Uranium in Some Rocks of Pennsylvanian Age in Oklahoma, Kansas and Missouri

GEOLOGICAL SURVEY BULLETIN 1147-B

Prepared on behalf of the U.S. Atomic Energy Commission and published with the permission of the Commission

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By HAROLD J. HYDEN *and* WALTER DANILCHIK

CONTRIBUTIONS TO THE GEOLOGY OF URANIUM

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CONTENTS

ILLUSTRATIONS

[Plates are in Pocket]

TABLES

CONTRIBUTIONS TO THE GEOLOGY OF URANIUM

URANIUM IN SOME ROCKS OF PENNSYLVANIAN AGE IN OKLAHOMA, KANSAS, AND MISSOURI

By HAROLD J. HYDEN and WALTER DANILCHIK

ABSTRACT

The distribution of uranium and other trace elements in sedimentary rocks of Middle Pennsylvanian (Des Moines) age in Oklahoma, Kansas, and Missouri was studied during 1955 and 1956. This investigation was directed principally toward radioactive black-shale beds, some of which contain uranium-bearing phosphatic nodules. Samples of coal, oil well water, and naturally occurring hydrocarbons also were collected for chemical analysis for uranium and semiquantitative spectrographic analysis for other trace elements.

Very dark gray to black shale examined in this investigation is designated as either carbonaceous shale or phosphatic shale. The carbonaceous shale is soft and coaly in appearance, yields little or no oil on destructive distillation, and is less radioactive; the phosphatic shale is more resistant to weathering, yields oil on destructive distillation, contains phosphatic nodules or laminae, and is more radioactive. Phosphatic shale contains more uranium than carbonaceous shale. The average uranium content in each of eight phosphatic shale units ranges from 0.002 to 0.005 percent. The average uranium content of each of six carbonaceous shale units ranges from 0.001 to 0.002 percent. Uranium is concentrated in the phosphatic nodules found in the black shale. The average uranium content in the phosphatic nodules is 0.016 percent, and the uranium content of individual samples ranges from 0.002 to 0.060 percent.

As much as 0.085 percent uranium is present in ash of coal from the uppermost few inches of a coal bed immediately underlying a phosphatic shale unit; the lower part of the coal bed contains much less uranium, but contains as much as 0.07 percent germanium in the ash. No unusual amounts of other trace elements were found in any of the other rocks, or in the black shale, but the phosphatic nodules contain rare earths, including dysprosium, erbium, and neodymium, in concentrations that correlate directly with P_2O_5 contents. The rare-earth contents are generally higher than in phosphatic rocks from other areas.

Recycled water in areas of secondary production in the Nowata oil field, Oklahoma, was collected at injection and at production wells; gains of sulfate, uranium, and radioactive daughter products of uranium were obtained in some of the samples of produced water. Uranium contents of the oil from this field range from 0.007 to 0.052 percent of the ash and from 0.0010 to 0.035 parts per million

in the oil. The highest percentages of uranium are in samples from the Lowery waterflood area in the Nowata oil field. Coaly material, asphaltlike material, and extracted oil from cores taken from the oil-producing horizon in this area are not highly uraniferous.

INTRODUCTION

Radioactive "black" shale beds have been the subject of recent investigations by the U.S. Geological Survey and others on behalf of the Atomic Energy Commission. These investigations began during World War II. The fieldwork and compilations herein reported were conducted in 1955 and 1956. Although the uranium content of Pennsylvanian black shale in the central midcontinent region, and indeed of all shale, proved to be much too low for present-day mining, studies of these shale beds provide important information on the affinities and habits of uranium.

Some of the "black" shale beds in the Des Moines series of the Pennsylvanian system are known to be relatively radioactive, to extend over large distances in outcrop, and to be present in large areas of the subsurface of the midcontinent region. These shale units and adjacent rocks and organic materials of the Des Moines series are the main subject matter of this investigation by the U.S. Geological Survey on behalf of the Division of Raw Materials of the U.S. Atomic Energy Commission.

