan Sandstone and Chickasha Formation, along with their gradational equivalents, the Flowerpot Shale, Blaine Formation and Dog Creek Shale. At the southeast end of the Anadarko basin the Duncan Sandstone and Chickasha Formation form a clastic wedge which is gradational into shales toward the northwest. The El Reno Group is 670 feet thick in Grady County and thins to less than 200 feet in northern Stephens County (Fay, 1964).

(a.) Duncan Sandstone. The Duncan Sandstone consists of two or three massive sandstones which are exposed along a prominent west-northwest-trending escarpment that extends through northern Stephens and Comanche Counties. Self (1966) described the Duncan as a buff to gray-

green, fine- to very fine-grained sandstone containing some dolomitic lenses. The Duncan is gray-green near the city of Duncan but has a buff color around the southeast end of the Anadarko basin. Northward from the nose of the basin the sandstone is orange-brown to red-brown. It is coarser upward, and near the top it is conglomeratic, cherty, and contains clay galls. Brown (1937) observed that in T.4N., R.4W. the upper conglomerate contains some arkosic materials.

The sandstone has some lenticular cross-beds and in certain areas has channel-like characteristics. A number of siltstone and shale beds occur intermittently throughout the section. The sandstone is finer grained westward and northward along the flanks of the Anadarko basin. It is laterally gradational into the Flowerpot Shale outside the study area. The Duncan is 100 to over 400 feet thick in the study area.

The Duncan Sandstone is composed primarily of quartz, with microcline and plagioclase feldspars constituting less than 2 per cent of the rock (Self, 1966). Freie (1930) found small quantities of pyrite in the sandstone in Sec. 14, T.2N., R.3W.

Anomalous radioactivity was detected from readings on the upper Duncan Sandstone at Cox City in southeast Grady County (Plate 1).

(b.) Chickasha Formation. Overlying the Duncan Sandstone are 100 to 200 feet of varigated sandstones, siltstones, shales, and mudstone conglomerates of the Chickasha Formation. The Chickasha is distinguished from the overlying Duncan Sandstone by its purple color and shaly characteristics. At its base the Chickasha consists of a deep red to purple, cross-bedded sandstone composed of mudstone conglomerates and containing some concretionary boulders (Brown, 1937). The lower part corresponds to Green's (1936) arkosic conglomerate member of the Duncan Sandstone.

According to Green, the conglomerate attains its maximum thickness of 150 feet and has its greatest arkosic content in Ts.2-3N., R.5W. The wedge shaped conglomerate is abruptly thinner toward the north.

Approximately 50 feet of uncemented pink sandstones with thin beds of red shale separate the lower sandstone members from an upper unit consisting of purple sandstones and mudstone conglomerates (Gould, 1924). The lower portion of this upper member consists of purple mudstone conglomerates overlain by thin pink sandstones. The top of the Chickasha Formation consists of 25 to 30 feet of massive purple sandstones which are cross-bedded and contain several thin mudstone conglomerate lenses.

Northward and westward along the limbs of the Anadarko basin, the Chickasha Formation is laterally gradational into brick red gypsiferous shales and siltstones. Outside of the study area the lower part of the Chickasha is gradational into the Flowerpot Shale, whereas the upper part grades into members of the Blaine Formation and Dog Creek Shale.

(c.) Dog Creek Shale-Blaine Formation, Undifferentiated. Davis (1955) was unable to differentiate the Blaine Formation and overlying Dog Creek Shale in Grady County and mapped the two as an undifferentiated unit. The section, which is gradational southward into the upper Chickasha Formation, consists of dark red, blocky, silty shales. Several two- to three-foot mudstone conglomerates are found locally throughout the section. In the lower and middle portions of the sequence the shales are interbedded with fine-grained gypsiferous sandstones which are gradational locally into pure gypsum. A fossiliferous dolomite which is sandier toward the south, crops out at the base of the section (Brown, 1937). The Dog Creek-Blaine section is between zero and 230 feet thick throughout the study area.

Whitehorse Group. The Whitehorse Group consists of fine-grained sandstones and siltstones which contain thin dolomite and gypsum beds. The Marlow and overlying Rush Springs Formations comprise the Group which is 435 feet thick in Grady County (Fay, 1964).

(a.) Marlow Formation. The Marlow Formation consists of 105 to 135 feet of reddish-brown, silty shales and fine-grained sandstones. The formation is gypsiferous throughout, containing randomly oriented veins of satin spar. In the upper part of the formation 15 to 20 feet of sandstones and shales separate two persistent thin-bedded dolomitic limestones named the Relay Creek and Emanuel Beds. A thin, pink, sandy shale (termed the Gracemont Bed) occurs below the upper limestone (Emanuel Bed). This shale unit and a similar shale which occurs about 60 feet above the base of the formation, are believed to altered volcanic ash deposits (Davis, 1955). Satin-spar veins and gypsum concretions are common in the lower part of the formation.

A light-brown, lenticular sandstone called the Verden Lentil is found near the middle of the Marlow Formation. The lentil crops out in a northwest-trending linear pattern through the north-central part of the study area. The medium- to coarse-grained, cross-bedded, fossiliferous sandstone is composed of quartz and chert with calcium carbonate cement (O'Brien, 1963).

(b.) Rush Springs Formation. In Caddo, Grady, and northern Stephens Counties the Rush Springs Formation consists of a cross-bedded to even-bedded, quartzose sandstone. Iron-oxide coatings on the sand grains gives the sandstone its characteristic medium- to light-red coloration (O'Brien, 1963). At Cement, in southeast Caddo County, the

normal red coloration of the sandstone has been altered to a buff or white color. In this area the sandstone contains minute concentrations of pyrite and is well indurated with carbonate cement (McKay and Hyden, 1956).

The fine-grained sandstone consists of subangular to subrounded quartz grains which average 0.124 millimeters in diameter (Davis, 1955). Feldspars are not common in the rock, however, they may be locally abundant comprising up to 30 per cent of the sandstone (Hamm, Merritt and Frederickson, 1957). Very coarse, frosted, spherical grains are common in the lower part of the formation. The Rush Springs is generally friable, being weakly indurated with iron oxide and clay cement. The sandstone displays remarkable homogeneity throughout the study area. Siltstone and shale constitute only a minor part of the formation, however, a silty shale phase does crop out south of the town of Rush Springs (Davis, 1955).

A massive pink gypsum occurs in the upper part of the Rush Springs Formation. The gypsum, which is 1 to 40 feet thick, is called the Weatherford Gypsum Bed. Tanaka and Davis (1963) found that throughout most of Caddo County the unit is dolomitic with local variations to anhydrite or gypsum. The Weatherford Gypsum Bed is separated from the overlying Cloud Chief Formation by 10 to 15 feet of dolomitic sandstones and siltstones. The thickness of the Rush Springs Formation ranges from 135 feet (where eroded) to over 300 feet (where complete). According to Tanaka and Davis (1963) the formation is thicker westward toward the axis of the Anadarko basin.

Uranium mineralization and radioactive anomalies have been reported in the Rush Springs Formation at several places in and around the

town of Cement (Plate 1).

Cloud Chief Formation. The Cloud Chief Formation consists of 60 to 120 feet of gypsum and dolomite at the base, overlain by 300 feet or more of siltstone and sandstone in the middle and reddish-brown shale at the top. In the study area the Moccasin Creek Gypsum Member is at the base of the formation (Fay, 1969). The Moccasin Creek Gypsum is the only member of the Cloud Chief Formation found in the study area. This basal member is 85 feet thick and is composed of a massive, pink to white, crystalline gypsum which contains a few gray sandstone lenses. This unit caps several topographic highs in the northwestern part of the study area.

Cretaceous

Lower Cretaceous, Undifferentiated. Sedimentary rocks of Lower Cretaceous age crop out in the southeastern portion of the study area. The basal Mesozoic formation is the Antlers Sand which consists of conglomerates and calcareous sandstones at the base overlain by poorly cemented sandstones and sandy shales. Carbonized wood generally associated with marcasite, is found locally in the lower part of the Antlers Sand (Frederickson, Redman, and Westheimer, 1965).

A thick carbonate and shale sequence which includes, in ascending order, the Walnut Clay, Goodland Limestone, and the Kiamichi, Caddo, and Bokchito Formations, overlies the Antlers Sand.

Environment of Deposition

The Upper Pennsylvanian and Permian red beds of southern Oklahoma were deposited in an environment characterized by deltaic, marginal

marine, and marine conditions (Fig. 3). East and southeast of the Arbuckle and Wichita Mountains, westward flowing streams carried detrital materials from the Ouachita Mountains and Llanoria (Miser, 1921) into a depositional basin which extended from western Oklahoma and Texas into eastern New Mexico. The basin, which encompassed both the Anadarko and Hollis basins (Fig. 4), was continually subsiding, receiving marine carbonate and evaporite deposits (Ham, 1960). The Arbuckle and Wichita Mountains supplied local material, but they were covered by Hennessey time.

Flood (1969) concluded that the sandstone lenses which occur in western Jefferson County were fluvial, having been deposited by westward flowing streams. The siltstones and shales which surround these lenses represent the finer grained materials which were deposited on flood plains and delta flats. The similarities of the interbedded sandstones and shales in the southern part of the study area suggest that their mode of origin was not unlike that described by Flood. Marine encroachment into the area is evidenced by the calcareous sandstones and carbonate, clay-pebble conglomerates commonly found in the Lower Permian deposits.

Fragments of Colbert Rhyolite Porphyry and Tishomingo Granite in the Oscar Group were derived from the Arbuckle Mountains. Flood concluded that by the beginning of Wellington time, however, the mountains were no longer a major source area and the detrital materials in the Permian formations were derived primarily from the Ouachita Mountains in northern Texas and southern Oklahoma (Fig. 5).

In southwestern Oklahoma the Wichita Mountains probably were part of an archipelago which separated the Hollis and Anadarko basins (MacLachlan, 1967). The mountains did furnish detrital material to the ad-

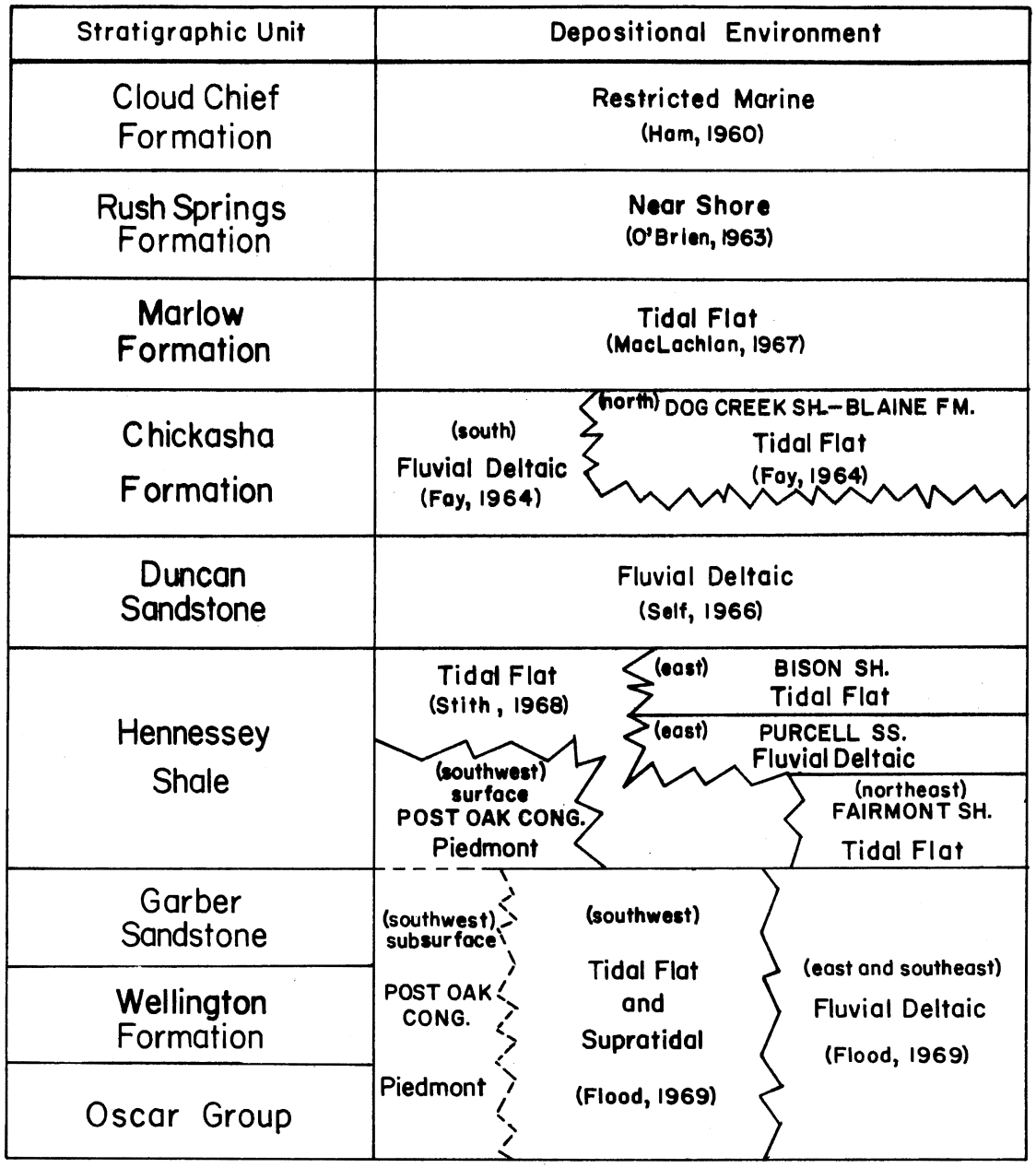

Fig. 3.-Stratigraphic units and equivalent depositional environments, south-central Oklahoma

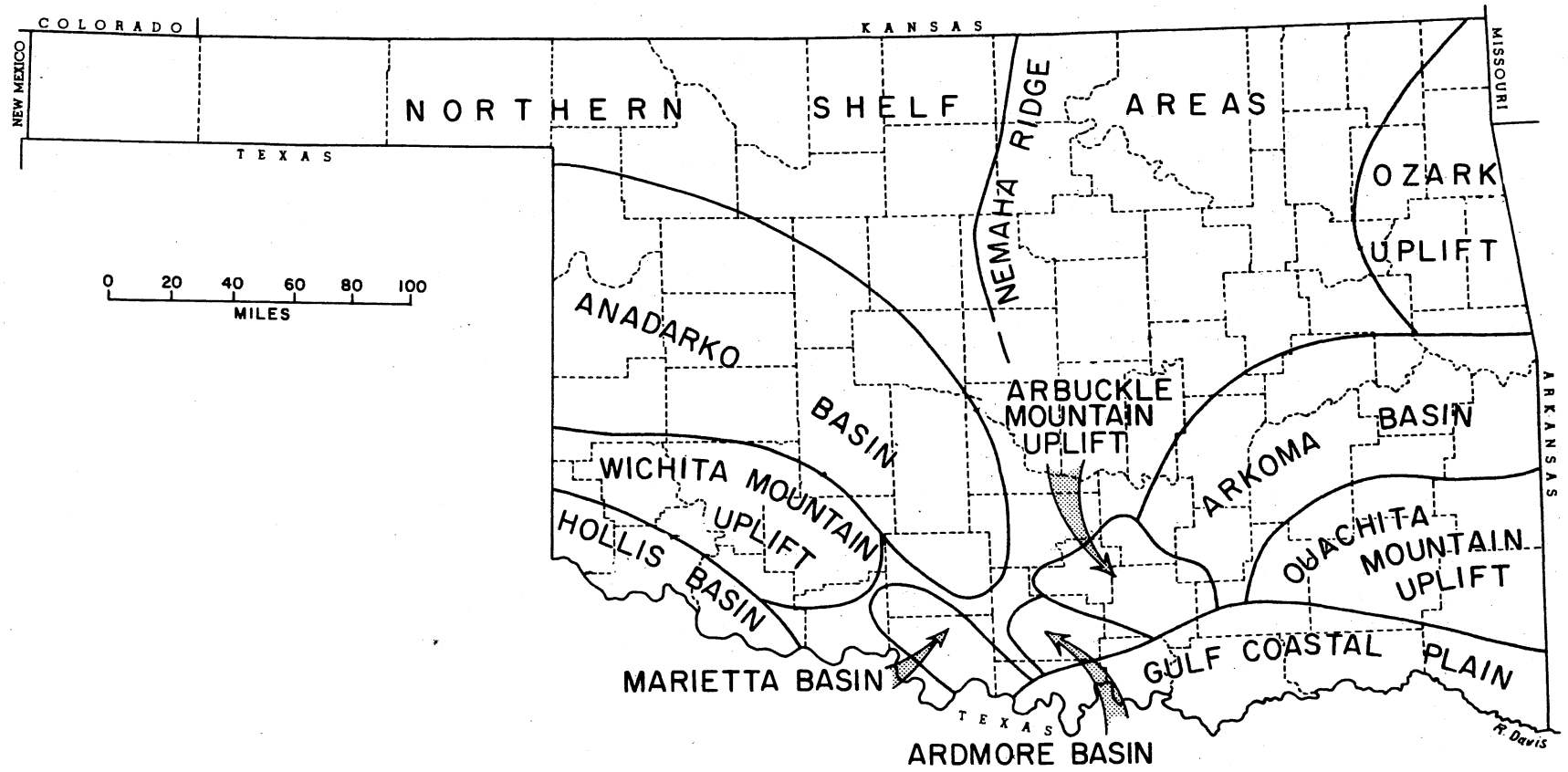

Fig. 4.-Major geologic provinces of Oklahoma. After Johnson and Denison (1973)