Field examination with the aid of Geiger-Mueller and scintillation counters was conducted over an outcrop area that extends from northeastern Oklahoma through southeastern Kansas and into western Missouri (pl. 1). Rock, coal, crude-oil, and water samples were collected to be analyzed for the content of uranium and other metals.

The field studies and the sampling work necessary for this investigation were conducted during September and October of 1955 and March of 1956. The many chemical analyses for uranium and other elements were performed in the laboratories of the U.S. Geological Survey in Washington, D.C., and Denver, Colo.

ACKNOWLEDGMENTS

Information given the authors about local stratigraphy and about outcrops suitable for the collection of samples was of invaluable aid in this study. Dr. Carl C. Branson, Director of the Oklahoma Geological Survey, made available from the University of Oklahoma many unpublished theses that contain stratigraphic information unavailable elsewhere. Edward P. Heuer of Tulsa University provided the authors with important information on stratigraphy and outcrops in northeastern Oklahoma.

The members of the State Geological Survey of Kansas and of the Missouri Division of Geological Survey and Water Resources were very cooperative and helpful. Special thanks are due A. L. Hornbaker of the State Geological Survey of Kansas for his help in the location of sample localities in southeastern Kansas. The authors are especially grateful to the following: L. H. Warwick, Lee Hagen, and George Hayworth of Climax Molybdenum Co.; L. A. Payne, H. R. Holmes, and L. Lookingbill of Winona Oil Co.; and J. Wyrick and W. Grovenburg of Pure Oil Co.

PREVIOUS WORK

Among the first references to radioactivity in rocks of the midcontinent area are reports based on studies connected with the early development and application of radioactivity well logging (Russell, 1941, p. 1769). In a later report Russell (1945) described the relatively high radioactivity of some Pennsylvanian shale beds and the uraniferous phosphate nodules in these shale units near Tulsa, Okla. Whitehead (1952), in a study of radioactivity as an agent in the formation of petroleum, found the radioactivity in samples of shale, including the Cherokee, to be related both to organic carbon content and to phosphorus content. Other radioactivity studies were made in 1948 by Gott and Hill (1953) on radium-bearing precipitates from oil well fluids in oil and gas fields of southeastern Kansas.

Slaughter (written communication, 1945) investigated the Pennsylvanian black-shale beds and their phosphatic nodules as a possible future source of uranium; he concluded at that time that the uranium content is too low to be considered further as a commercial source of uranium. The possibility of obtaining uranium as a byproduct of oil extraction from shale and, more probably, in the manufacture of superphosphate fertilizer from phosphatic nodules was considered by Runnels and others (1949, 1952, and 1953) in reports on oil shale and uranium-bearing phosphatic nodules of Kansas. A reconnaissance for uranium in asphaltic rocks in this area was made by Hail (1957), who found relatively high concentrations of the metal in ash of oils extracted from sandstone collected in Missouri.

The following unpublished theses are among the most recent geologic and stratigraphic studies of Des Moines rocks in Oklahoma and Kansas and they provided very useful information for this investigation:

Abernathy, G. E., 1936, The Cherokee of southeastern Kansas: Kansas Univ., Ph. D. thesis, 108 p.

Chrisman, L. P., 1951, The geology of the Big Cabin Creek area, Craig County, Oklahoma: Oklahoma Univ., M.S. thesis.

Claxton, C. D., 1952, The geology of the Welch area, Craig County, Oklahoma: Oklahoma Univ., M.S. thesis.

Faucette, J. R., 1954, Geology of the Marmaton group of southeastern Nowata County, Oklahoma: Oklahoma Univ., M.S. thesis.

Gruman, W. P., 1954, Geology of the Foyil area, Rogers and Mayes Counties, Oklahoma: Oklahoma Univ., M.S. thesis.
Howe, W. B., 1954, Stratigraphy of pre-Marmaton Desmoinesian rocks in southeastern Kansas: Kansas Univ., Ph. D. thesis.
Lohman, Clarence, Jr., 1952, Geology of the Whiteoak area, Craig and Rogers Counties, Oklahoma: Oklahoma Univ., M.S. thesis.
Lontos, J. T., 1952, The geology of the Coweta area, Wagoner, Muskogee, and Okmulgee Counties, Oklahoma: Oklahoma Univ., M.S. thesis.
Schell, B. J., 1955, The stratigraphy and depositional history of the Verdigris-Higginsville interval in northeastern Oklahoma: Tulsa Univ., M.S. thesis.
Sparks, B. J., 1955, The geology of the Marmaton group of northwestern Rogers County, Oklahoma: Oklahoma Univ., M.S. thesis.
Tillman, J. L., 1952, Geology of the Tiawah area, Rogers and Mayes Counties, Oklahoma: Oklahoma Univ., M. S. thesis.
Ware, H. E., Jr., 1954, Surface and shallow subsurface investigation of the Senora formation of northeastern Oklahoma: Oklahoma Univ., M.S. thesis.

Few trace-element analyses of midcontinent Pennsylvanian rocks or their products are listed in the literature. Gott and Hill (1953, p. 88) listed the trace-element content of some radium-bearing precipitates from oil-well brines of southeastern Kansas. Erickson, Myers, and Horr (1954), in their report on the association of metals with crude oils, included uranium and trace-element determinations of crude oils from some Kansas oil fields. Hyden (1956) described the metal content of the ash of crude oils from many oil fields in the midcontinent and the western part of the United States and found the largest amount of uranium in the ash of crude oil from the Nowata oil field, Oklahoma. Runnels (1949) reported on trace-element content of phosphatic shale in connection with his studies on the possibilities of using eastern Kansas shale as sources of agricultural fertilizer.

Schleicher and Hambleton (1954) found that the germanium content of some of the coal beds of Pennsylvanian age is large enough to be of possible economic interest.

GENERAL GEOLOGY

The rocks of the Des Moines series are late Middle Pennsylvanian in age. The rocks of the Des Moines series in the area of this report consist of thin lithologic units that are cyclically repeated many times in vertical sequence. These units include limestone, black shale, gray shale, coal, and sandstone beds that were deposited in alternating marine and continental sedimentary environments. The cyclic nature of these beds is well known (Weller, 1930; Moore, 1950), and varying opinions on the nature and significance of the cyclothems of the Pennsylvanian system have been published (Wanless and Weller, 1932; Wanless and Shepard, 1936; Weller, 1956; Wheeler and Murray, 1957).

The exposed rocks of Des Moines age studied in this investigation form a belt of gently northwestward dipping rocks that is 30 to 45 miles wide and extends from the Arkansas River, near Tulsa, Okla., northeast across southeastern Kansas into western Missouri.

The outcrop belt has low relief and is characterized by gently sloping hills and broad flat valleys, both generally oriented northeast. The hills most commonly are cuestas capped by thin gently dipping beds of sandstone or limestone with very little soil cover. Some hills have the form of low buttes and mesas that are capped by outliers of the sandstone or limestone beds. The valleys are underlain by shale and are extensively covered by soil or alluvium. Natural outcrops are generally poor and are confined to gullies and to escarpment slopes of the cuestas. Some good exposures are present along master streams that flow across the fabric of the region. The rocks are exposed best in road cuts, coal strippings, and quarries. The strata in coal strippings, however, are commonly inaccessible because of standing water or because they are covered by slumped waste-pile material.

West and north of their outcrops, Des Moines rocks are present in the subsurface in Kansas, Oklahoma, and northwestern Missouri, except over parts of the Nemaha granite ridge (Moore, 1949, p. 37). The rocks have a remarkably uniform character and thickness over wide areas in the subsurface.