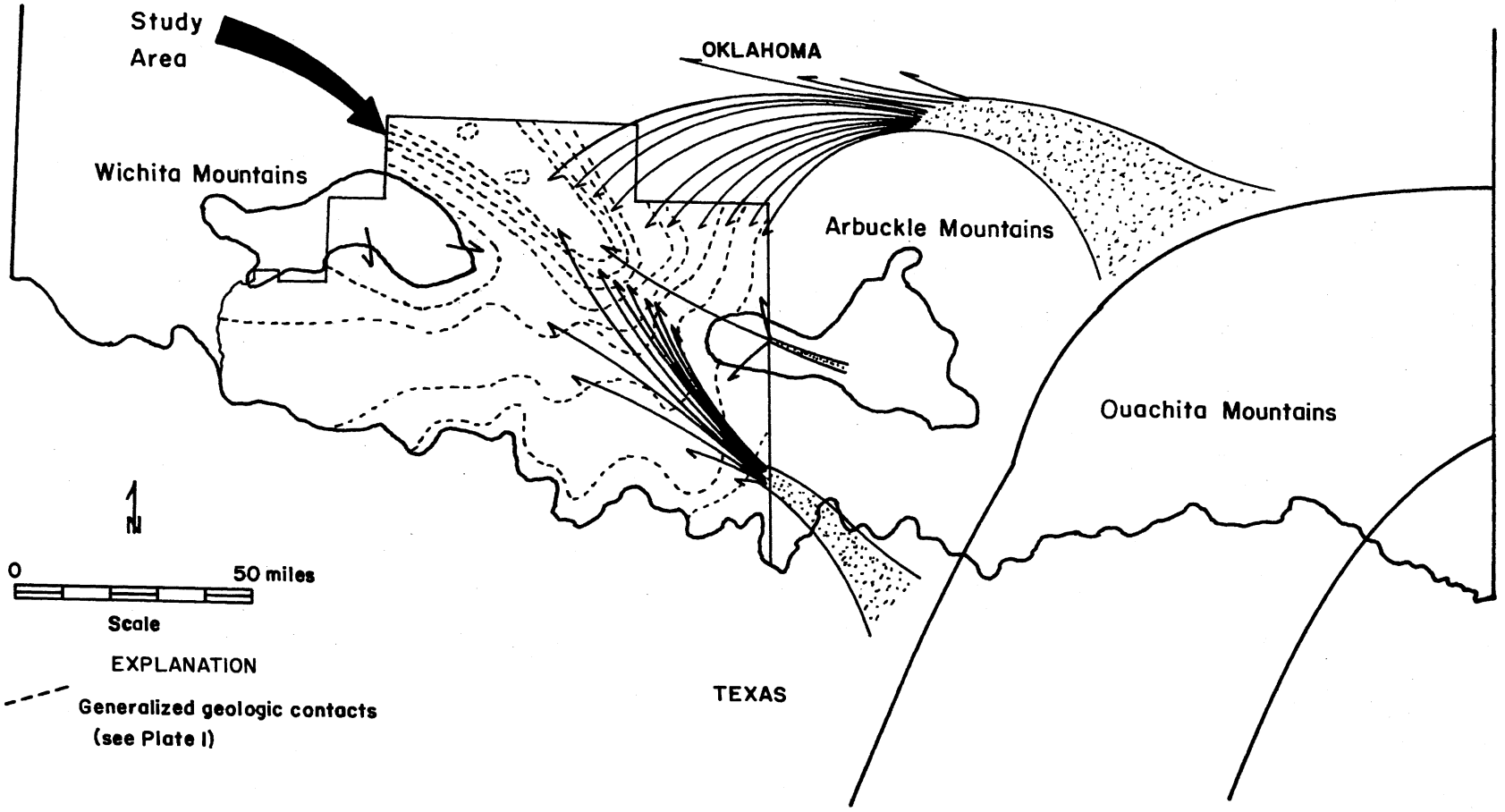

Fig. 5.-Source areas during Late Pennsylvanian and Permian times

joining areas, as evidenced by the Post Oak Conglomerate, but they probably were not a major source of sediments after Hennessey time. Ham, Merritt, and Frederickson (1957) believe the Wichitas were at least partly exposed during deposition of the Hennessey Shale but were probably covered by Late Hennessey time. They believe that the Duncan Sandstone may have extended over the Wichita Mountains above the Hennessey Shale.

North of the Arbuckle Mountains the Tussy delta (Green, 1937) formed during Early Permian time. Northwestward flowing streams carried detrital materials from the Arbuckle and Ouachita Mountains into the Anadarko basin and westward around the Wichita Mountains (Fig. 5). According to Robert O. Fay of the Oklahoma Geological Survey (oral communication, 1975), the thickest Upper Pennsylvanian and Permian sedimentary rocks in southern Oklahoma are found 20 to 30 miles northeast of the study area. The fact that these rocks thin northward, westward, and southward from this area implies that fluvial systems on the delta carried large quantities of sediment into the study area. Deposition of coarse clastics and arkosic materials in alluvial channels on the Permian delta record periods of uplift in the Arbuckle and Ouachita Mountains. A short period of quiescence which followed the earlier structural movements resulted in the deposition of the Hennessey Shale (Green, 1937).

The Duncan and Chickasha Formations are considered by Fay (1964) to have been deposited at the mouth of a large north-westward flowing river. The source area is believed to have been the Ouachita Mountains, with deposition occurring in an area characterized by alternating fluvial and marine conditions (Self, 1966). Basinward equivalents of

the Duncan Sandstone and Chickasha Formation contain evaporitic and some dolomitic deposits which are indicative of a restricted, shallow-marine environment (MacLachlan, 1967).

By the end of Chickasha time the Tussy delta was slowly sinking and a transgressing sea began to deposit the shallow-water, brackish-marine siltstones and sandstones of the Marlow Formation (Fay, 1964). The Verden Lentil probably represents a channel which formed in the mudflats that bordered the Marlow sea (MacLachlan, 1967).

According to Davis (1955) the Rush Springs Formation was probably deposited in a shallow marine bay, with sediment apparently being supplied by the newly uplifted Ouachita Mountains (Fay, 1964). Periodic fluctuations in sea level may have exposed portions of the sandstone to the surface where eolian conditions swept the sands into large dunes. Recurrent inundations by marine waters probably resulted in the formation of large pools which deposited silts and shales on the sand.

The final stages of Permian deposition in the study area contributed to the development of the Cloud Chief Formation. Deposition took place in a semi-enclosed arm of a sea which had a periodic influx of sulphate rich waters (Ham, 1960).

Structure

Two episodes of Pennsylvanian deformation are responsible for the present tectonic setting of the study area (Fig. 6). During the Wichita and Arbuckle orogenies, Paleozoic sedimentary rocks underwent intense deformation, resulting in the formation of numerous northwest-trending anticlinal structures (Waterschoot Van der Gracht, 1931). According to Ham, Denison, and Merritt (1964) the basement rocks of southern Okla-

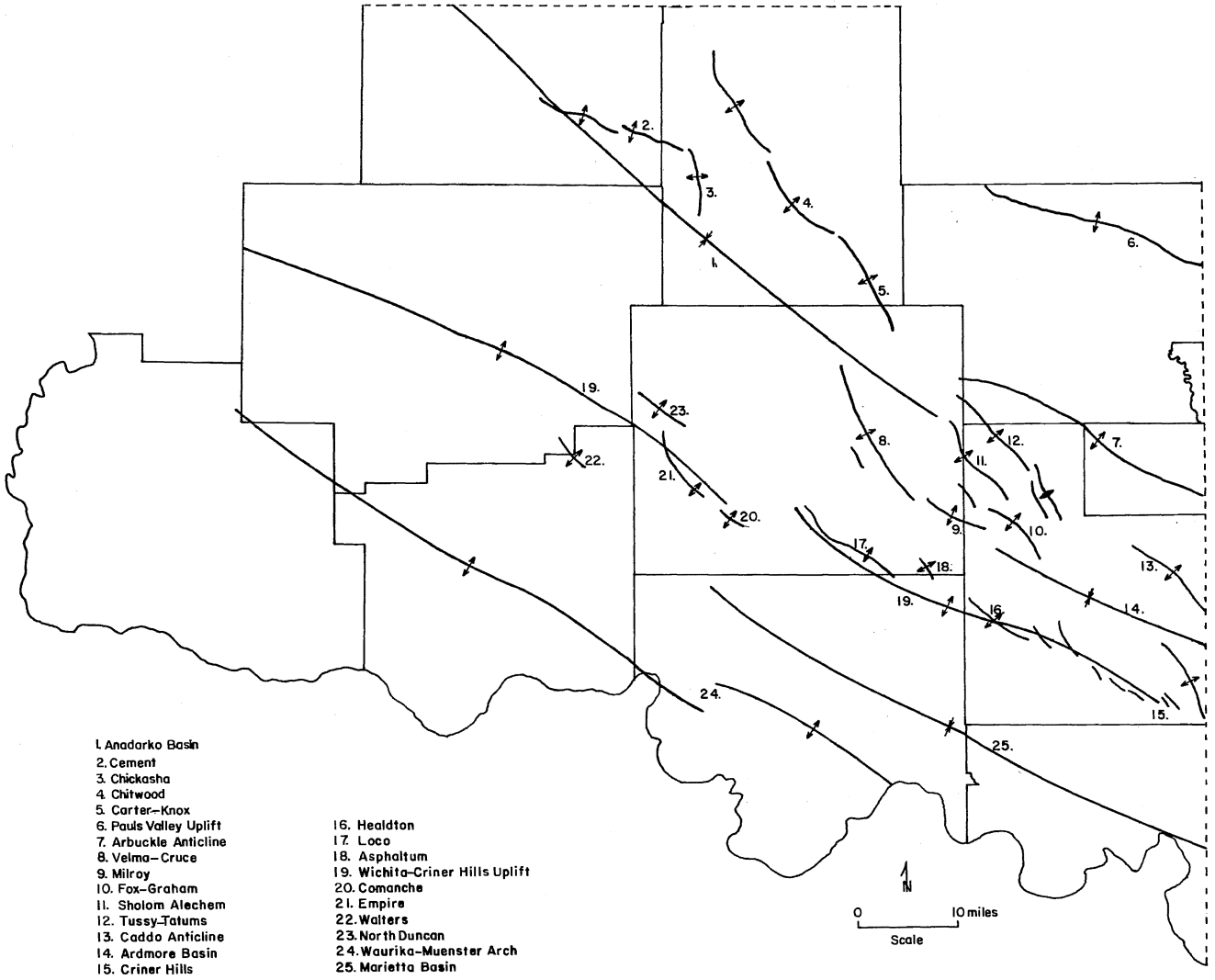

Fig. 6.-Major structural axes in the study area

homa had a profound influence on the formation of these structural features.

The Paleozoic rocks that were folded during the Pennsylvanian orogenies were deposited in a major structural trough that developed on the basement complex. Ham, Denison, and Merritt (1964) called the structure the Southern Oklahoma geosyncline and concluded that before deposition had ceased in Permian time the geosyncline had accumulated over 60,000 feet of sediment. According to the authors, during the earliest stage the geosyncline was bounded by basement faults and began filling with Early and Middle Cambrian graywackes, bedded cherts, spilitic basalts and rhyolites. During this stage a portion of the margin was injected by gabbroic lenses, followed by the intrusion of granitic sills and plutons. These intrusive rocks later formed the core of the Wichita Mountains.

The second stage was dominated by the deposition of about 11,000 feet of Late Cambrian through Devonian carbonate rocks. This stage was followed by the third and final period of deposition during which approximately 27,000 feet of Late Devonian through Permian clastics accumulated. Part of the sediment deposited during the concluding stage was derived from the uplifting Wichita Mountains during Pennsylvanian time (Ham, Denison and Merritt, 1968).

The Wichita and Arbuckle Mountains are located on the southwest and northeast margins, respectively, of the geosyncline. The trough, which consists of the Anadarko, Ardmore, and Marietta basins (Fig. 4), at one time included the western edge of the Arbuckle Mountains where the closely folded rocks of the Arbuckle anticline now occur. The present Wichita Mountains are located in the area which was near the

center of the geosyncline in Ordovician time (Robert O. Fay, oral communication, 1975).

The Criner Hills uplift divides the southeast portion of the geosyncline into the Marietta and Ardmore basins. The Ardmore basin is bordered on the north by the Arbuckle Mountains and minor uplifts to the northwest separate it from the Anadarko basin. South of the Anadarko basin the Wichita uplift plunges eastward, merging with the Criner Hills uplift, and together they form the northern boundary of the Marietta basin. The southern margin of the Marietta basin is defined by the northwest-trending Waurika-Muenster arch which represents the margin of the North Texas craton (Ham and Wilson, 1967).

According to Tomlinson and McBee (1959), the Early Pennsylvanian, Wichita orogeny formed the Criner Hills and was responsible for the uplift which produced the Wichita Mountains. The oil producing structures found along the Wichita-Criner Hills uplift were also formed at the time, as was the Waurika-Muenster arch.

During Middle Pennsylvanian time the Wichita Mountains experienced some additional uplifting, but the principal orogenic movement was taking place to the east in the eastern Arbuckle Mountains. The Criner Hills and Waurika-Muenster arch were completely covered by the close of this period and the Marietta basin began filling with sediments. The Ouachita Mountains area was also under water in Middle Pennsylvanian time. By the end of Middle Pennsylvanian time the early stages of the Arbuckle orogeny had begun and the western Arbuckle Mountains had attained a structural relief of approximately 20,000 feet (Tomlinson and McBee, 1959).

The Arbuckle orogeny lasted throughout Late Pennsylvanian time and

represents the final and most intense period of crustal deformation in southern Oklahoma. During this episode the Arbuckle anticline was tightly folded and the eastern Arbuckles were uplifted again. Most of the folding in the Ardmore, Marietta, and Anadarko basins was taking place and the Ouachita Mountains were formed in southeastern Oklahoma. Many of the previously formed oil field structures, such as Velma, Carter-Knox, and Apache, were overturned and faulted. The Criner Hills were re-elevated and some of the folds along the Wichita-Criner Hills uplift were faulted and re-folded. The Arbuckle Mountains were uplifted as much as 40,000 feet above the Ardmore basin and a substantial re-elevation of the Wichita Mountains also took place (Tomlinson and McBee, 1959).

Orogenic activity was at an end by Early Permian time and sedimentary red-bed deposits, derived primarily from the Ouachita Mountains, spread over much of western Oklahoma. Minor folding of Permian strata took place during a later period. According to Robert O. Fay (oral communication, 1975) much of the folding had to take place before Triassic time since Triassic red beds are found resting on eroded Middle to Upper Permian formations in western Oklahoma.

Due to their similar tectonic histories the anticlines that formed as a result of the Wichita and Arbuckle orogenies have a number of common structural characteristics. The folds which are generally assymetrical with overturning toward the north, typically have a north-northwest-trending axis which has been cut by several normal faults. Upthrusts are evident on a few of the structures, and low angle thrust faults which parallel the axial trend of the folds are common. Several anticlines show a decrease in structural complexity with depth. This is re-

lated to incompetent Upper Mississippian shales which provided a platform for the disharmonic folding of the overlying Pennsylvanian units.

Permian sedimentary rocks unconformably overlie the tightly folded and faulted pre-Permian structures. Although these Upper Paleozoic rocks generally display only minor deformation, several of the structures, such as Velma, Carter-Knox, Healdton, and Cement, are reflected at the surface by slight deformation of the overlying Permian strata.

CHAPTER V

THE URANIUM POTENTIAL OF THE CEMENT, COX CITY, AND RED RIVER AREAS

Hydrogeochemical anomalies, obtained during the reconnaissance phase of exploration in south-central Oklahoma, outlined several areas requiring extensive evaluation. The ground-water anomalies in the Cement, Cox City, and Red River areas appear to be associated with oil-producing anticlines having alteration of red beds near the crests of the structures. Several other anticlines in southern Oklahoma, including West Cement, Chickasha, Velma-Cruce, Eola, and Healdton have similar surface alterations. Due to the lack of geochemical anomalies near these structures further evaluation of these areas was not undertaken in this study.

The discovery of ground-water anomalies near the former uranium deposit at Cement prompted the choosing of this area as a test site for the development of a uranium exploration program in order to evaluate the anomalies found in the Cox City and Red River areas. If geologic features similar to those found at Cement could be recognized at Cox City and along the Red River, further exploration in these areas might be warranted.

Cement Uranium Deposit

Geologic Setting

Large quantities of oil and natural gas have been produced from the Cement anticline in southeastern Caddo County. The structure has also produced the only uranium deposit of commercial value in the state of Oklahoma. The structure is a west northwest-trending, assymetrical anticline that is slightly overturned toward the north. The anticline consists of 2,500 feet of unfaulted Permian strata which unconformably overlie a faulted and tightly folded pre-Permian structure. A major south-dipping reverse fault intersects the pre-Permian unconformity along the north flank of the anticline (Fig. 7). The fault parallels the fold and also parallels a northward-dipping normal fault system which has been truncated by the unconformity near the crest of the structure. Several minor, normal faults cut the anticline at an angle, resulting in the displacement of the pre-Permian fold axis.

Minor structural deformation which took place following Permian time produced a nearly symmetrical Permian anticline with an axis which nearly coincides with that of the earlier Paleozoic structure. As contoured on the top of the outcropping Rush Springs Formation, the Permian fold is approximately 11 miles long and two miles wide (Reeves, 1921). Its crest is a topographic high dominated by two domes. The East and West Cement domes are approximately four miles apart and are capped by the basal member of the Cloud Chief Formation. The town of Cement is located on the west side of East Cement dome.

The oldest rocks exposed on the Cement structure are the sandstones of the Rush Springs Formation and the overlying Moccasin Creek Gypsum

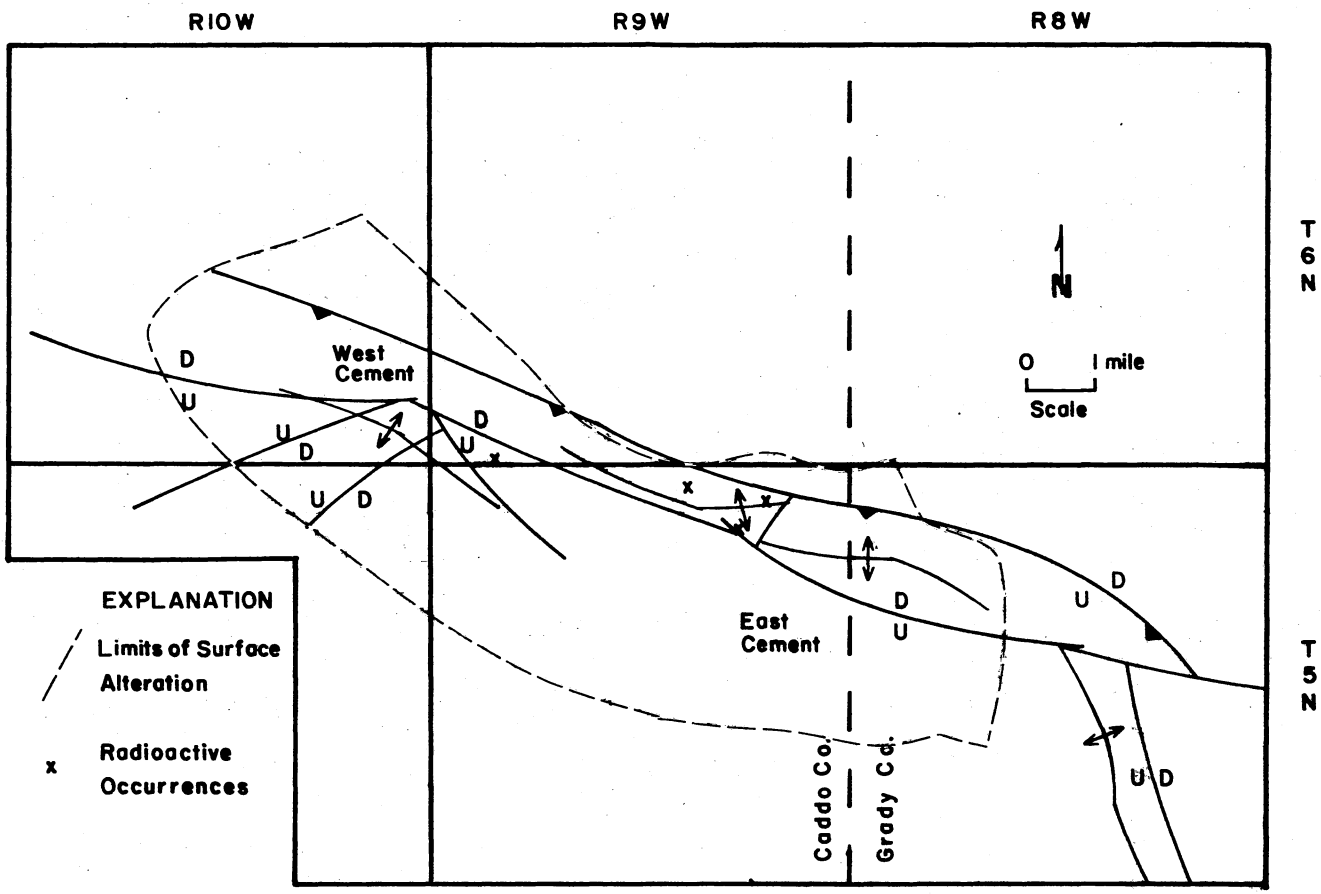

Fig. 7.-Pre-Permian structure map of the Cement area showing radioactive occurrences and surface alteration. After Herrmann (1961) and Donovan (1972)

Member of the Cloud Chief Formation. The Rush Springs Formation is approximately 250 feet thick in the Cement area.

Petrology and Petrography

Near Cement the Rush Springs Formation is a fine- to very fine-grained, subarkose composed of quartz, orthoclase, plagioclase, microcline and chert. The sandstone consists of well to very well sorted, subangular to subrounded sand grains. The friable sandstone is cemented with hematite which occurs as rims on the sand grains and gives the sandstone its characteristic red color. Beds of very fine-grained silty sandstone were found in the Rush Springs Formation in Sec. 2, T.5N., R.9W.

In the vicinity of the Cement oil field the Rush Springs Formation is altered to colors of yellow, buff, or white along the flanks of the anticline. Near the crest of the structure the sandstone has a gray coloration. In these areas most of the sandstones are extremely hard and are indurated with carbonate cement.

Thin section studies were conducted on each of the four types of sandstone found in the study area. The samples included: the yellow to white sandstone found on the flanks of the structure; the gray, well-cemented sandstone found near the crest of the fold; the silty sandstone found in Sec. 2; and the red unaltered sandstone.

Quartz accounted for 50 to 60 per cent of the total rock in each sample, excluding the silty sandstone. The grains showed both straight and undulatory extinction and several composite quartz grains with sutured contacts were observed. A few quartz grains with straight, unaltered edges were found, however, most of the grains had rough, jagged

edges and showed evidence of carbonate replacement.

Orthoclase constituted from 8 to 12 per cent of the rock, with microcline and plagioclase each accounting for 2 to 3 per cent of the sample. Most of the orthoclase showed extensive surface alteration to clay and sericite. Fresh microcline and plagioclase were observed, however, they were generally found altered to sericite on the surface and carbonate around the edges. Several feldspars were completely altered to sericite.

Chert pebbles were identified in the sandstone and constituted up to one per cent of the rock. Traces of biotite, chlorite, sericite, and zircon were also observed.

The samples collected along the flanks of the structure were tightly bound with a carbonate cement which accounted for 29 to 35 per cent of the sample. The sand grains were widely spaced and appeared to "float" in the carbonate cement. Most of the detrital grains showed evidence of carbonate replacement.

Remobilization had removed a great deal of the hematite from the light colored sandstones found near the flanks of the structure. Several grains, however, had iron oxide stains and limonite was observed rimming many of the fragments. Small hematite concretions containig fresh sand grains were also found in the sandstone. Carbonate cement was found in the sandstone, however, a lack of cement in certain areas made the samples porous.

One of the samples collected on the flanks of the structure was soft, friable and had a yellow limonitic color. The sandstone contained no carbonate cement. Some of the sand grains had limonite rims and were in point contact.

A sample of gray, well-cemented sandstone collected near the crest of the anticline contained small amounts of pyrite and had no visible traces of iron oxide. The sandstone was well cemented with carbonate and contained little pore space.

In the silty sandstones, quartz accounted for 38 per cent of the sample, with 16 per cent orthoclase and 1 per cent each of chert, microcline and plagioclase. A reddish-brown clay matrix, accounting for 30 to 40 per cent of the sample, bound the detrital portion of the rocks. No chemically precipitated cement was found in the sandstones.

The unaltered reddish-brown sandstone contained no carbonate cement. Hematite in the form of grain coatings and as pore fillings was the primary cementing medium. The sand grains were generally well rounded and mostly in point contact. Quartz overgrowths were visible on a few quartz grains.

Surface Alteration

Unique features of the Cement anticline are the coloration and mineralogic changes which occur in the Permian sedimentary rocks over the structure (Fig. 7). According to Donovan (1972), approximately two-thirds of the distance up the flanks of the structure the friable, reddish-brown sandstones of the Rush Springs Formation show a marked change in color to white, yellow, and pink. The sandstones have a gray coloration near the crest of the structure where they are tightly bound with a carbonate cement. At the crest of the anticline the Moccasin Creek Gypsum Member of the Cloud Chief Formation is altered to a carbonate which is predominantly calcite.

Donovan (1972) attributed the alteration of the gypsum and sand-

stone to hydrocarbon leakage which was controlled by the distribution of faults and the pre-Permian unconformity. Oxidation of the migrating hydrocarbons by sulfates, resulted in the formation of carbonate replacements of gypsum near the crest of the structure. Donovan stated that hydrogen sulfide released either as a by-product of the sulfate-hydrocarbon reactions or contained in the escaping hydrocarbons, reduced the ferric oxides in the Rush Springs Formation. The soluble ferrous compounds were then removed by water, producing the coloration change characteristic of the sandstone. In the subsurface, carbonate mineralization is restricted to the sandstone intervals of the underlying formations and is reported to a depth of 2,500 feet (Donovan, 1972). Donovan speculated that the probable source for the hydrocarbons was oil and gas reservoirs of Upper Pennsylvanian (Missourian) age.

Radioactive Anomalies

Cement Deposit. The ore body at Cement (p. 15) was found in a west northwest-trending joint located near the crest of the Cement anticline. Carnotite and tyuyamunite were confined to the upper side of the southwest-dipping fracture and occurred as a series of pods along the opening. Radioactive readings on the deposit ranged from 0.05 to 0.80 MR/HR. The host for the ore was the sandstone in the upper Rush Springs Formation. In the ore zone the sandstone was white in color with dark-brown, yellow-brown, and red stains. McKay and Hyden (1956) mostly found white sandstone parallel to the mineralized fracture. A halo of reddish-brown sandstone was observed separating the ore zone from the barren portions of the host. Away from the joint the sandstone was yellow with dark-brown staining. The yellow sandstone contained some

hematitic, red sandstone and occurred as diffusion bands away from the fracture. Although it did contain several hard, limy concretions, the white sandstone was generally more friable than the iron-stained, yellow sandstone. McKay and Hyden (1956) found non-radioactive pyrite nodules, some up to six inches in diameter and veined with anhydrite, in the yellow rock. A gray, well-cemented, very limy, pyritic sandstone was found beyond the outer limits of the yellow sandstone.

Ground Water. Hydrogeochemical methods of prospecting for uranium are based upon the fact that through the processes of weathering and erosion, secondary dispersion aureoles of uranium dissolved in ground water will be established near mineralized rocks. During passage through the host rock, ground water will tend to attain a uranium concentration which is roughly proportional to the content of the rock. Anomalous concentrations of uranium in ground water may, therefore, serve as a rough indication of the uranium content of nearby geologic materials and can be very helpful in exploring for new deposits.

The highest concentration of uranium in ground-water samples collected throughout the United States by Scott and Barker (1962) was in a sample taken from a well at Cement, Oklahoma. The well, located in Sec. 3, T.5N., R.9W., contained water with a concentration of 120 ppb uranium. A second sample collected nearby in Sec. 1, T.5N., R.10W., contained only 2.2 ppb uranium. The difference between the uranium contents of the two samples, and the presence of a uranium ore body in the vicinity of the ground-water anomaly, suggest that hydrogeochemical prospecting might be helpful in exploring for uranium in southern Oklahoma.

Forty-eight ground-water samples were collected in a 24 square

mile area around Cement for the purpose of determining the usefulness of hydrogeochemical prospecting as an exploration guide. It was also hoped that ground-water anomalies might delineate new zones of uranium mineralization. Results from the survey (Fig. 8; Appendix A) show several ground water anomalies in the vicinity of East Cement dome. In the town of Cement three water wells located near the former ore body contained anomalous concentrations of uranium. One of the wells is located approximately 200 feet northeast of the former deposit. Two water samples collected from the well in June, 1974, had concentrations of 120 and 145 ppb uranium. Water samples collected from the same well in March, 1975, had 140 and 160 ppb uranium. The well is 165 feet deep and produces from the Rush Springs Formation, as do most wells in the area.

Discrepancies between the uranium content of ground water collected in June, 1974, and March, 1975, may be attributed to seasonal variations in rain fall. According to Davis (1955) recharge by local precipitation in the Rush Springs Formation is high because of the permeable nature of the sandstone. Measurements of rain fall during the month of June, 1974, at Chickasha, located about 20 miles northeast of Cement, and at Waurika, in western Jefferson County, show a total precipitation of 0.74 and 0.95 inches respectively. In 1975, the total precipitation during the month of March was 2.04 inches at Chickasha and 2.34 inches at Waurika.

The highest concentration of uranium in ground water collected during this study was in a well located about 700 feet north of the former ore body. Several samples were collected from the municipal well which is 85 feet deep. One sample collected in June, 1974, contained 465 ppb

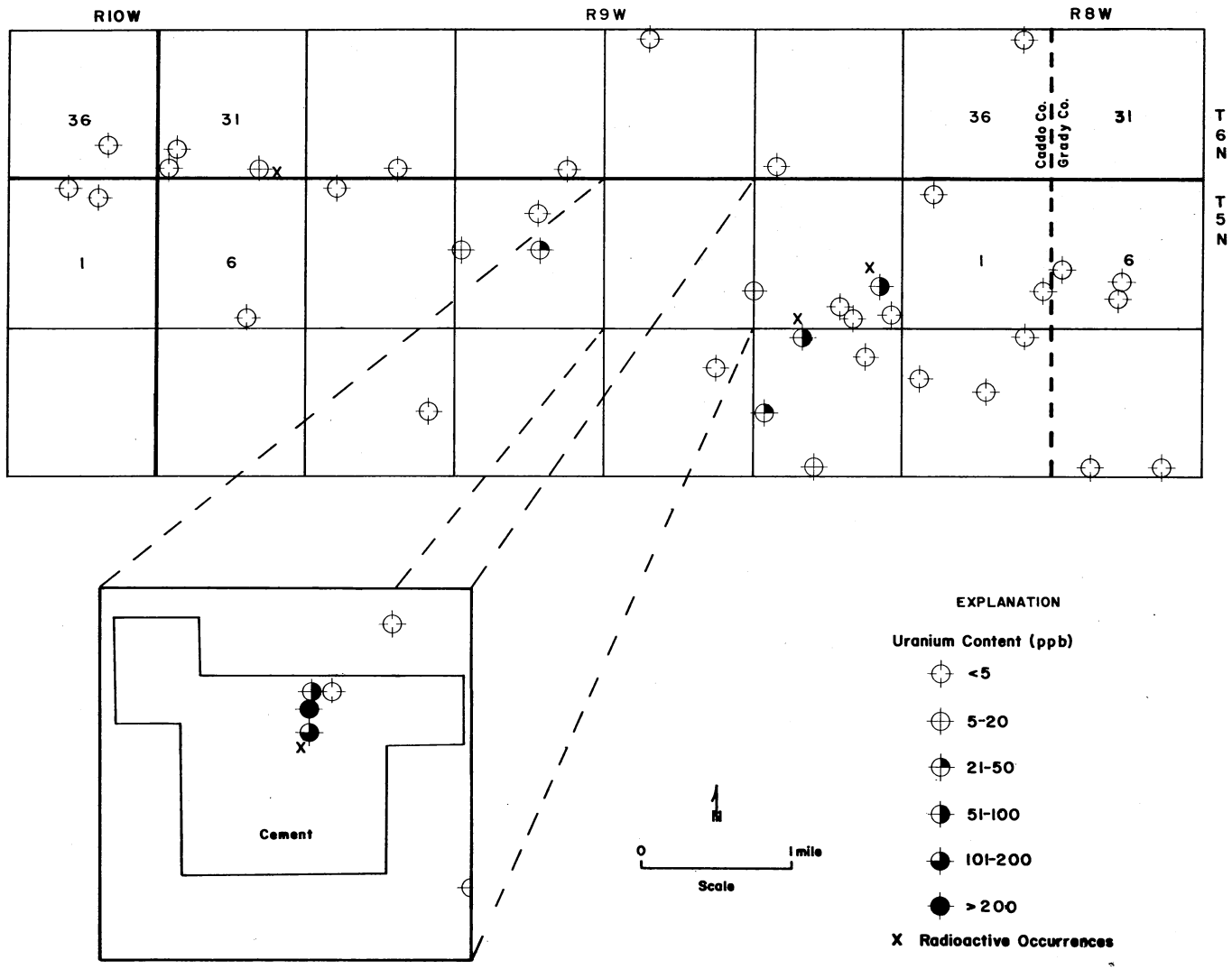

Fig. 8.-Ground-water anomalies and radioactive occurrences in the Cement area

uranium. In March, 1975, the well was again sampled and the ground water contained 700 and 860 ppb uranium.

Two private wells a short distance north of the municipal well were also tested. The wells are 200 feet apart and 142 and 154 feet deep. Eighty ppb uranium was reported in the deeper well, whereas less than 2 ppb uranium was found in the other.

High concentrations of uranium were also reported in water samples collected in Secs. 2, 4, and 11, T.5N., R.9W. The wells in Secs. 2 and 11 produce water from the Rush Springs Formation. A spring in the NE¼, SE¼, Sec. 2 contained 85 ppb uranium. The spring is located in an area where radioactive anomalies had previously been reported (p. 15). Ground-water anomalies reported in Sec. 4 were obtained from municipal wells 400 and 600 feet deep. A water sample obtained from the deepest well, which is in the center of Sec. 4, contained 38 ppb uranium. The aquifer in the well consists of a series of water bearing sandstones with a basal sandstone 100 feet thick. The sandstones are probably in the upper Duncan Sandstone or lower Chickasha Formation.

New Surface Anomalies. Anomalous concentrations of uranium in the ground water at Cement and in the spring in Sec. 2 apparently reflect the presence of nearby mineralized rocks. This association suggests that other ground-water anomalies in the Cement area might also be indicative of mineralization.

Car-borne scintillometer surveys were conducted in the vicinity of the wells having anomalous uranium concentrations. The radiometric surveys resulted in the discovery of two previously unreported mineralized areas.

In the SE¼, SW¼, Sec. 2, T.5N., R.9W. anomalous radioactivity was detected in an outcrop two feet high along the west side of an old oil-field service road. The highest radioactivity recorded along the outcrop was 0.03 MR/HR, with a normal background of 0.009 MR/HR. Anomalous radioactivity was recorded for two to three feet along the contact between a gray-green, thin-bedded, silty sandstone and an underlying massive, buff to gray, silty sandstone.

The second radioactive occurrence was discovered along the north side of the county road in the SE¼, SE¼, Sec. 31, T.6N., R.9W. The radioactivity occurred in a one-foot thick, reddish-brown sandstone, interbedded with a massive, buff colored sandstone. Asphalt concretions, some measuring up to six inches in diameter, were the most radioactive. Radioactivity near the asphaltic sandstones averaged 0.07 MR/HR compared to a background of 0.009 MR/HR. The anomalous concretions were scattered along an outcrop approximately 15 feet in length. Attempts were made to follow the gently dipping anomalous sandstone northward from the road cut but no radioactivity was detected. An increase in the background radiation to approximately 0.011 MR/HR was noted one-half mile west of the radioactive occurrence. No outcrop anomalies were reported in the area to the west.

Examination of gamma ray logs has indicated anomalous radioactivity at depth on the Cement structure. Logs were obtained from wells located in the SE¼, SE¼, Sec. 3, T.5N., R.9W. The log traces started at a depth of 100 feet below the surface. Mobil Oil Company's Surbeck No. 6, located in the NW¼, SE¼, Sec. 3, showed several near surface radioactive anomalies. The readings indicated that three anomalous zones exist 100 to 150 feet below the surface. The highest radioactivity was 130 feet

below the surface in a zone five feet thick. A second anomalous interval was indicated in the Rush Springs Formation between 280 and 300 feet below the surface and a third anomaly was found on a sandstone of the Hennessey Shale at a depth of 1,345 feet.

Subsurface anomalies were also found at several localities on West Cement dome in Secs. 34-36, T.6N., R.10W. Examination of gamma ray logs revealed several anomalous zones within 2,900 feet of the surface. The shallowest mineralization was in Sec. 35 where anomalous radioactivity was indicated at a depth of 10 to 20 feet. Additional information for gamma ray logs which showed subsurface mineralization in the study is given in Appendix C.

Cox City Deposit

Geologic Setting

In southeastern Grady County the village of Cox City is located near the crest of a major structural feature known as the Carter-Knox anticline (Fig. 9). The fold trends northwest-southeast through T.3N., R.5W. and extends into the northeastern part of T.2N., R.5W. Two episodes of deformation were responsible for the present configuration of the anticline. During the Arbuckle orogeny faulting and folding of pre-Permian rocks produced an elongate, northwest-trending, nearly symmetrical fold which was slightly overturned toward the north. A southwest-dipping thrust fault, which parallels the pre-Permian structure, displaces the north limb of the fold. The fault dies out with depth in incompetent upper Mississippian shales (Reedy and Sykes, 1959).