STRATIGRAPHY

The nomenclature of rocks of the Des Moines series is not uniform in the area of investigation, and the nomenclature for each of the three states, Oklahoma, Kansas, and Missouri, is shown in tables 1, 2, and 3. Some units are given the same name but a different stratigraphic status in different states.

A thin dark shale bed is present immediately below the Marmaton group throughout the area of investigation. According to current usage, this bed is the Excello shale member of the Senora formation in Oklahoma (Branson, 1954) and the Excello formation in Missouri (Searight, 1959) and although not shown on the rock chart for Kansas (Jewett, 1959), has been called the Excello formation in Kansas (Schoewe, 1959, p. 205). In order to avoid confusion, the term Excello is used in this report to designate the dark shale bed immediately below the Marmaton group in the entire area of the report. In addition to the Excello other names locally in use are shown in tables 1, 2, and 3 and the author of the report in which the term was used.

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TABLE 1.—*Rock units of Des Moines age in northeastern Oklahoma*

Northeastern Oklahoma			
Series	Group	Formation	Member or coal bed
Des Moines series	Marmaton group	Holdenville shale.	
		Lenapah limestone.	
		Nowata shale.	
		Oologah limestone.	Altamont limestone member.
			Bandera shale member.
			Pawnee limestone member.
		Labette shale.	
		Fort Scott limestone.	Little Osage shale member of Oakes, 1952.
			Blackjack Creek limestone member of Oakes, 1952.
	Cabaniss group	Senora formation.	Excello shale member of Branson, 1954.
			Breezy Hill limestone member.
			Kinnison shale member of Branson, 1954.
			Iron Post coal bed.
			Verdigris limestone member.
			Croweburg coal bed.
			Chelsea sandstone member.
			Tiawah limestone member of Alexander, 1954.
			Tebo coal bed.
	Krebs group	Boggy formation.	Inola limestone member.
			Bluejacket sandstone member.
		Savanna formation.	Drywood coal bed.
			Doneley limestone member of Branson, 1955
			Sam Creek limestone member.
			Spaniard limestone member.
		McAlester formation.	Warner sandstone member.
		Hartshorne sandstone.	

The Des Moines rocks in the area of this investigation were deposited on a submerged cratonal shelf to the north of the McAlester basin of Oklahoma and to the south of the Forest City basin of Kansas, Missouri, and Iowa. During the deposition of a thick sequence of rocks of Morrow and Atoka age in the McAlester basin a thin wedge of sediments was deposited on the southern part of this shelf. Weirich (1953) has placed the northern shoreline of the Atoka sea in the vicinity of the city of Tulsa, Okla., and he has postulated a northward transgression of the sea over the area of this investigation in early Cherokee (early Krebs) time. The Hartshorne sandstone is present only in the southernmost tip of the area of this investigation, but the overlying formations of the Krebs group, the McAlester, Savanna,

TABLE 2.—*Rock units of Des Moines age in southeastern Kansas*

Group	Formation	Member or coalbed
Marmaton group	Holdenville shale.	
	Lenapah limestone.	Idenbro limestone member of Jewett, 1941.
		Perry Farm shale member of Jewett, 1941.
		Norfleet limestone member of Jewett, 1941.
	Nowata shale	
	Altamont limestone.	Worland limestone member of Cline, 1941.
		Lake Neosho shale member of Jewett, 1941.
		Amoret limestone member of Cline and Greene, 1950.
	Bandera shale.	
	Pawnee limestone.	Laberdie limestone member of Jewett, 1941.
		Mine Creek shale member of Jewett, 1941.
		Myrick Station limestone member of Cline, 1941.
		Anna shale member of Jewett, 1941.
	Labette shale.	
	Fort Scott limestone.	Higginsville limestone member of Cline, 1941.
		Little Osage shale member of Jewett, 1941.
		Blackjack Creek limestone member of Cline, 1941.