A Permian anticline unconformably overlies the deeper fold (Fig. 9). The upper structure was formed by closure against a normal fault which

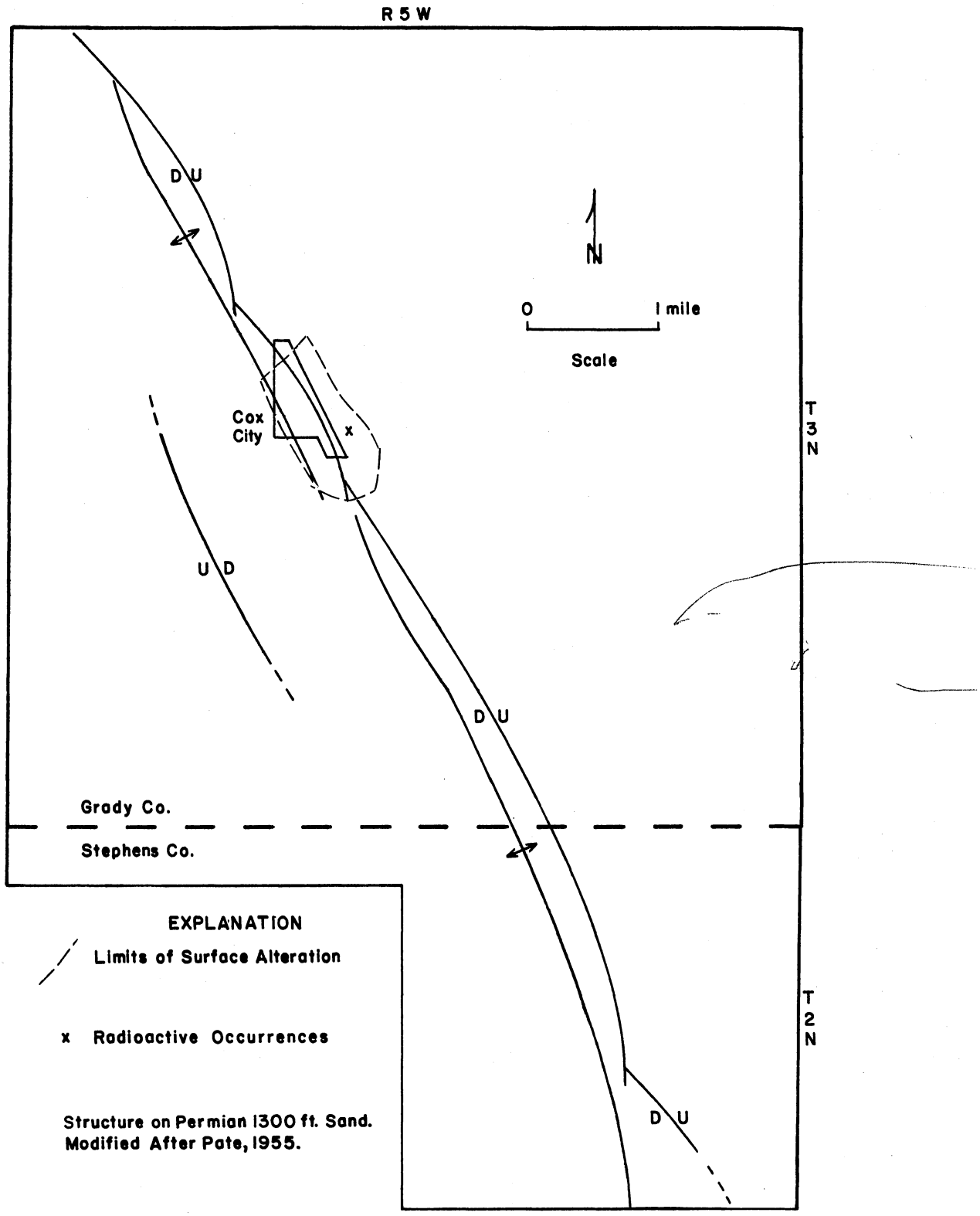

Fig. 9.-Structure map of the Cox City area showing radioactive occurrences and surface alteration

strikes N30°W and dips 60 to 65 degrees toward the southwest (Pate, 1955). One hundred to two hundred feet of displacement has occurred along the fault. One mile west of the anticlinal axis a northeast-dipping normal fault forms the west boundary of a graben which parallels the fold. Both normal faults extend through the Permian section into the underlying Pennsylvanian structure.

The Permian section on the Carter-Knox anticline is approximately 2,100 feet thick. Outcropping formations on the structure include the Chickasha Formation and underlying Duncan Sandstone.

Petrology and Petrography

Members of the upper Duncan Sandstone and lower Chickasha Formation crop out near Cox City. The exposed rocks are fine- to very fine-grained sandstones with interbedded silty sandstones and a few carbonate, clay-pebble conglomerates. The sandstones which crop out near the crest of the structure generally are buff to yellow-brown in color, with some reddish-brown staining. In Cox City these sandstones are white and contain small brown concretions. The sandstones in this area are hard and contain carbonate cement.

The silty sandstones and carbonate conglomerates are found along stream channels and on the flanks of the anticline. The sandstones are generally buff to yellow-brown, however, in several areas they are blue-gray.

The buff colored carbonate conglomerates contain carbonate and clay pebbles in a detrital matrix. The conglomerates are well-indurated and are bound by carbonate cement.

The calcareous sandstone which crops out near the crest of the

anticline at Cox City is similar to the carbonate sandstones at Cement. The fine- to very fine-grained sandstone contains 53 per cent quartz, 5 per cent orthoclase, and traces of chert, microcline, and plagioclase. Thirty-six per cent of the rock is carbonate cement with iron oxide accounting for 6 per cent.

Most of the detrital grains are altered to either carbonate, sericite or clay, but some fresh quartz, microcline, and plagioclase were observed. The carbonate alteration occurs as replacements along grain boundaries with clay and sericite alteration being on the surfaces of the grains. Iron oxide rims were observed on several grains and a deep red, iron oxide cement was noticed around several of the grains.

The silty sandstones are very fine-grained, poorly sorted, and contain up to 41 per cent clay matrix. Hematite squares (probably formed after pyrite) are common in the matrix of the blue-gray sandstones. The squares range from 0.03 to 0.10 millimeter across and have iron oxide halos. Reaction rims of sericite and reddish-brown clay were observed on most of the detrital grains.

Quartz is the primary detrital constituent, accounting for 47 per cent of the sample. A few composite quartz grains with sutured contacts were observed and several grains displayed undulatory extinction.

Eight per cent of the rock consists of orthoclase with traces of plagioclase, microcline, chert, and sericite. The feldspars, including plagioclase and microcline, are in various stages of alteration to sericite and clay, however, a few fresh plagioclase and microcline grains were observed.

Several carbonate grains with detrital nuclei were also found in the sandstone.

The clay-pebble conglomerate contains carbonate and clay pebbles in a detrital matrix and is bound by carbonate cement. The clay pebbles consist of reddish-brown calcareous mud with some very fine-grained quartz. Some of the pebbles contain very fine-grained carbonate rhombs, with a few small hematite grains.

The carbonate pebbles, some measuring over 1.0 millimeter in diameter, contain small grains of quartz which show evidence of replacement by the carbonate. Several of the pebbles have nuclei consisting of fine-grained carbonate crystals which appear as "islands" in a carbonate, mud matrix. Many of the pebbles are rimmed by iron oxide and clay.

The matrix of the rock consists primarily of quartz, with lesser amounts of orthoclase, plagioclase, microcline, and chert. The quartz is both fresh and heavily altered, being replaced by carbonate cement. Most of the orthoclase is altered to clay and a few of the feldspars show evidence of sericitic alteration. Traces of microcline and plagioclase with fresh surfaces and carbonate altered edges were also observed.

A very fine-grained carbonate cement binds the rock together. In several areas the cement consists of very fine-grained rhombs which have small hematite grains at their centers.

Surface Alteration

A small area on the axis of the Carter-Knox structure was outlined by McKay and Hyden (1956) as showing evidence of surface alteration (Fig. 9). Units of the lower Chickasha Formation and upper Duncan Sandstone which generally have a purple and reddish-brown coloration, have been altered to shades of buff, gray, and white. Near the intersection of State Highway 17 and the county road in Cox City, the Duncan Sandstone

is white in color and is well indurated with carbonate cement. A short distance south and east of the intersection, blue-gray siltstones and shales are found interbedded with yellow and buff colored sandstones.

Radioactive Anomalies

Ground Water. An intensified hydrogeochemical survey was conducted in the Cox City area for the purpose of locating areas of radioactive mineralization. Twenty samples were collected in a 36 square mile area in T.3N., R.5W. Results from the survey (Fig. 10; Appendix A) show a major anomaly in the SW¼, SW¼, Sec. 17, T.3N., R.5W. on the west edge of Cox City. Ground water collected from the well in June, 1974, contained 365 ppb uranium. Two samples taken from the same well in March, 1975, contained 440 and 480 ppb uranium.

The well is 225 feet deep, with water production from the Duncan Sandstone. The well which serves several households in Cox City is reported by the owners as commonly having a gaseous smell.

Surface. Radioactive anomalies were detected by a car-borne scintillometer survey conducted in a six square mile area around Cox City. T e anomalous readings were obtained on outcrops in a drainage ditch along the south side of a county road approximately 200 yards east of the intersection in Cox City. The highest readings which were found at several places along the ditch averaged 0.02 MR/HR compared to a normal background of 0.009 MR/HR.

The anomalous radioactivity occurred on several blue-gray, argillaceous sandstones which were interbedded with yellow limonitic sandstones and buff colored, carbonate conglomerates. The radioactivity

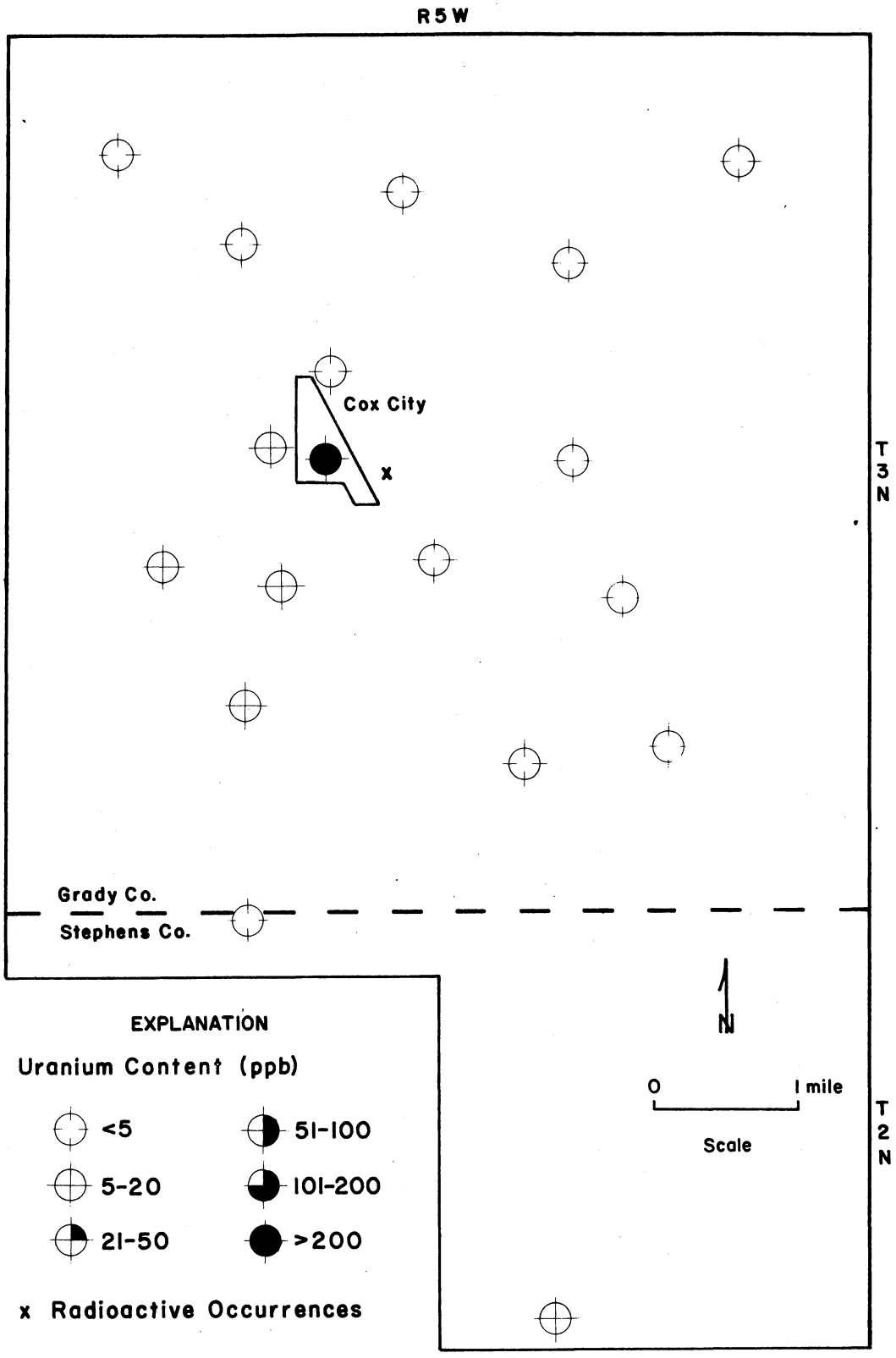

Fig. 10.-Ground-water anomalies and radioactive occurrences in the Cox City area

generally was found near the contact between the conglomerate lenses and the blue-gray sandstones. The radioactivity occurred on several discontinuous zones approximately six inches thick which could not be detected away from the road cut.

Gamma ray logs from oil wells in the north half of Sec. 21, T.3N., R.5W. were studied and indicate the presence of radioactivity in the Cox City area (Fig. 11). Several near surface anomalies are indicated in the NE¼, NW¼, Sec. 21, with the highest radioactivity occurring on a zone five- to seven-feet thick. The anomalies are located on a zone within 100 feet of the surface in an area close to the normal fault, near the axis of the Carter-Knox structure. The mineralized horizons occur on either side of the fault but are not continuous throughout its entire length. The strongest mineralization was encountered 45 and 75 feet below the surface.

Red River Deposit

Geologic Setting

The Waurika-Muenster arch, a buried paleo-topographic ridge, is the dominant structure in the southern part of the study area. Entering Oklahoma in southeastern Jefferson County, the arch trends northwestward across Jefferson, Cotton, and Tillman Counties intersecting with the Wichita Mountains in southwestern Comanche County. The structure which has a maximum structural relief in excess of 5,000 feet is essentially a buried mountain range composed of granite and limestone (McBee and Vaughn, 1956). The arch was buried by Middle and Upper Pennsylvanian sedimentary rocks and has many oil fields located along its axis and on minor flanking structures.

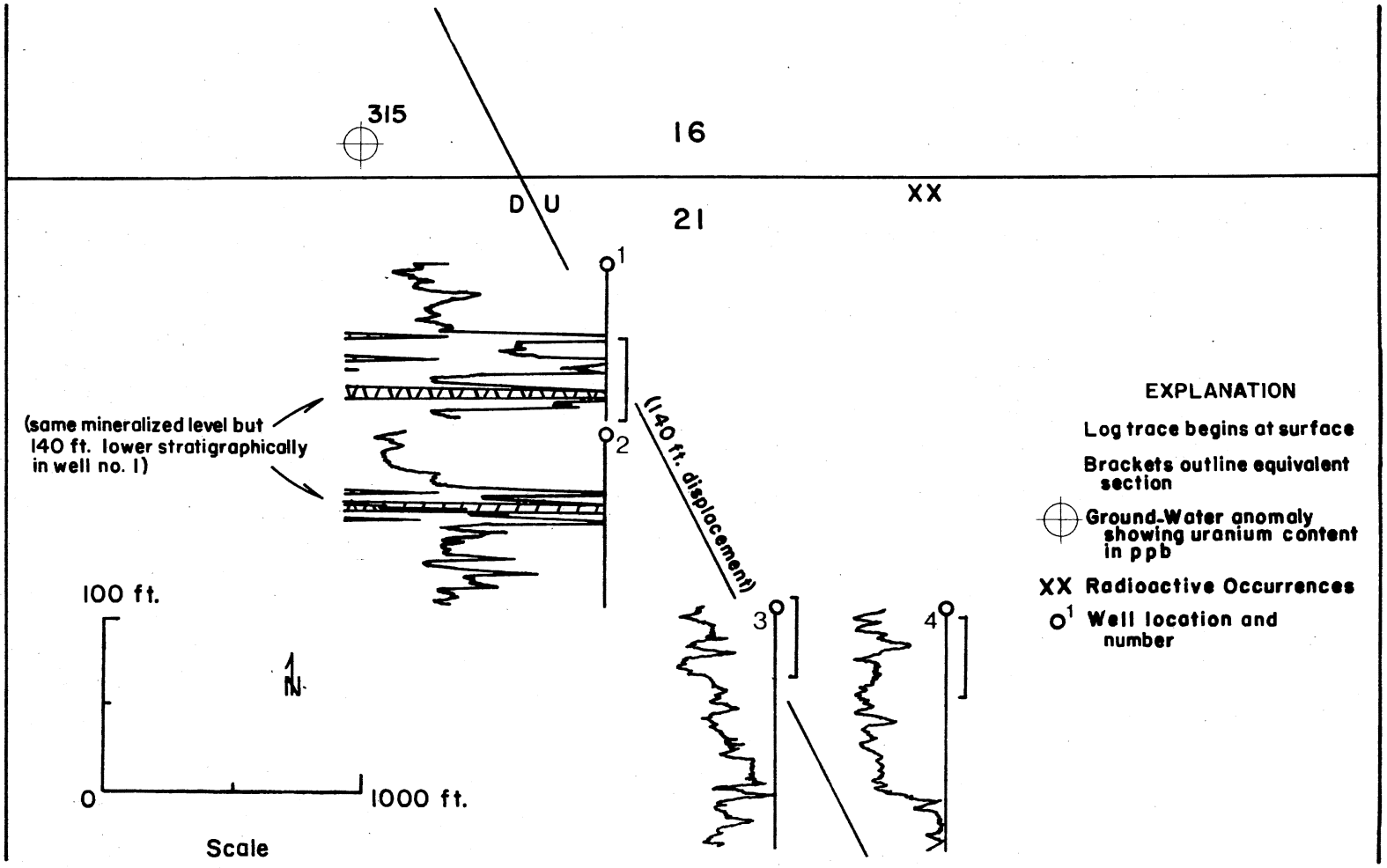

Fig. 11.-Gamma ray log map of the Cox City area showing subsurface mineralization

North of the Waurika-Muenster arch the axis of the northwest-trending Marietta basin extends through central Jefferson and Love Counties. The basin separates the arch from the Wichita-Criner Hills uplift which is located in southern Stephens and Carter Counties.

Core-drilling and geologic studies conducted by Bunn (1930) showed numerous small surface structures throughout Jefferson County. All of the folds were situated on or near the axis of either the Waurika-Muenster arch or the Wichita-Criner Hills uplift. The structures are generally characterized by shallow dips on their flanks and little, if any, topographic relief.

Sedimentary rocks cropping out in the Red River area are of Upper Pennsylvanian and Permian ages. They include the Pennsylvanian Oscar Group and the Permian Wellington Formation, Garber Sandstone, and Hennessey Shale.

Petrology and Petrography

The formations which crop out in the southern part of the study area consist of reddish-brown to gray shales and siltstones with lenses of weakly-indurated, friable sandstone. The sandstones generally have a buff to gray or reddish-brown coloration. They are fine- to very fine-grained and are composed of subangular to subrounded sand grains. The sandstones are generally very well sorted.

Silty sandstones also are found in the study area and occur interbedded with shale or in the lower part of the sandstone channels. They generally have a buff to yellow-brown color. The sandstones are very fine-grained and are poorly sorted.

A few conglomerate lenses were also found in the study area. The

conglomerates generally are buff to reddish-brown and are composed of carbonate and clay pebbles in a detrital matrix. The conglomerates are cemented with iron oxide and carbonate.

Quartz comprises approximately 60 per cent of the channel sandstones. Although fresh quartz grains are present most of the grains are cloudy. Several grains have quartz overgrowths and some composite quartz grains have sutured contacts.

Orthoclase constitutes from 8 to 10 per cent of the sandstone, with plagioclase comprising about 2 per cent of the rock. The orthoclase and plagioclase are extensively altered to clay and sericite.

Hematite stains occur on many of the grains and iron oxide rims are common in the reddish-brown sandstone. Very little iron oxide was found in the buff to gray colored samples.

Chert pebbles account for about 6 per cent of the rock and the samples contain a clay matrix composed of illite with some kaolinite and vermiculite, which constitutes about 9 per cent of the rock. The samples contain a great deal of void space and many of the grains are in point contact.

Quartz is the primary detrital constituent of the silty sandstones, accounting for approximately 50 per cent of the rock. Several of the quartz grains have quartz overgrowths. Composite quartz grains with sutured contacts occur in the samples.

Orthoclase constitutes about 6 per cent of the sample and traces of microcline and plagioclase are also present. Most of the orthoclase is extensively altered to sericite and clay and several individual sericite grains occur. Both fresh and altered microcline and plagioclase are present.

A clay matrix consisting primarily of kaolinite, illite, and vermiculite constitutes up to 40 per cent of the sample. Some fresh and slightly altered pyrite squares occur in the clay. The pyrite is altered to limonite and hematite and in several areas the hematite is cemented to some of the grains.

Chert pebbles comprise 1 to 2 per cent of the sample. Several biotite and chlorite grains occur in the sandstone along with a few heavy mineral grains. Flood (1964) identified the heavy minerals in the sandstones of western Jefferson County as primarily zircon, tourmaline, and leucoxene.

A reddish-brown carbonate conglomerate found interbedded with silty sandstones and shale is composed of large carbonate pebbles in a fine-grained quartz, feldspar, and clay matrix. Very fine-grained quartz fragements showing evidence of replacement by carbonate are found in the carbonate pebbles. The pebbles are rimmed by iron oxide and clay. Several clay and iron oxide pebbles are also present in the rock.

Most of the sample is bound by a very fine-grained carbonate cement, however, in places the rock is cemented by iron oxide. In the areas cemented by iron oxide the grains generally have fresh edges, however, surface alteration of some grains is visible.

Surface Alteration

Although surface alterations are not readily recognized in southern Jefferson and Cotton Counties, core-drilling conducted by Bunn (1930) showed that there is a pronounced color change in the formations over some of the major structures in Jefferson County. He observed that brown colored shales generally contained a larger proportion of light-

blue or gray color toward the apex of the structure. The drilling fluids and shale chips from a well on a structure in Sec. 24, T.7S., R.6W. were recognized as having a light-gray color to a depth of 1,000 feet. According to Bunn these same formations were found to be red in a hole drilled three-fourths mile down the structure.

Radioactive Anomalies

Several radioactive occurrences have been reported in southern Jefferson and Cotton Counties (p. 13, 14; Plate 1). The largest deposit and the one having the highest concentration of uranium was found in the SW¼, Sec. 30, T.5S., R.12W. south of Randlett in Cotton County. Uraninite, torbernite, autunite, uranophane, carnotite, and bayleyite were found in a sandstone channel approximately 600 feet long, 300 feet wide, and 25 feet thick. The channel has a N20°E orientation (Beroni, 1954). Mineralization is confined to the lower portion of the channel in an area 25 feet long and two to four feet thick. A high silt and clay content along with abundant carbonaceous material characterizes the sandstone in the mineralized area. The host, a fine- to very fine-grained sandstone, has a glue-gray coloration due to the abundant clay content. The predominant clay mineral is kaolinite with smaller concentrations of illite and vermiculite. The mineralized sandstone grades upward into a buff to gray, fine- to very fine-grained barren sandstone which contains no carbonaceous material and very little silt or clay.

Descriptions and locations for the other mineralized areas in southern Jefferson and Cotton Counties are given on pages 13 and 14 and in Appendix B.

Ground Water. Analyses of ground-water samples collected in the

southern part of the study area reveal several anomalies in western Jefferson and southeastern Cotton Counties (Plate 2; Appendix A).

A concentration of 18 ppb uranium was in a sample of water from a well 75 feet deep in the NE¼, NE¼, Sec. 11, T.6S., R.8W. The owner of the well had drilled several water wells throughout Jefferson County and noted that the aquifer in his well contained a lighter-colored sandstone than other water bearing zones he had drilled. The aquifer is a sandstone in the upper Oscar Group.

Samples collected from three wells in western Jefferson and southeastern Cotton Counties have the highest uranium content of the samples collected in the southern part of the study area. A well 20 feet deep in NE¼, SE¼, Sec. 35, T.4S., R.9W. had water that contained 26 ppb uranium and a well 42 feet deep in Sec. 33, T.4S., R.9W., had water containing 30 ppb uranium.

The highest concentration of uranium was in a sample obtained from a well of unknown depth at a service station in the SW¼, SW¼, Sec. 34, T.4S., R.10W. A sample collected in June, 1974, contained 44 ppb uranium and two samples collected in March, 1975, contained 48 and 55 ppb uranium.

Surface. Car-borne radiometric surveys conducted in western Jefferson and southeastern Cotton Counties outlined an anomaly in Sec. 17 and 18, T.5S., R.8W. The radioactivity was detected on a series of interbedded argillaceous sandstones and shales which were found in outcrops along a county road. The anomalous readings were obtained on outcrops approximately 175 feet apart which occurred on both sides of a small drainage that intersects the road near the center of Secs. 17 and 18. The highest recorded radioactivity was 0.07 MR/HR compared to a

normal background of 0.009 MR/HR. The anomalous readings were obtained on a reddish-brown and blue-gray mottled shale six- to eight-inches thick that was interbedded with buff-colored argillaceous sandstones.

An argillaceous sandstone four- to six-inches thick about two feet below the previously described shale, is also radioactive. The buff-colored sandstone is mineralized along its contact with an underlying reddish-brown and blue-gray, mottled shale. The mineralized portion of the outcrop has a radioactivity of 0.025 MR/HR.

A carbonate conglomerate approximately eight-inches thick, occurs in the road cut on the north side of the small drainage. The conglomerate is not radioactive, however, an overlying silty shale 1.5-feet thick has zones of anomalous radioactivity which averaged 0.025 MR/HR.

Other Geochemical Anomalies

Several wells in northern Cotton and southwestern Stephens counties contained water having high concentrations of uranium (Plate 2). Excluding the well located in Sec. 36, T.1S., R.12W. which produces water from stream gravels at a depth of 24 feet, each of the anomalies is located on or near a subsurface structural feature.

Eighteen ppb uranium was in a water sample from a well in Sec. 25, T.2S., R.13W. The well is 50 feet deep and is situated near the buried axis of the Waurika-Muenster arch.

The anomalies in T.2S., Rs.7-10W. also are in areas underlain by pre-Permian anticlines. The structures which include the Comanche, Empire, West Duncan, and Walters anticlines, are all major oil producing structures. The high concentrations of uranium found in T.2S., Rs. 7 and 10W. suggest that this area might contain radioactive mineralization and should be studied in detail.

CHAPTER VI

ORE GENESIS

A study of the distribution of geochemical anomalies in south-central Oklahoma (Plate 2) reveals a close association between oil-producing structures and water samples, having anomalous concentrations of uranium. Many of the uranium anomalies are associated with structures that have evidence of the vertical migration of hydrocarbons. The primary indication of this migration is the alteration of red beds to colors of gray, yellow or white and the occurrence of carbonate cement in normally weakly-indurated, friable sandstones which overlie the leaking pools.

Hydrocarbon Migration and Alteration

The mineralogic changes which are found in sedimentary rocks over leaking oil reservoirs are indicative of reducing conditions which prevail within the zone of surface alteration. According to Levandowski, et al. (1973) the color changes result from the oxidation of the migrating hydrocarbons, which in turn reduce the ferric oxides contained in the red beds to pyrite and soluble ferrous ions. Figure 12 is a stability field diagram for the aqueous ferric-ferrous system. If the redox potential (Eh) and pH of the ground waters lie within the field of ferrous iron, the iron will remain in solution and be removed with the waters. Levandowski, et al. (1973) noted that the reducing conditions

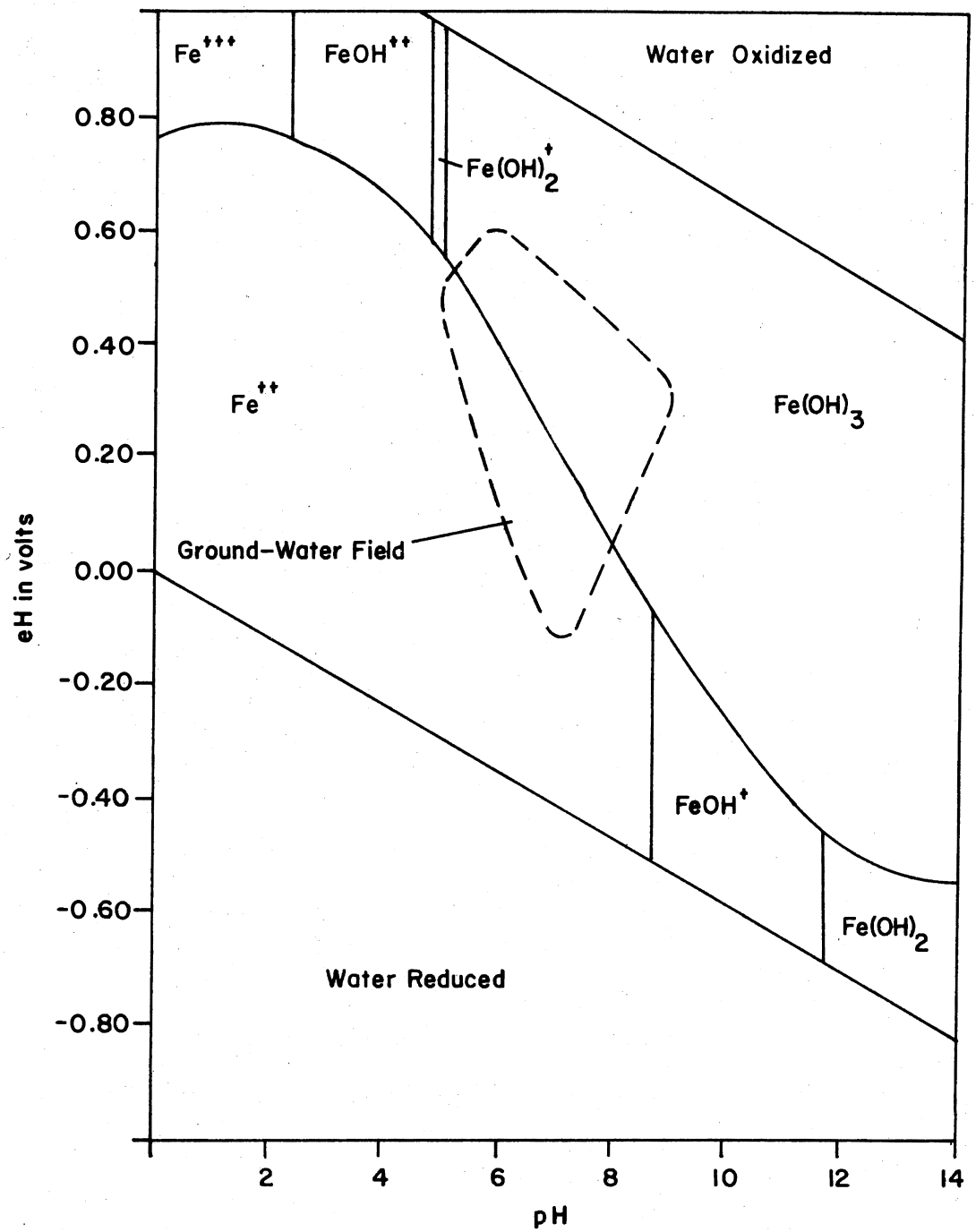

Fig. 12.-Stability field diagram for the aqueous ferric-ferrous system. After Donovan (1972)

within the zone of alteration result from reactions between sulfates or iron oxides and migrating organic materials. Using sulfate and methane for an example, Krauskopf (1967) showed the oxidation process as:

$$2H^{+} + SO_4^{=} + CH_4 \rightarrow H_2S + CO_2 + 2H_2O$$

A complex solid hydrocarbon commonly is produced along with carbon dioxide and water. In addition to hydrogen sulfide, the reduced products of the reaction may include pyrite. Hydrogen sulfide contained within the escaping hydrocarbons also has been sighted as contributing to the formation of the reducing environment (Donovan, 1972; Eargle and Weeks, 1961).

The migrating hydrocarbons are commonly introduced into the overlying formations along faults or fractures near the leaking reservoirs. According to Donovan (1972) the limits of alteration at Cement were controlled by a pre-Permian unconformity. Faults which were truncated by the unconformity provided the primary conduits for the migration of hydrocarbons into the overlying Permian formations. The most intense alteration occurred in areas which were superimposed over the fault traces. Diffusion of hydrocarbons through the unfaulted Permian formations resulted in extensive alteration of the red beds. Localized fracturing of the Permian section provided further avenues for the upward migration of the hydrocarbons.

During hydrocarbon migration carbonate cement commonly is deposited in the pore spaces of the overlying sandstones. Thode, Wanless and Wallouch (1954) have shown that the carbonates result from the reduction of sulfates during the oxidation of petroleum. The carbon dioxide produced during the reaction dissolves in the ground waters and subse-

quently reacts with cations to produce the carbonate cement. Although the oxidation processes may involve anaerobic bacteria, Toland (1960) has shown that the reaction may be inorganic under relatively mild conditions in the presence of hydrogen sulfide.

Based upon the carbon and oxygen isotopes found in the calcareous sandstones at Cement, Donovan (1972) concluded that the carbonate reflects a decrease in the influence of hydrocarbon oxidation with increasing distance away from the crest of the structure and away from areas over projected fault traces. The most intense zones of alteration and mineralization are characterized by a carbonate cement that is enriched in both C^{12} and O^{18} (light carbon-heavy oxygen). Donovan interpreted these cements as having formed through evaporation of formation waters in the presence of oxidized petroleum. As the gas and low-molecular-weight liquid fractions moved toward the surface, pore waters evaporated into the expanding vertically migrating hydrocarbons, resulting in the concentration of dissolved salts. Gradual concentration of carbonate through such a mechanism ultimately resulted in the precipitation of the interstitial cements.

Donovan (1972) observed that the carbonate derived from oxidized petroleum decreases away from the primary avenues of subsurface to surface migration, until on the perimeters of the zone of alteration, the carbonate has an isotopic composition typical of diagenetic or freshwater carbonates (normal carbon-normal oxygen). According to Donovan these carbonate cements formed through micropore-filtration from circulating ground waters.

The carbonate near the mineralized fracture at Cement probably formed through the process of micropore filtration from waters migrating

along the flanks of the fold. Donovan (1972) concluded that carbonate rich waters migrated through negatively charged clay particles contained in the host rocks and that carbonate anions in the ground waters were repulsed by the clay particles and remained behind attracting cations. Eventually the solution became saturated with carbonate and precipitations occurred where hydrocarbons were present. Donovan (1972) noted that the presence of calcite in the sandstones at Cement establishes a minimum pH of 8.3 for the system. The bleaching of the sandstones took place as a result of the reduction of ferric iron to the soluble ferrous state, and it can be seen from Figure 12 that at the time of alteration, the redox potential (Eh) of the ground waters must, therefore, have been in the range of .05 to .10 volts.

Another result of the oxidation of migrating hydrocarbons is the formation of residual solid hydrocarbons through the process of polymerization (the building up of large molecules from simple molecules by condensation). These solid hydrocarbons are deposited as grain coatings and interstitial fillings in the sandstones. Erickson, Myers, and Horr (1954) have shown that metallic ions are concentrated in the residual solid hydrocarbons, with oxidation of the hydrocarbons and loss of the lighter fractions of the oil. Deposition and metalliferous enrichement of solid hydrocarbons by such a mechanism probably accounts for the radioactive asphaltic materials found near Cement (p. 53) and at other places in southern Oklahoma (p. 12).

Uranium Mineralization

Deposition of uranium along the fracture at Cement probably resulted from the interaction of hydrogen sulfide with uraniferous ground

waters. Reduction of soluble uranyl ions by the hydrogen sulfide probably resulted in the precipitation of uranium.

Although the migrating hydrocarbons may have contained some uraniferous materials, the intense reducing conditions of the migrating solutions precludes the hydrocarbons as a transporting medium. The uranium must, therefore, have been transported in solution to the site of deposition by ground waters. This conclusion is supported by Donovan's (1972) findings concerning the origin of the carbonate cement found in the sandstones near the former ore deposit. Donovan stated that the carbonate had formed through micropore-filtration from waters which had converged on the anticline. The formation of carbonate through such a mechanism would have required the movement of large quantities of water into the area of mineralization. The probability that these solutions could have contained sufficient quantities of uranium to produce the ore body is suggested by the chemical nature of the waters.

In order for the carbonate cement to have formed by micropore-filtration, the migrating ground waters must have contained large quantities of dissolved CO_2. The carbon dioxide may have been derived from the atmosphere, or from the dissolving of limestones and dolomites. Lisitsin (1962) and Hostetler and Garrels (1962) have shown that the solubility of uranium increases sharply in waters of intermediate pH containing dissolved CO_2. The authors have found that most of the uranium in these solutions occurs as uranyl dicarbonate dihydrate $[UO_2(CO_3)_2 \cdot 2H_2O]^{-2}$ and partly as uranyl tricarbonate $[UO_2(CO_3)_3]^{-4}$. One of the ways in which the dicarbonate complex may form is through oxidation of solid uranium oxide, according to the equation:

$$UO_{2(s)} + 2(CO_3)^{=} + 2H_2O \rightarrow [UO_2(CO_3)_2 \cdot 2H_2O]^{-2} + 2e^-$$

The tricarbonate complex will form in solutions which have higher concentrations of dissolved CO_2.

The abundance of dissolved CO_2 in the waters which moved onto the anticline and the increased solubility of uranium in carbonate rich solutions imply that migrating ground waters moving up the flanks of the structure transported uranium into the ore zone.