TABLE 2.—*Rock units of Des Moines age in southeastern Kansas*—Continued

Group	Formation	Member or coal bed
Cherokee group	Cabaniss formation.	Excello.
		Mulky coal bed.
		Breezy Hill limestone member.
		Verdigris limestone member.
		Croweburg coal bed.
		Fleming coal bed.
		Mineral coal bed.
		Scammon coal bed.
		Chelsea sandstone member.
		Tiawah limestone member of Jewett, 1959.
		Tebo coal bed.
		Weir-Pittsburg coal bed.
	Krebs formation.	Bluejacket sandstone member.
		Drywood coal bed.
		Rowe coal bed.
		Riverton coal bed.

and Boggy formations, are present in most of the Oklahoma sector of the area of investigation.

The lowermost formations of the Cabaniss group, the Thurman and the Stuart of the McAlester basin, do not extend northward into the area of this investigation, and in the opinion of Weirich (1953, p. 2044), "Boggy sediments were exposed to erosion over the shelf area." The Senora formation, which includes the Excello, overlies the Boggy formation and is the only formation of the Cabaniss group present.

Sandstone, siltstone, and shale, abundant thin coal beds, and a few thin limestone beds characterize the Cherokee rocks, whereas limestone beds are more common and thicker in the Marmaton group. The limestone beds of the Marmaton are thickest in southeastern Kansas; they thin northward toward the Forest City basin and southward toward the McAlester basin (pl. 2; and Lee, 1943, p. 87). Limestone beds of the Oologah and Fort Scott limestones pinch out in the southern part of the area of investigation (pl. 2).

The Bourbon arch, which trends northwest from the southeast corner of Kansas (Lee, 1943, p. 85), is the south boundary of the Forest City basin. The location of the axis of this arch in Bourbon, Allen, and Coffey Counties is based on the relative thinness of Cherokee strata. The total thickness of rocks of Des Moines age over the arch is about 250 feet (Moore, 1949, p. 47), and their thickness in the deepest part of the Forest City basin is about 400 feet (Lee, 1943, p. 85–86).

The southward thickening of beds from the Bourbon arch is much more pronounced than the northward thickening (pl. 2). The rate of

TABLE 3.—*Rock units of Des Moines age in western Missouri*

Group	Subgroup	Formation	Member or coal bed
Marmaton group		Holdenville shale.	
		Lenapah limestone.	Perry Farm shale members as used by Greene and Searight, 1949.
			Norfleet limestone member as used by Greene and Searight, 1949.
		Nowata shale.	
		Altamont limestone.	Worland limestone member of Cline, 1941.
			Lake Neosho shale member of Jewett, 1941.
			Amoret limestone member of Cline and Greene, 1950.
		Bandera shale.	
		Pawnee limestone.	Mine Creek shale member of Jewett, 1941.
			Myrick Station limestone member of Cline, 1941.
			Anna shale member of Jewett, 1941.
		Labette shale.	
		Fort Scott limestone.	Higginsville limestone member of Cline, 1941.
			Little Osage shale member of Jewett, 1941.
			Summit coal bed.
			Blackjack Creek limestone member of Cline, 1941.

TABLE 3—*Rock units of Des Moines age in western Missouri*—Continued

Group	Subgroup	Formation	Member or coal bed
Cherokee group	Cabaniss subgroup as used by Searight (1959)	Excello formation of Searight 1959.	
		Mulky formation of Searight, 1959.	Mulky coal bed.
			Breezy Hills limestone member of Searight and others, 1953.
		Bevier formation of Searight, 1959.	Bevier coal bed.
		Verdigris formation of Searight, 1959.	
		Croweburg formation of Searight, 1959.	Croweburg coal bed.
		Fleming formation of Searight, 1959.	Fleming coal bed.
		Mineral formation of Searight, 1959.	Mineral coal bed.
		Scammon formation of Searight, 1959.	Scammon coal bed.
			Tiawah limestone member of Searight and others, 1953.
		Tebo formation of Searight, 1959.	Tebo coal bed.
		Weir formation of Searight, 1959.	Weir-Pittsburg coal bed.
	Krebs subgroup as used by Searight (1959)	Bluejacket formation of Searight, 1959.	
		Drywood formation of Searight, 1959.	Drywood coal bed.
		Rowe formation of Searight, 1959.	Rowe coal bed.
		Warner formation of Searight, 1959.	Warner coal bed.
		Riverton formation of Searight, 1959.	Riverton coal bed.

thickening increases at the hinge line of the McAlester basin, which lay to the south of the area of this investigation during all of Cherokee time (Weirich, 1953), and the rocks of the Des Moines series are 9,350 feet thick (Branson, 1958, p. 45) within the McAlester basin.

The Excello shale uppermost unit of the Cherokee, and the Little Osage shale member of the Fort Scott limestone are the beds from which the most samples were collected. These two units are the focal point of this study because of their higher radioactivity, extensive occurrence, and good surface exposures. Some of the other black-shale beds that were sampled extensively are not named; these are identified in this report by reference to adjacent named units. For instance, many samples were collected from the black-shale bed underlying the Verdigris limestone member, as this unit was well exposed in coal strip pits.

STRUCTURE

The outcrop belt examined in this investigation trends northward and northeastward across Oklahoma and Kansas. The outcropping Des Moines rocks dip gently westward and northwestward, generally less than 60 feet to the mile, away from the Ozark dome. The importance of the Ozark dome in restricting sedimentation during Cherokee time is conjectural. On the other hand, the Nemaha anticline to the west was a positive structural element which limited part of the Des Moines sedimentation. Precambrian granite along the crest of the Nemaha anticline was exposed during Krebs time and may have been a source area for sediments of the Bluejacket sandstone (Weirich, 1953, p. 2039). Beds of Cabaniss age overlie the granite.

SEDIMENTARY ROCKS OF DES MOINES SERIES

Cyclical repetition of rock types is common in Pennsylvanian sedimentary rocks in many parts of the United States, including most of the area of this report, but classification of the rock sequence into cyclothems represents a detailed breakdown unessential to this report, and a larger grouping of beds has been used.

SANDSTONE

At least 4 principal sandstone units occur in the Cherokee group and 2 in the Marmaton group. Each sandstone member consists of numerous irregularly lenticular and discontinuous sandstone beds that are arranged in definite zones. Some individual sandstone beds within the units are thin, broad, and sheetlike. Lenticular sandstone bodies are common in surface exposures; in the subsurface, elongate channel fills and bar deposits or shoestring sands that are as much as 50 feet thick comprise the important oil and gas reservoirs of the area.

Typically, the sandstone beds are composed of well-sorted fine-grained angular to subangular moderately cemented quartz grains. The sandstone contains abundant coalified wood fragments and thin clay or ironstone partings. The units are massive to thin bedded and commonly are steeply crossbedded.

SILTSTONE

Units of thin-bedded medium- to dark-gray siltstone or silty shale are abundant and relatively thick. The siltstone commonly is evenly bedded, micaceous, ferruginous, and sandy. Fossil fauna are rare, but abundant macerated coalified plant fragments are present along thin laminae.

UNDERCLAY AND COAL

Underclay of coal beds commonly overlies the siltstone with a generally gradational contact. Locally the underclays of some coal beds in the Cherokee rest on impure nodular limestone. This limestone corresponds to the "fresh-water" limestone unit of the ideal cyclothem of Weller (1930), but in southeastern Kansas it is reported by Howe (1954, p. 4 of this report) to be of marine origin. The underclays are light colored, plastic, lack sedimentary structures, and are generally less than 1 foot thick, although some underclays are as much as 7 feet thick locally.