As the uraniferous solutions passed through the sandstone, precipitation of calcite stripped the carbonate anion from the uranyl carbonate complex. The freed uranyl cation was then reduced by hydrogen sulfide. The hydrogen sulfide was contained in the escaping hydrocarbons, or was produced as a by-product of the reduction of sulfates by the hydrocarbons. The following equations are used to illustrate these reactions:

$$[UO_2(CO_3)_2 \cdot 2H_2O]^{-2} \rightarrow UO_2^{++} + 2(CO_3)^{=} + 2H_2O$$

$$UO_2^{++} + 2e^- \xrightarrow{\text{reduction by } H_2S} UO_{2(s)}$$

The resulting insoluble uraninite (UO_2) was probably precipitated from solution along the fracture where the reducing conditions were the strongest.

Oxidation of the uraninite at a later date probably resulted in the formation of new uranium minerals. According to Garrels and Christ (1959) uranyl ions produced during oxidation of uraninite may unite with vanadium, phosphorus or arsenic contained in the oxidizing solutions, resulting in the formation of insoluble sheet-like structures. The sheets are bound by cations which were also contained in the oxidizing solutions. The presence of the vanadates carnotite $[K_2(UO_2)_2(VO_4)_2 \cdot$

1-3H_2O] and tyuyamunite [$Ca(UO_2)_2(VO_4)_2 \cdot 7\text{-}10\frac{1}{2}H_2O$] in the ore zone at Cement, suggests that calcium, potassium, and vanadium must have been present in the solutions which oxidized the ore body. These ground-water constituents probably reacted with uranyl ions, resulting in the formation of the insoluble uranium minerals currently found in the deposit.

The diffusion bands of yellow, limonite-colored sandstone around the white host in the ore zone (McKay and Hyden, 1956) implies that the effects of reduction were diminished away from the fracture. Because the ground water apparently contained high concentrations of carbonate, reduction of uranium (UO_2^{++}) probably could take place only under the intense reducing conditions which occurred along the fracture.

The mechanisms responsible for uranium precipitation at Cement are not necessarily near surface phenomena and may, therefore, have occurred in the subsurface. According to Donovan (1972) the alteration which is confined to sandstone intervals, extends to a depth of at least 2,500 feet. A study of ground-water anomalies and gamma ray logs of the Cement area (Fig. 8) indicates that mineralization has occurred at shallow depths (100-600 feet) over the structure. Gamma ray logs in Secs. 2-3, T.5N., R.9W. and Secs. 34-36, T.6N., R.10W. (Appendix C) recorded radioactive mineralization from zones near the surface to depths in excess of 2,800 feet.

Gypsums and anhydrites commonly occur in the subsurface throughout the Anadarko basin. According to Robert O. Fay (oral communication, 1975) some of the sulfate deposits may extend as far south as Caddo, Grady, and northern Stephens Counties. Reduction of these evaporites by migrating hydrocarbons would result in the formation of an environ-

ment favorable for uranium precipitation. Subsurface brines or connate waters migrating through sandstones could transport uranium into these areas. Reduction of the uraniferous solutions by hydrogen sulfide produced through reduction of the sulfates by migrating hydrocarbons would result in the formation of an ore deposit. Subsurface sandstone and evaporite deposits near oil-producing structures should, therefore, be considered as favorable sites for future exploration.

Studies of the mineralization at Cox City suggest that the ore controls in this area were similar to those found at Cement. Carbonate cementation and bleaching of the surface formations occur over the Carter-Knox anticline, implying that hydrocarbon leakage has taken place. The surface alteration is along a normal fault near the crest of the structure. The fact that oil has been produced from Permian reservoirs formed by closure against the fault, further supports the assumption that hydrocarbon migration has occurred.

The wells with subsurface mineralization at Cox City are located on either side of the fault which probably was a primary avenue for hydrocarbon migration (Fig. 11). According to Pate (1955) 100 to 200 feet of displacement occurred during faulting. After adjustments are made for elevations of the wells it is evident that the mineralization occurs at the same level across the fault. Deposition of radioactive materials must, therefore, have occurred after fault movement and was probably related to hydrocarbon seepage along the fault. The mechanics of deposition were probably very similar to those described at Cement.

The role played by migrating hydrocarbons in the reduction and subsequent precipitation of uranium has been substantiated by workers who studied several large uranium deposits near oil-producing structures

along the Texas Gulf Coast. Eargle and Weeks (1961) concluded that faults near the petroleum reservoirs may have provided passages for hydrogen sulfide to seep into the overlying rocks. Uranium deposition resulted from the movement of uraniferous ground waters into the areas where suitable reducing environments prevailed.

Stratigraphic Ore Controls

In the southern part of the study area a few geochemical anomalies were noted which are apparently unrelated to structural features (Plate 2). In addition, several radioactive anomalies were found on sandstones which contained appreciable amounts of silt and clay, and mineralization was also detected along the contact between sandstone lenses and the surrounding argillaceous materials.

Most of the economic uranium deposits in the United States occur in sandstones which contain interfingering mudstone lenses. According to Gableman (1971) the primary features of uranium host-rock favorability are: a permeable host which allows movement of large volumes of ground water; interruption or delay of flow rate to allow uranium precipitation; and chemical precipitants in the rock. A study of the relationship of mineralization to silt- and clay-rich sandstones in the southern part of the study area suggests that the movement of uranium bearing solutions may have been restricted by the fine-grained materials. The resultant slower velocity apparently contributed to the stagnation of the solutions, causing precipitation of uranium.

Several geochemical anomalies were discovered in the southwestern part of the study area on Upper Pennsylvanian and Lower Permian red beds (Plate 2). In the southeastern part of the study area, however, the

same stratigraphic interval contained little anomalous ground water. According to Flood (1964) the source area for the sedimentary rocks in the southern part of the study area was the Ouachita and possibly Arbuckle Mountains. As materials were carried westward into the Hollis basin the silt and clay content of the sediment would be greater with increasing distance away from the source area. Thus, a higher silt and clay content would be expected in the sandstones toward the southwest, in comparison to the same stratigraphic units toward the southeast. The greater amount of argillaceous materials toward the west may have aided in uranium precipitation and may account for the anomalies in that area.

The presence of small amounts of pyrite in several of the mineralized clayey sandstones indicates that reducing agents contained within the silt and clay may also have contributed to the deposition of uranium. In the N.20°E.-trending channel deposit in Sec. 30, T.5S., R.12W., wood fragments and fine-grained organic matter occur along with large quantities of silt and clay, in the zone of mineralization. The relatively clean sandstones in the upper portion of the channel show no evidence of uranium mineralization. Uranium impregnated solutions passing through the more permeable sandstone apparently came in contact with the reductants which were concentrated in the lower portion of the channel, resulting in the precipitation of uranium.

The reduction of uranium by carbonaceous materials has frequently been sighted as a major factor in the formation of uranium deposits, thus sand bodies containing wood fragments or disseminated organic materials provide a suitable environment for the deposition of uranium. In addition to the mineralized channel in T.5S., R.12W., sandstones containing organic matter and radioactive materials have been discovered

at other localities throughout central Oklahoma (p. 13, 14; Appendix B). The sandstones were probably deposited in a near-shore to deltaic environment, and thus contain many plant fragments. All of the clastic formations in the study area have evaporite equivalents further northward and westward, therefore, an arid climate must have prevailed in Late Pennsylvanian and Permian times.

The uranium in the silt- and clay-rich sandstones at Cement, Cox City, and along the Red River in T.5S., R.8W., probably resulted in part from velocity changes of the ground water and reduction by chemical precipitants contained in the host rocks. The position of these radioactive deposits near the axes of major oil and gas producing structural features, suggests that reduction and precipitation of uranium may also have been aided by migrating hydrocarbons.

Host Petrology and Petrography

The host rocks in the area of investigation are primarily fine- to very fine-grained subarkoses. Thin section analyses of the samples showed that the Rush Springs Formation contained more feldspar than the other hosts in the study area (Fig. 13). The sandstones at Cement were primarily subarkosic with few arkoses, whereas the other host rocks were predominantly subarkosic, approaching quartzarenites (classification after McBride, 1963).

According to Fay (1964) the sandstones in the Rush Springs Formation may record periods of uplift in the Ouachita Mountains. By Hennessey time the Arbuckle and Wichita Mountains were under water, so the source of the feldspar of the Rush Springs Formation was farther southeastward. There could have been a duel source which included the

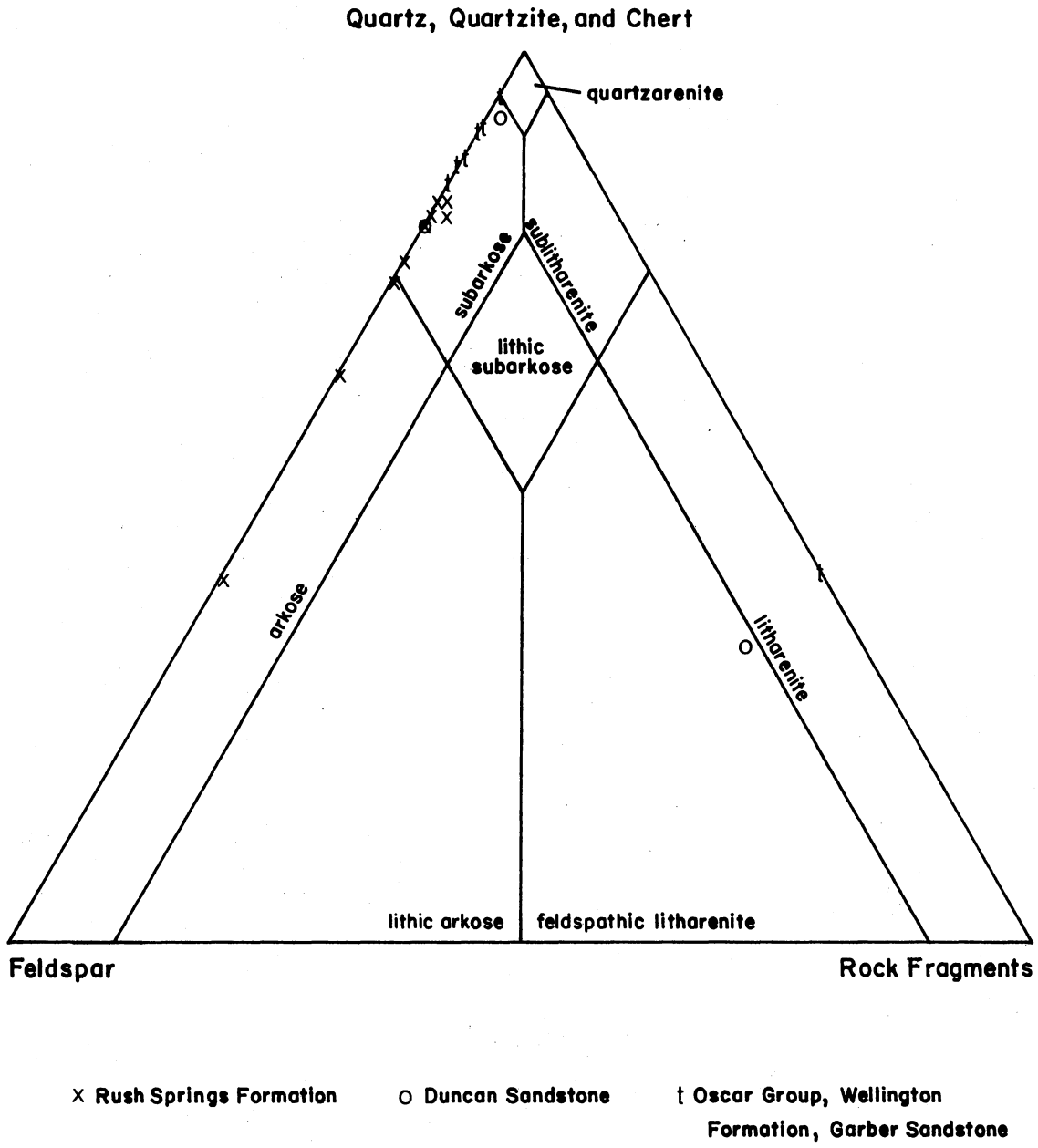

Fig. 13.-Classification of sedimentary rocks in the study area

Ozarks. Arid or semi-arid conditions, which may have prevailed during the time of sediment transport and deposition, aided in the preservation of the feldspar grains.

The sandstones which were sampled in the vicinity of the ore deposit at Cement contained less than 40 per cent carbonate cement (Fig. 14). Pore spaces in these rocks were abundant and many of the samples had hematite and limonite rims on the sand grains. McKay and Hyden (1956) reported that in the ore zone a friable white sandstone was common. Although no samples of this sandstone were collected, a sample of weakly-indurated, yellow sandstone in the same area contained no carbonate cement.

In contrast to the samples collected near the ore deposit, the gray calcareous sandstones near the zone of intense alteration on the crest of the structure contained very little pore space and the iron occurred as pyrite with no traces of hematite or limonite. The carbonate cement in these samples accounted for over 50 per cent of the total rock (Fig. 14).

The oxidized iron in the slightly porous sandstones near the mineralized fracture may have formed in mobile, oxygenated ground waters during carbonate cementation. The pyrite, the lack of pore space, and the abundant carbonate cement in the gray sandstones imply that ground water movement was greatly restricted in these areas. The absence of uranium in the gray calcareous sandstones supports the conclusion that oxygenated mobile ground waters probably transported uranium into the ore zone.

Some of the quartz found in the sandstones of the study area have moderate to strong undulatory extinction, and some composite quartz

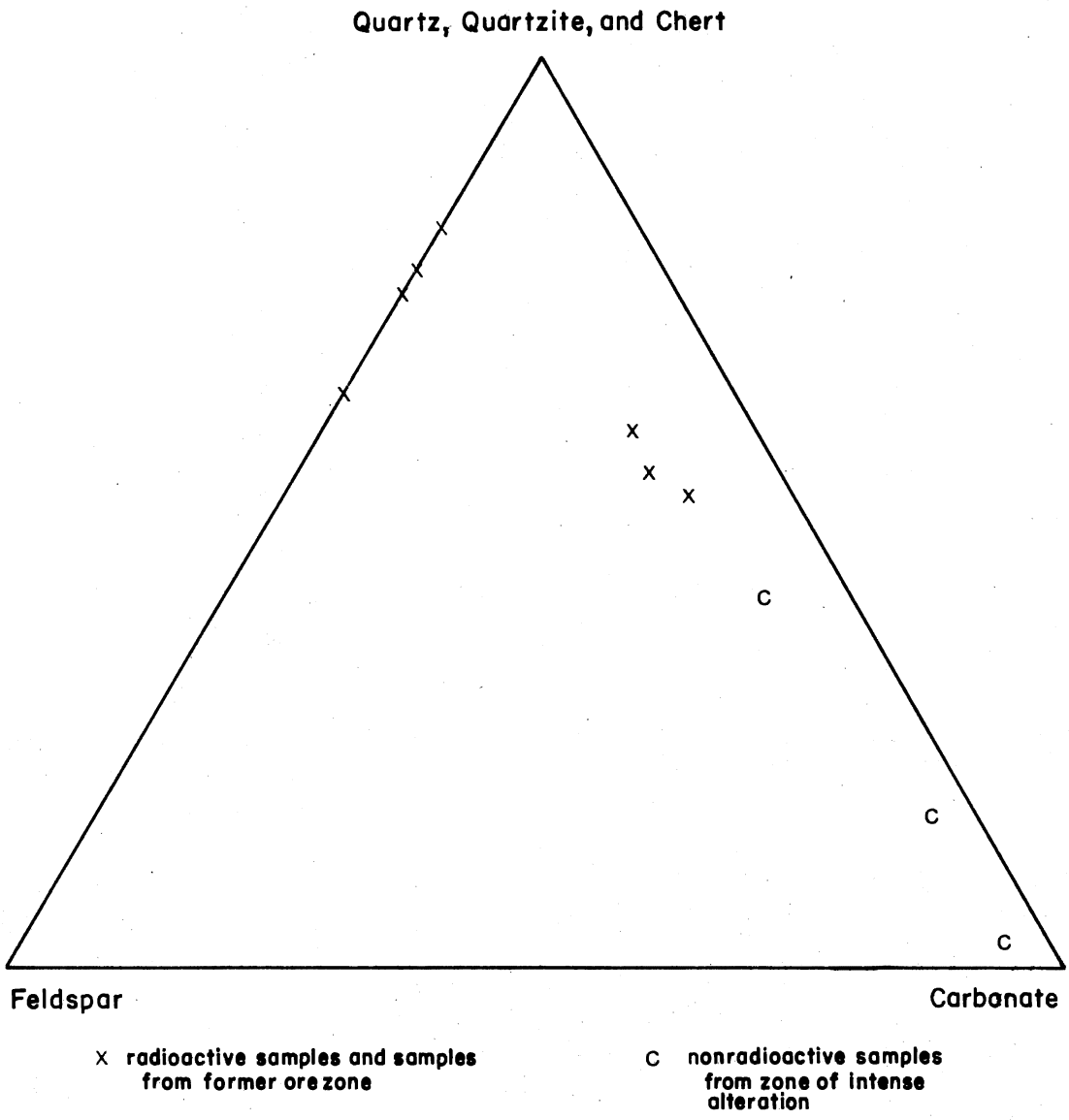

Fig. 14.-Tertiary diagram showing carbonate content of Rush Springs Formation near Cement

grains have sutured contacts. According to Folk (1968) stretched metamorphic quartz generally displays undulatory extinction, and intensely crenulated or sutured contacts between grains are common. Because low-grade metamorphic rocks are present in the Ouachita fold belt (Flawn, 1961) the metamorphic quartz grains in the sandstones probably came from the Ouachita Mountains, as suggested by Fay (1964), Self (1966), and Flood (1969).

Pyrite, and hematite squares formed after pyrite, occur in the fine-grained matrix of several mineralized silt- and clay-rich sandstones. The association suggests that uranium reduction and precipitation resulted from reactions with organic matter in the sandstones, or with migrating hydrocarbons.

Source Area

The consensus among most geologists is that the uranium in sandstone-type ore deposits was derived from surficial materials. Nearly every major sandstone-type uranium deposit in the United States contains or is overlain by volcanic ash deposits (Fischer, 1974). This association gave birth to the ash-leach theory which contends that the uranium was produced through leaching of the volcanic ash.

McKelvey, Everhart and Garrels (1955) have shown that some siliceous and alkaline igneous rocks contain unusually high concentrations of uranium. This fact, along with the association of uranium deposits with arkosic sediments or in basins adjacent to granitic highs, has lead many to believe that the uranium was derived from weathered granitic materials.

Volcanic ash deposits in Oklahoma are widely scattered throughout

the state. Most of the deposits are thought to be Plicoene or Pleistocene in age and the size of individual deposits has been estimated at 500 to 10,000,000 cubic yards (Burwell and Ham, 1949). According to Burwell and Ham, most of the deposits formed as the ash settled from the atmosphere into small lakes. Only one deposit of this nature occurs in the study area. The ash is located in extreme northwestern Tillman County.