Coal rests directly on the underclay. The coal is high volatile bituminous and has a low ash and sulfur content. It is bright, blocky, brittle, and moderately hard. The Cherokee group of Kansas contains at least 15 coal beds. Six of these beds are locally as much as 4 feet thick; the remaining beds are 1 foot or less thick. Only 2 coal beds in the Krebs and Cabaniss groups of Oklahoma are as much as 2 feet thick. The Marmaton group contains at least 3 thin coal beds, 1 of which is 14 inches thick locally in southeastern Kansas.

BLACK SHALE

The "black" shale beds of this report are not all black: some "black shale" units contain medium-gray to very dark gray shale, but they are nevertheless distinctively darker than other shales and the term "black shale" is used. These shales are all rich in organic matter, generally have good fissility, and have relatively high radioactivity.

Two distinct types of black shale can be recognized at the outcrop, phosphatic or carbonaceous. Contrasting characteristics of these two types are briefly summarized as follows.

Phosphatic shale	*Carbonaceous shale*
1. Conspicuous phosphatic nodules or laminae.	1. Phosphatic nodules or laminae absent or rare; ironstone and carbonate concretions common.
2. Jointing prominent on weathered surface; weathers to brittle booklike leaves.	2. Weathered surface soft and lacking distinctive character.
3. More radioactive, greater uranium content.	3. Less radioactive, smaller uranium content.
4. Yields appreciable amounts of oil by distillation.	4. Yields very little oil; seems to be coaly.
5. Marine fossils common.	5. Fossils rare.
6. Commonly overlain by marine limestone caprock.	6. Commonly overlain by sandstone or siltstone caprock, but locally overlain by limestone caprock.

Most black-shale units are 2 to 4 feet thick, but some are locally as much as 13 feet thick. The thickest and most numerous black-shale units are in the Cherokee, which contains as many as twelve. All of the black-shale beds in the lower part of the Cherokee (Krebs group in Oklahoma) are carbonaceous except two that are locally phosphatic. The upper part of the Cherokee (Senora formation in Oklahoma) contains as many as 5 carbonaceous shales and 3 phosphatic shales. Three and locally four units of black phosphatic shale occur in the Marmaton group.

CARBONACEOUS SHALE

The Krebs group in Oklahoma contains the following carbonaceous shale units: (a) shale in the McAlester formation, (b) locally carbonaceous shale above the Spaniard and Sam Creek limestones of the Savanna formation, (c) a shale bed above the Drywood coal, and (d) a shale bed above the Inola limestone of the Boggy formation. The Kinnison shale member of Branson (1954) of the Senora formation, Cabannis group, contains a carbonaceous shale unit. The Cherokee group in Kansas and Missouri contains carbonaceous shale above the Riverton coal and the Fleming coal. A carbonaceous shale overlying the Dawson coal of Missouri age was examined and tested in this investigation.

The carbonaceous shale units generally vary in thickness and overlie coal beds (pl. 2) with a very sharp contact, although locally a transition bed a fraction of an inch thick is present. This bed is black fissile locally pyrite-rich commonly calcareous shale containing numerous fossils of both flora and fauna and minute laminae of vitreous coal.

Carbonaceous shale beds commonly contain ironstone or limestone nodules. Generally the shale is firm and waxlike and tends to become plastic when wet. The carbonaceous shale is generally less fissile than the phosphatic shale, although some of the thin carbonaceous shale units are locally very fissile and closely resemble the phosphatic shale but lack phosphatic nodules.

Some of the carbonaceous shale beds in the upper part of the Cherokee are fossiliferous, but marine fossils are absent in carbonaceous shale beds in the lower part of the Cherokee group. Some of the units in the Krebs group in Oklahoma are capped by fossiliferous marine limestone, and the calcareous basal beds of the fossiliferous black shale in the upper part of the Cherokee contain a few scattered fossils of large well-preserved but mechanically deformed chonetid, productid, and spiriferid brachiopods, horn corals, and crinoid columnals.