The small size and lack of volcanic ash deposits within the study area indicates that these volcanic materials could not have been a source for uranium in southern Oklahoma. Although the pink shales in the Marlow Formation may represent altered volcanic ash deposits (Davis, 1955), their size and distribution in a shale sequence precludes their viability as a source.

Alkalic igneous materials, including granites, rhyolites, and consolidated volcanic tuffs crop out in the Wichita and Arbuckle Mountains. The fact that some of the ore hosts in the study area were derived from these igneous rocks implies that the granitic units may also have been the source for the ore minerals.

The uranium which has been reported in the Post Oak Conglomerate (p. 15; Appendix B) came from the granites in the Wichita Mountains either directly, or indirectly through disintegration of arkosic materials in the host. Chase (1954) has clearly shown that the conglomerate was derived from the Wichitas. Although no determinations of the uranium content of the granitic materials has yet been made, the mineralization near Osage Lake (p. 12; Appendix B) suggests that the uranium content may be anomalous.

The fact that the Wichita Mountains did provide sediment to the

surrounding areas before the end of Hennessey time may account for some of the ground-water anomalies obtained in northern Tillman and western Cotton Counties. Chase (1954) found arkosic materials derived from the Wichitas 20 to 30 miles south of the mountains. These arkosic sandstones and interfingering shales provide excellent conditions for uranium mineralization.

The interbedded shales and arkoses have been found in the subsurface over oil fields in western Tillman County and over the Altus field, west of the study area (Markley, 1959; Ryniker, Shortridge, and Maxwell, 1959). Migrating hydrocarbons from subsurface reservoirs may have reacted with solutions passing through the arkoses, resulting in the precipitation of uranium. These areas should be considered for future exploration, as should some of the currently non-productive structural features in the western part of the study area.

In southern Cotton and Jefferson Counties, and in other areas farther from the Wichitas, sediment from the Ouachita and Arbuckle Mountains was deposited in west-northwest-trending stream channels. As Flood (1969) has stated, the granitic rocks in the Arbuckle Mountains, including the Colbert Rhyolite Porphyry and Tishomingo Granite, were shedding arkosic materials during Oscar time. From Wellington through Marlow time, however, these granitic rocks apparently were not major sources of sediment. Although arkosic materials are confined to members of the Oscar Group, the arkoses may have produced uranium, not only for radioactive mineralization in the Oscar Group itself, but also for mineralization in younger formations.

Melton (1930) has shown that at least one period of uplift in the Ouachita Mountains occurred after deposition of the Garber Sandstone.

Self (1966) has stated that the Duncan Sandstone contains fragments of reworked sediment. Arkosic materials previously deposited around the Arbuckles may have been continually reworked and redeposited in younger sediments as renewed periods of uplift occurred in the Ouachita Mountains. Although these arkosic materials comprise only a small proportion of the sandstones, they may have provided enough uranium over an extended period of time to be the source of radioactive mineralization found in several parts of the study area.

According to Fay (1964) uplift in the Ouachita Mountains may have contributed to the deposition of sandstones in the Rush Springs Formation. The abundance of feldspars in the sandstone, relative to other formations in the study area, suggest that granitic rocks in the Arbuckle Mountains may have contributed to the sandstone. The igneous rock fragments contained in the sand may then have supplied the uranium for the deposit at Cement.

Although the primary source of sediment for the host rocks in the study area was the Ouachita Mountains this positive element probably was not the major source of the radioactive minerals found in southern Oklahoma. Granites and rhyolites in the Arbuckle and Wichita Mountains probably provided the bulk of the arkosic materials found within the study area and these granitic units were probably the major sources of uranium.

Erickson, Myers, and Horr (1954) point out that there is evidence to suggest that uranium and associated metals may be leached from asphaltic rocks by ground water. The authors concluded that over an extended period of time slightly acid ground waters may leach metals concentrated in the asphalts during oxidation and volitization of hydro-

carbons. The abundance of asphaltic materials in southern Oklahoma, along with the high concentrations of uranium found in the ground water throughout the study area, make this theory of a source for the uranium very appealing. The intense reducing conditions of the hydrocarbons suggest, however, that uranium might be fixed by the asphaltic rocks rather than leached from them by ground water.

Uranium - Groundwater System

The uranium found in most sandstone-type ore bodies was transported to the sight of deposition in low-temperature, aqueous solutions. Hostetler and Garrels (1962) have shown that in the $U\text{-}O_2\text{-}H_2O$ system uranium is soluble only in acidic or alkaline solutions. Pure water, however, is rarely found in the subsurface, and analyses show that dissolved carbon dioxide is a common constituent of the ground waters.

According to Lisitsin (1962) and Hostetler and Garrels (1962) carbon dioxide dissolved in ground water greatly increases the solubility of uranium. They concluded that the primary dissolved carbonate types are the uranyl dicarbonate complex ($[UO_2(CO_3)_2 \cdot 2H_2O]^{-2}$) and uranyl tricarbonate complex ($[UO_2(CO_3)_3]^{-4}$). The dicarbonate complex is found in neutral to weakly acidic or alkaline solutions and the tricarbonate complex forms under more alkaline conditions. In extremely alkaline solutions uranium occurs as the HUO_4^- ion, whereas the UO_2^{++} ion commonly is found in strongly acidic solutions (Fig. 15).

Because atmospheric CO_2 has only limited access to the ground-water system, the percolating waters may be considered as a closed system which receives fixed or periodic additions of CO_2 (Hostetler and Garrels, 1962). The type of carbonate complex formed in the water depends upon

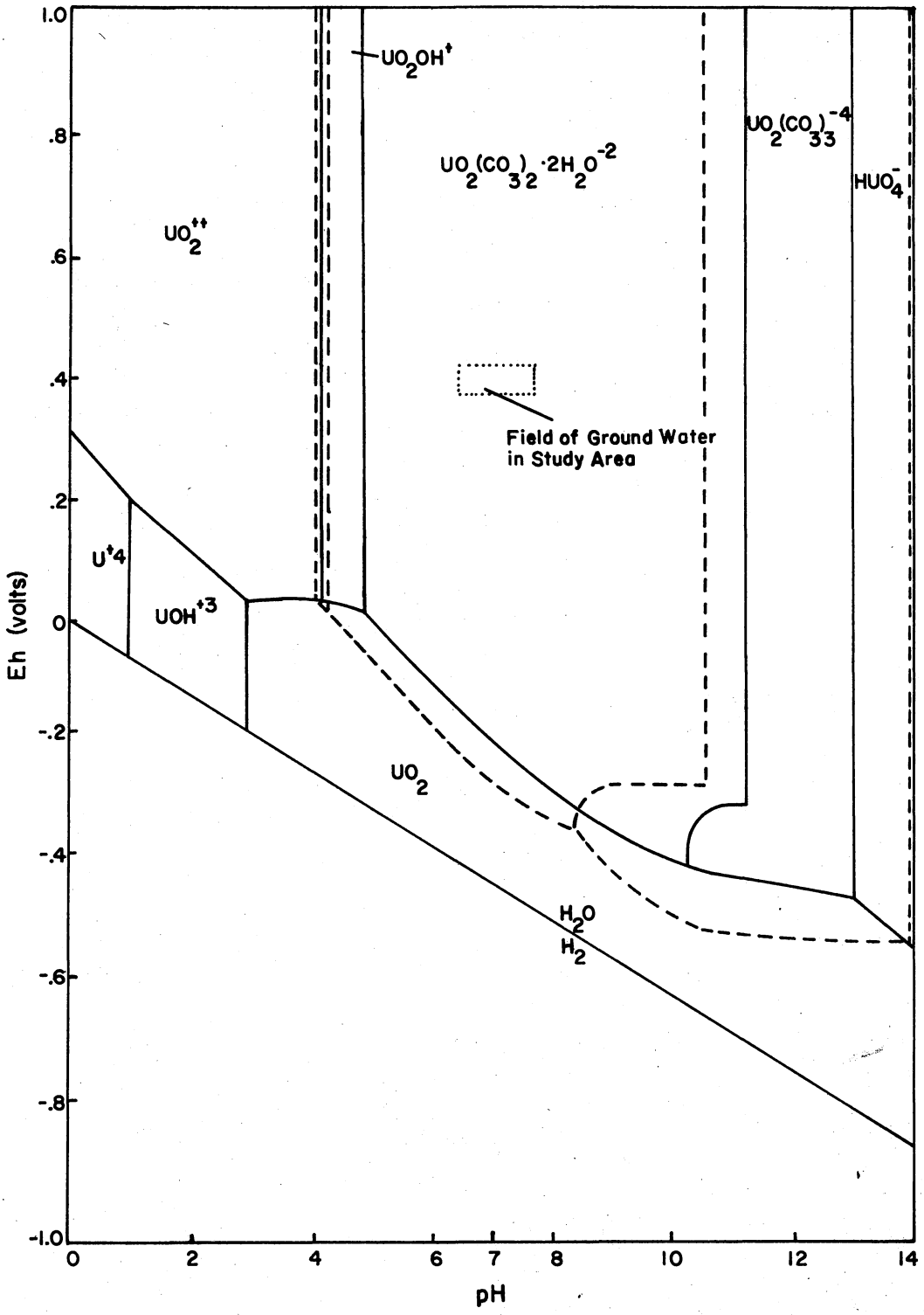

Fig. 15.-Aqueous equilibrium diagram of the $U-O_2-H_2O-CO_2$ system with total $CO_2 = 10^{-3}$ M. Dashed lines show boundaries for system with total $CO_2 = 10^{-2}$ M. Modified after Hostetler and Garrels (1962)

the redox potential (Eh), the pH, and the amount of CO_2 dissolved in the ground water.

In a closed system the sum of the CO_2 will represent the carbonate content of the solution. As this value increases, the stability range of the uranyl tricarbonate complex increases relative to the dicarbonate complex (Fig. 15). Hostetler and Garrels (1962) have shown, however, that as the amount of total CO_2 falls below $10^{-3.8}$M. the uranyl tricarbonate complex disappears and the dominant species is the dicarbonate.

As was shown earlier, the pH of the solution also controls the type of uranium complex. It should be noted that with an increase in the alkalinity of the solution, stronger and stronger reducing agents are required to precipitate uranium.

Figure 15 shows the Eh and pH ranges of the ground water samples plotted on an aqueous equilibrium diagram of the $U\text{-}O_2\text{-}H_2O\text{-}CO_2$ system. The diagram has a range of total carbonate for the system which would be comparable to that found in southern Oklahoma. The redox potentials (Eh) of the samples analyzed range from .386 to .421 volts and the pH values range from 6.4 to 7.7. Analyses of ground-water samples by the Oklahoma State Health Department were also obtained for over 130 wells throughout the study area. The total carbonate content of the samples averaged 6.6×10^{-3}M. From the figure it can be seen that the uranyl dicarbonate complex is the predominant ionic type found in these ground waters.

Sulfate and chloride occur in many of the samples analyzed by the State Health Department. According to Hostetler and Garrels (1962) these ions will form complexes with uranyl and uranous ions. However, the authors note that the sulfate and chloride complexes are stable only

for very low pH ranges and, as a result, the importance of these complexes in most ground waters is negligible.

As stated earlier, the apparent lack of mineralization away from the fracture at Cement may have been due to a decrease in the intensity of reduction away from the fracture. Dapples (1967) has noted that calcite decreases in solubility and silica is more soluble as the pH is elevated. The abundance of carbonate replacements of quartz and feldspar in the sandstone near the ore body suggests that strongly alkaline conditions must have prevailed in the sandstone during deposition of the carbonate cement. Donovan (1972) concluded that the presence of calcite cement establishes a minimum pH of approximately 8.3.

The aqueous equilibrium diagram (Fig. 15) shows that stronger reducing agents are required to remove uranium from solution as the pH increases. The position of the ore along the fracture at Cement and near the fault at Cox City suggests that only along these avenues of hydrocarbon migration was the intensity of reduction strong enough to precipitate uranium in the alkaline environment.

Future Prospects

A study of geochemical anomalies near other oil-producing structures in southern Oklahoma (Plate 2) suggests that additional exploration is needed. Although several structures, including West Cement, Velma-Cruce, Eola, and Healdton had no significant anomalies, red-bed alteration and carbonate mineralization over the structures indicates that further evaluation of these areas is required. The ore controls established at Cement and Cox City should be utilized during the evaluation of these prospects. Unconformities at the base of the Permian

and Upper Pennsylvanian section should be mapped and the overlying formations should be examined for evidence of hydrocarbon migration. Red-bed alteration and carbonate cementation indicative of hydrocarbon migration should be considered as favorable criteria. Faults or fractures along the structures are favorable sites for uranium deposition and should be explored in detail. Arkosic materials over oil producing structures in the western part of the study area should also be considered for future exploration.

CHAPTER VII

CONCLUSIONS

The major conclusions of this study are as follows:

1) Fault or fracture controlled uranium deposits constitute one of the two principal types of ore bodies found in southern Oklahoma. The host rocks are Permian red-bed sandstones which have been altered near the crests of oil-producing structures to colors of buff, yellow or white. The deposits are found along faults or fractures near the crests of the anticlines. The openings have been major avenues for vertically migrating hydrocarbons. Hydrogen sulfide contained in the hydrocarbons or formed through reduction of sulfate by the hydrocarbons, probably precipitated uranium from ground waters which passed through the faulted and fractured host. Mineralization occurred in the openings probably in response to the intense reducing conditions found along the avenues of hydrocarbon migration. Solid hydrocarbons produced during the oxidation process were enriched in radioactive materials as a result of the loss of the lighter fractions of the oil.

2) Radioactive ore bodies, which roughly parallel the bedding of the host, constitute the second major type of ore deposit found in the study area. The mineralization occurs in silt- and clay-rich sandstones which are found at the base of channels or on the crests and flanks of oil producing structures. Precipitation of uranium from ground waters passing through the host was aided by a reduction in velocity of the

solutions caused by the argillaceous materials. Deposition of the ore also occurred as a result of reduction by organic materials contained in the sand, or H_2S introduced into the host by migrating hydrocarbons. Channel sandstones, containing abundant organic matter including woody materials, are common in Early Permian formations.

4) The host rocks in the study area are fine- to very fine-grained subarkoses. Carbonate cement is characteristic of the hosts near the fault or fracture controlled ore bodies. The ore bodies which parallel bedding planes occur in hosts which have a silt or clay matrix that may contain small grains of pyrite.

5) Primary sources for the radioactive materials in the study area were probably granites, rhyolites, and consolidated volcanic tuffs, eroded from the Wichita and Arbuckle Mountains. Radioactive materials were also derived through erosion and redeposition of previously deposited arkoses.

6) Several ground waters in southern Oklahoma contain high concentrations of uranium. Four new radioactive occurrences near Cement, Cox City, and along the Red River were discovered through exploration activities conducted in areas having ground-water anomalies. The presence of other anomalous ground waters in the study area suggests that further evaluation is necessary. Oil field structures, such as West Cement, Chickasha, Velma-Cruce, Eola, and Healdton have surface alteration, and should be considered for future exploration. Interbedded arkoses and shales of the Post Oak Conglomerate which overlie oil-producing structures in the western part of the study area should be examined for possible mineralization.

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APPENDIX A

URANIUM IN GROUND WATER

No.	Location	Well Depth (ft.)	Aquifer	Eh (mv)	pH	ppb Uranium
1	SE SE 19-6N- 9W	100	Rush Springs			-2*
2	SW SW 31-6N- 9W	130	Rush Springs			-2
3	NW SW 31-6N- 9W	Spring	Rush Springs			-2
4	SW SE 31-6N- 9W	86	Rush Springs			15
5	SW SE 32-6N- 9W	100	Rush Springs			-2
6	SE SE 33-6N- 9W					-2
7	NE NW 34-6N- 9W	155	Rush Springs			-2
8	SW SW 35-6N- 9W	100	Rush Springs			-2
9	NE NE 36-6N- 9W					-2
10	NE NW 35-6N-10W	115	Rush Springs			-2
11	NW SE 36-6N-10W	150	Rush Springs			-2
12	NW SW 20-5N- 5W	125	Duncan			-2
13	SW SW 14-5N- 7W	156	Duncan			16
14	SW SE 32-5N- 7W	105	Rush Springs			-2
15	NW SE 5-5N- 8W	200	Chickasha			-2
16	NW SW 6-5N- 8W	75	Rush Springs			-2
17	SE SW 6-5N- 8W	75	Rush Springs			-2
18	NE SW 6-5N- 8W	106	Rush Springs			-2
19	SE SW 7-5N- 8W	83	Rush Springs			-2
20	SW SE 7-5N- 8W					-2
21	SW NE 14-5N- 8W	400	Duncan			-2
22	SW SW 20-5N- 8W	140	Rush Springs			-2
23	NE NE 21-5N- 8W	135	Rush Springs			5
24	SE SE 22-5N- 8W	100				-2
25	SE SE 23-5N- 8W					-2
26	SE NE 1-5N- 9W					3
27	NW NW 1-5N- 9W	Spring	Rush Springs			-2
28	SE SE 2-5N- 9W	100	Rush Springs			3

*Less than 2 ppb uranium

No.	Location	Well Depth (ft.)	Aquifer	Eh (mv)	pH	ppb Uranium
29	NE SE 2-5N- 9W	Spring	Rush Springs			85
30	SW SE 2-5N- 9W	90	Rush Springs			-2
31	SW SE 2-5N- 9W	150	Rush Springs			-2*
32	SW SW 2-5N- 9W	100	Rush Springs			18
33	NE NE 3-5N- 9W	120	Rush Springs			-2
34	SW NE 3-5N- 9W	142	Rush Springs			-2
35	SW NE 3-5N- 9W	154	Rush Springs			80
36	SW NE 3-5N- 9W	80	Rush Springs			465
37	(Duplicate Sample)			393	7.1	860
38	(Duplicate Sample)			393	7.1	700
39	SW NE 3-5N- 9W	165	Rush Springs			120
40	(Duplicate Sample)					145
41	(Duplicate Sample)			414	7.0	140
42	(Duplicate Sample)			414	7.0	160
43	SW NW 4-5N- 9W	400				16
44	SW NE 4-5N- 9W	600				38
45	NW NE 4-5N- 9W	160	Rush Springs			2
46	NW NW 5-5N- 9W	58	Rush Springs			-2
47	SW SE 6-5N- 9W	85	Rush Springs			-2
48	NE SE 8-5N- 9W	80	Rush Springs			-2
49	SW NE 10-5N- 9W	48	Rush Springs			-2
50	NW SW 11-5N- 9W	100	Rush Springs			42
51	SE SW 11-5N- 9W	70	Rush Springs			16
52	NE NW 11-5N- 9W					75
53	NW NE 11-5N- 9W	Spring	Rush Springs			3
54	(Duplicate Sample)					4
55	SW NW 12-5N- 9W	85	Rush Springs			-2
56	NE NE 12-5N- 9W					4
57	C 12-5N- 9W					2
58	NW NW 13-5N- 9W	40	Rush Springs			16
59	SW SW 16-5N- 9W					-2
60	SE SE 23-5N- 9W					4
61	NE NW 1-5N-10W					-2
62	NW NE 1-5N-10W	150	Rush Springs			-2
63	SE NE 3-5N-10W	85	Rush Springs			-2
64	SE NE 14-5N-10W	90	Rush Springs			-2
65	NE NW 16-4N- 1E	80		400	7.1	-2
66	SW SE 10-4N- 1W	68	Garber	408	7.1	6
67	NE NW 10-4N- 2W	60		401	7.1	-2
68	SW SW 31-4N- 2W			404	7.0	20
69	SW SE 6-4N- 3W			401	7.1	2

*Less than 2 ppb uranium

No.	Location	Well Depth (ft.)	Aquifer	Eh (mv)	pH	ppb Uranium
70	NW NW 19-4N- 5W					20
71	NE NE 5-4N- 6W	105	Duncan			-2*
72	NW NW 30-4N- 6W	40	Rush Springs			5
73	NW SE 34-4N- 7W	110	Rush Springs			-2
74	NE NE 22-4N- 8W	65				-2
75	SW SW 20-4N- 9W	80	Rush Springs			-2
76	SE SW 11-3N- 1W	70		399	7.2	2
77	SE SE 19-3N- 1W	385	Oscar	412	7.1	3
78	SW SW 1-3N- 5W	100	Duncan			-2
79	NW SE 6-3N- 5W	80	Duncan			-2
80	SW NE 8-3N- 5W	100	Duncan			-2
81	NW NE 9-3N- 5W	100	Duncan			3
82	NE SE 10-3N- 5W					-2
83	SE SE 15-3N- 5W					-2
84	SE NW 16-3N- 5W	80	Duncan			-2
85	SW SW 16-3N- 5W	225	Duncan			315
86	(Duplicate Sample)			402	6.6	440
87	(Duplicate Sample			402	6.6	480
88	SE SE 17-3N- 5W			402	6.9	12
89	NE SW 20-3N- 5W	128	Duncan			8
90	NE SE 20-3N- 5W	105	Duncan	414	6.9	9
91	NE SE 21-3N- 5W	75	Duncan			2
92	SE SW 23-3N- 5W	55	Duncan			2
93	SW SE 26-3N- 5W					4
94	NW SE 29-3N- 5W	90	Duncan			9
95	NW NE 34-3N- 5W					-2
96	SE NW 1-3N- 6W					4
97	SE SE 4-3N- 6W	120	Chickasha			7
98	NE NE 7-3N- 7W	210	Rush Springs			-2
99	NE NE 27-3N- 7W	145	Rush Springs			-2
100	SW NW 15-3N- 8W	93	Rush Springs			-2
101	NE NE 30-3N- 9W	100		399	7.1	-2
102	SE SE 15-2N- 1W	214		403	7.4	-2

*Less than 2 ppb uranium

No.	Location	Well Depth (ft.)	Aquifer	Eh (mv)	pH	ppb Uranium
103	SW NW 1-2N- 3W					20
104	SE SW 15-2N- 4W			399	7.0	-2*
105	NW NE 5-2N- 5W	115	Duncan			-2
106	SE SE 15-2N- 5W	65	Duncan			5
107	SW SW 34-2N- 5W	25	Duncan			-2
108	NW SW 35-2N- 6W	110	Duncan			-2
109	NE NW 27-2N- 7W	200				9
110	SW SW 7-2N- 8W	95	Duncan			3
111	SE SE 4-1N- 3W	200		416	6.4	-2
112	C 10-1N- 4W	40	Duncan			-2
113	SW SW 34-1N- 4W	65	Duncan			6
114	SE SE 17-1N- 5W	65	Duncan			-2
115	SE SE 32-1N- 5W					-2
116	SW NE 24-1N- 6W	75				3
117	NE NE 4-1N- 8W					18
118	SW SW 19-1N- 8W	150	Garber			-2
119	NE NE 14-1N- 9W	54				-2
120	NW NE 35-1N- 9W	100	Garber			-2
121	SE NE 14-1N-10W	40		411	7.1	-2
122	SW SW 19-1N-11W	35		399	7.2	4
123	SE SW 16-1N-14W	35		411	7.3	8
124	SE SE 36-1N-15W	24		410	7.5	9
125	SW SW 10-1S- 3W	260				-2
126	NW NW 26-1S- 4W	90	Garber			5
127	NE NE 22-1S- 5W	62				-2
128	NE NW 12-1S- 6W	276				-2
129	NE NE 35-1S- 6W	110	Garber			2

*Less than 2 ppb uranium

No.	Location	Well Depth (ft.)	Aquifer	Eh (mv)	pH	ppb Uranium
130	SE SE 15-1S- 7W	100	Garber			2
131	NW NW 4-1S- 8W	240				-2*
132	NW SW 21-1S- 8W	66	Garber			-2
133	SE SE 32-1S- 8W	180	Garber			9
134	SE NE 24-1S- 9W	90	Garber			6
135	NE SE 36-1S- 9W	100	Garber			6
136	SW SW 11-1S-10W	25		411	7.2	3
137	SW SW 34-1S-10W					2
138	NE NW 2-1S-11W	20		399	7.2	7
139	NE SE 36-1S-12W	24		413	7.7	28
140	NW NE 5-2S- 2W	96	Wellington			-2
141	NW NW 31-2S- 2W	28				3
142	NE NE 4-2S- 3W					-2
143	SE NW 11-2S- 4W	40				-2
144	NE NE 2-2S- 5W	100				-2
145	SE NW 13-2S- 5W	60	Garber			2
146	NE SE 16-2S- 6W	140				2
147	NE NE 15-2S- 7W	150				38
148	NW NE 22-2S- 8W	150				2
149	SW NW 30-2S- 8W					15
150	SW SW 3-2S- 9W					14
151	SW SW 11-2S-10W	90	Garber			50
152	SW SW 35-2S-10W	30	Garber	417	7.2	6
153	NW NW 33-2S-11W	16				7
154	NW SW 25-2S-13W	50	Garber	398	7.4	28
155	SE SE 2-2S-15W			420	7.0	11

*Less than 2 ppb uranium

No.	Location	Well Depth (ft.)	Aquifer	Eh (mv)	pH	ppb Uranium
156	SW SE 3-3S- 1E					3
157	SE SE 19-3S- 1W	160	Oscar			3
158	NE NE 29-3S- 2W	132	Oscar			-2*
159	SE SW 32-3S- 3W	350	Oscar			-2
160	SE NE 33-3S- 3W	200	Oscar			-2
161	SW SW 36-3S- 3W	500				-2
162	(Duplicate Sample)					-2
163	SE NE 10-3S- 4W	100				3
164	NE SE 2-3S- 5W	90				-2
165	SE SE 3-3S- 6W	180	Oscar			2
166	NE NE 7-3S- 7W	100	Oscar			20
167	NW NW 32-3S-10W	30		410	7.5	15
168	SE SW 20-3S-11W	12				-2
169	NW NW 26-3S-11W			410	7.2	14
170	NW SW 3-3S-12W	12		409	7.1	3
171	SW NW 24-3S-13W	36		394	7.2	14
172	SW NW 13-3S-15W	22		401	7.2	14
173	NW NW 8-4S- 2W	100				4
174	SE SE 10-4S- 2W	130	Oscar			7
175	SE SE 17-4S- 2W					3
176	SW NW 27-4S- 2W	500	Oscar			2
177	NE SE 35-4S- 2W	300	Oscar			2
178	SE SW 1-4S- 3W	120	Oscar			3
179	SE SE 18-4S- 3W	250	Oscar			-2
180	NW SW 22-4S- 3W	150	Oscar			-2
181	SE NW 25-4S- 3W	180	Oscar			-2
182	SE SW 27-4S- 3W	163				-2
183	NE NW 6-4S- 4W	65	Oscar			5
184	SE SE 33-4S- 4W					7
185	NE NW 2-4S- 6W	65		418	6.9	18

*Less than 2 ppb uranium

No.	Location	Well Depth (ft.)	Aquifer	Eh (mv)	pH	ppb Uranium
186	NW NE 18-4S- 8W	40	Oscar	416	7.3	18
187	NW NW 29-4S- 9W	12	Wellington	410	7.3	8
188	SE SW 33-4S- 9W	47				30
189	NE SE 35-4S- 9W	20	Oscar			26
190	NW NW 10-4S-10W	20	Garber	401	7.7	14
191	SE NE 28-4S-10W			405	7.6	20
192	SW SW 34-4S-10W					44
193	(Duplicate Sample)					48
194	(Duplicate Sample)					55
195	NE NE 35-4S-10W			397	7.5	4
196	SE NE 8-4S-11W	30		421	7.2	3
197	NW SW 29-4S-11W			399	7.5	3
198	NE NE 3-4S-12W	25	Wellington			4
199	NE NE 28-4S-14W	30		410	7.4	22
200	NW SW 20-4S-15W	Spring		390	7.5	12
201	SE NE 32-5S- 1E	55	Cretaceous			4
202	NW SW 14-5S- 1W	160				-2*
203	NE NE 11-5S- 3W	40				-2
204	SE NE 29-5S- 4W	40				7
205	SE SW 9-5S- 7W			401	7.2	6
206	NW SW 7-5S- 8W	50				10
207	NW SW 7-5S- 8W	Spring	Wellington			18
208	(Duplicate Sample)					22
209	SE NE 21-5S- 8W	33	Wellington			20
210	NW NW 17-5S-12W	30				16
211	NW NW 30-5S-12W	35				4
212	(Duplicate Sample)					2
213	C NE 22-6S- 5W	70				3
214	SW NW 32-6S- 5W					10

*Less than 2 ppb uranium

No.	Location	Well Depth (ft.)	Aquifer	Eh (mv)	pH	ppb Uranium
215	NE NE 21-6S- 7W	80		409	7.3	5
216	NE NE 11-6S- 8W	75	Oscar			18
217	NE NW 2-7S- 7W	41	Wellington	421	7.3	2
218	NE NE 24-7S- 7W	90		386	7.4	-2*

*Less than 2 ppb uranium

APPENDIX B

RADIOACTIVE OCCURRENCES

Location:

SE SE 31-6N- 9W

Host: Rush Springs Formation - asphaltic nodules in reddish-brown sandstone one foot thick.

Radioactivity: 0.07 MR/HR near several of the nodules; background: 0.006 MR/HR.

Location:

NE SE 2-5N- 9W[1]

Host: Rush Springs Formation - thin bedded, limonite stained, sandstone with some interbedded siltstone.

Radioactivity: 0.3 to 1.0 MR/HR on face of bulldozer cut; 0.2 to 0.5 MR/HR for 100 feet along white sandstone bed; background: 0.03 MR/HR.

Location:

SE SW 2-5N- 9W

Host: Rush Springs Formation - buff to gray, thin bedded silty sandstone.

Radioactivity: 0.03 MR/HR for two to three feet along outcrop; background: 0.006 MR/HR.

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[1] Taken from: United States Atomic Energy Commission, 1968.

Location:

SW NE 3-5N- 9W[1]

Host: Rush Springs Formation - yellow-brown to white, calcareous sandstone; ore found along fracture in the host.

Radioactivity: selected samples showed 1.18 to 2.046 per cent eU_3O_8; average radioactivity: ten times background over mineralized fracture.

Location:

NW NE 21-3N- 5W

Host: Duncan Sandstone - blue-gray, silty sandstone interbedded with carbonate pebble conglomerates.

Radioactivity: 0.02 MR/HR on blue-gray sandstone near contact with carbonate pebble conglomerates; background: 0.008 MR/HR.

Location:

SW 9-3N-11W[1]

Host: Garber Sandstone - asphaltic sandstone and shale in channels one to two feet thick.

Radioactivity: 0.001 per cent eU_3O_8; average radioactivity: 0.04 MR/HR; background: 0.03 MR/HR.

Location:

SE 22-3N-14W[1]

Host: Cambrian granite - ore occurs in branching veinlets two to three inches thick.

Radioactivity: 0.002 per cent eU_3O_8; average radioactivity: 0.03 MR/HR; background: 0.03 MR/HR.

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[1]Taken from: United States Atomic Energy Commission, 1968.

Location:

S½ 34-1N-15W[1]

Host: Post Oak Conglomerate - medium- to coarse-grained arkosic sandstone three to ten feet thick.

Radioactivity: 0.010 per cent eU_3O_8; average radioactivity: 0.45 MR/HR; background: 0.04 MR/HR.

Location:

SE SE 1-1S-16W[1]

Host: Post Oak Conglomerate - medium- to coarse-grained arkosic sandstone.

Radioactivity: 0.06 to 0.11 eU_3O_8; average radioactivity: 0.035 MR/HR; background: 0.005 MR/HR.

Location:

SE 35-2S- 6W[1]

Host: Garber Sandstone - coarse-grained asphaltic sandstone in channel two feet thick.

Radioactivity: selected sample contained 0.001 per cent eU_3O_8; average radioactivity: 0.03 MR/HR; background: 0.03 MR/HR.

Location:

SW 7-4S-12W[1]

Host: Garber Sandstone - fine-grained, pebbly sandstone and conglomerage containing plant remains and copper.

Radioactivity: 0.05 to 0.11 MR/HR; background: 0.030 MR/HR.

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[1]Taken from: United States Atomic Energy Commission, 1968.

Location:

S½ 25-5S- 6W[2]

Host: Oscar Group - arkosic conglomerate containing some copper minerals.

Radioactivity: selected samples contained 0.008 and 0.022 per cent eU_3O_8.

Location:

NW SW 7-5S- 8W[1]

Host: Wellington Formation - highest radioactivity on dark-red sandstone which occurred as "float" material upon shale.

Radioactivity: 0.052 per cent eU_3O_8; average radioactivity: 0.15 MR/HR; background: 0.03 MR/HR.

Location:

NW SW 17-5S- 8W

Host: Oscar Group - interbedded silty sandstones and shales.

Radioactivity: 0.07 MR/HR in sandy shales; background: 0.008 MR/HR.

Location:

SW 30-5S- 8W[2]

Host: Wellington Formation - ferruginous sandstone occurring as "float" material.

Radioactivity: selected sample contained 0.052 eU_3O_8.

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[1]Taken from United States Atomic Energy Commission (1968).

[2]Taken from McKay (1957).

Location:

NE 1-5S- 9W[1]

Host: Oscar Group - radioactivity on sandstone "float" material upon reddish brown shales.

Radioactivity: 0.040 MR/HR in sandstone; background: 0.015 MR/HR.

Location:

NE NE 3-5S-11W[1]

Host: Garber Sandstone - reddish brown sandstone and shale containing some azurite and malachite.

Radioactivity: 0.003 eU_3O_8.

Location:

NW SE 30-5S-12W[1]

Host: Garber Sandstone - buff colored channel sandstone 25 feet thick; ore in lower part of channel with copper minerals and plant material.

Radioactivity: 0.014 to 2.140 eU_3O_8; average radioactivity: 0.35 MR/HR; background: 0.01 MR/HR.

Location:

NW 4-6S- 5W[1]

Host: Garber Sandstone - radioactivity associated with red and black concretions in sandstone.

Radioactivity: 0.20 MR/HR in concretions; background: 0.025 MR/HR.

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[1]Taken from United States Atomic Energy Commission (1968).

Location:

NW NE 23-6S 5W[1]

Host: Wellington Formation - radioactivity associated with reddish colored concretions in rock.

Radioactivity: 0.08 MR/HR in concretions; background: 0.025 MR/HR.

Location:

SW 13-7S- 6W[2]

Host: Wellington Formation - carbonaceous sandstone in channel one foot thick.

Radioactivity: selected samples contained 0.004 and 0.029 eU_3O_8.

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[1]Taken from United States Atomic Energy Commission (1968).

[2]Taken from McKay (1957).

APPENDIX C

GAMMA RAY LOGS NEAR CEMENT AND COX CITY

INDICATING SUBSURFACE MINERALIZATION

Operator, Well Number, and Location	Depth to Anomaly (ft.)	Thickness (ft.)	Lithology
	Cement		
Ohio Oil Co. Surbeck #4 NE NW SW 2-5N-9W	110	10	sandstone
Mobil Oil Co. H. Surbeck #6 NW SE SE 3-5N-9W	106	5	sandstone
	130	7	sandstone
	141	3	sandstone
	290	4	sandstone
	1,345	3	sandstone
Palmer Oil Corp. Ulery #1 SE NE NE 34-6N-10W	393	3	sandstone
	437	10	sandstone
	1,000	35	shale
	1,810	7	sandstone
Palmer Oil Corp. Ulery #2 SW NE NE 34-6N-10W	412	5	sandstone
	465	10	sandstone
	524	5	sandstone
	1,040	30	shale
	2,810	30	shale
Palmer Oil Corp. Dixon #1 35-6N-10W	975	30	shale
	1,100	25	sandstone
	2,525	12	sandstone
Palmer Oil Corp. Dixon #3 35-6N-10W	15	12	sandstone
	258	3	silty sandstone
	1,025	18	shale
Mobil Oil Co. O Lindsay #9 NW NE NE 35-6N-10W	1,920	10	sandstone

Operator, Well Number, and Location	Depth to Anomaly (ft.)	Thickness (ft.)	Lithology
	Cox City		
Humble Oil Co. Kitty Howard #4 NE NE NW 21-3N-5W	75	7	silty sandstone
Humble Oil Co. Kitty Howard #5 SE NE NW 21-3N-5W	45	5	silty sandstone

VITA

Richard Warren Olmsted

Candidate for the Degree of

Master of Science

Thesis: GEOCHEMICAL STUDIES OF URANIUM IN SOUTH-CENTRAL OKLAHOMA

Major Field: Geology

Biographical:

Personal Data: Born in Norfolk, Nebraska, April 30, 1949, the son of Mrs. Marion E. Olmsted and the late Wilfred M. Olmsted.

Education: Graduated from Neligh High School, Neligh, Nebraska, in May, 1967; completed the requirements for a Bachelor of Science degree in geology from the University of Nebraska, Lincoln, Nebraska, in June, 1971; completed requirements for the Master of Science degree at Oklahoma State University in December, 1975, with a major in geology.

Professional Experience: Geological Technician, Wichita Testing Laboratories, Wichita, Kansas, summer, 1973; Teaching Assistant, Department of Geology, Oklahoma State University, Stillwater, Oklahoma, August, 1973 - May, 1975; Geological Assistant, Uranium Group, Atlantic Richfield Company, Denver, Colorado, summer, 1974; Student Member of the American Institute of Mining, Metallurgical and Petroleum Engineers.