The oil yield of the carbonaceous shale seems to be insignificant. Runnels and others (1952) obtained little or no oil in four samples of shale from the lower part of the Cherokee. Two samples of carbonaceous shale collected for this investigation (locs. S-40 and T-4, table 5) yielded 0.2 and less than 0.2 gallon of oil per ton.

PHOSPHATIC SHALE

The phosphatic shale units in the Cabaniss group and the Cherokee group are, in ascending order: (a) the black shale overlain by the Tiawah limestone member; (b) the black shale overlain by the Verdigris limestone member; and (c) the Excello shale which is immediately overlain by the lowermost limestone member of the Fort Scott limestone of the Marmaton group. The black shale overlying the Sam Creek limestone member of the Savanna formation and the black shale overlying the Inola limestone member of the Boggy formation of the Krebs group are locally phosphatic.

The phosphatic shale units in the Marmaton group are, in ascending order: (a) the Little Osage shale member of the Fort Scott limestone, (b) the Anna shale member of the Pawnee limestone, (c) the Lake Neosho shale member of the Altamont limestone, and (d) the Perry Farm shale member of the Lenapah limestone, which commonly is a light-greenish-gray calcareous shale in Oklahoma, but locally in Nowata County, Okla. (Oakes, 1952, p. 39), and in Linn County, Kans. (Jewett, 1945), is black and contains phosphatic nodules. In addition to these shales in the Des Moines series, a phosphatic shale unit overlying the Checkerboard limestone and a phosphatic shale unit in the Muncie Creek shale, both of Missouri age, were tested.

The Little Osage shale member is the only phosphatic black shale that can be recognized as far south as the south boundary of the area (pl. 2), and as none persist southward into the McAlester basin they are apparently of shelf facies. Units of the Marmaton group are recognizable only in a very small area in Oklahoma, and as their names do not appear on the geologic map of Oklahoma (Miser, 1954) names from Kansas for these shale units are used in this report.

Phosphatic shale units are generally 1 to 2 feet thick and are fairly uniform in thickness over wide areas but are locally as much as 13 feet thick. These shale beds are extremely persistent and are typically associated with overlying equally persistent limestone beds. The contact between the two may be either sharp or have a transition zone of dark-gray to light-yellowish-gray calcareous shale, 1 or 2 inches thick.

Some phosphatic shale units overlie coal beds, and others overlie limestone or shale. The Anna shale member of the Pawnee limestone conformably overlies gray claystone of the Labette shale with a remarkably sharp planar contact in Bourbon County, Kans.; a dark shale at the corresponding stratigraphic position, the base of the Pawnee limestone in Nowata County, Okla., overlies a thin limestone with a transition bed of gray calcareous shale more than 1 inch thick. The contact between phosphatic shale beds and underlying coal beds is generally sharp, and where transitional beds are present locally they most commonly are pyrite-rich black claystone less than an inch thick. The pyrite is in irregularly distributed aggregates of fine crystals, or masses of small stringers and nodules.

Ellipsoidal limestone concretions, as much as 4 feet in maximum diameter, occur at the base of the Excello shale member in Bourbon County, Kans., and are locally abundant elsewhere. The concretions have thick rinds of ironstone containing masses or pyrite. Thin beds containing abundant pyritized shells and shell fragments and nodular calcareous shale beds less than an inch thick have been found at the base of several other shale units that overlie coal beds in southeastern Kansas.

Most of the phosphatic shale units contain inconspicuous fossils of a marine fauna. The small disk-shaped brachiopod *Orbiculoidea* is probably the most abundant fossil and is well preserved as external casts randomly and sparingly distributed in all parts of the shale. Many well-preserved conodonts were observed in most parts of the shale unit underlying the Verdigris limestone member and the Little Osage shale member. Well-preserved *Orbiculoidea*, shark's teeth, and fish spines form the cores of many of the phosphatic nodules that are distributed in the phosphatic shale beds.

The bedding-plane surfaces of nearly all the phosphatic shale beds are medium dark gray and have a slatelike luster. Broken edges of the shale are black and jetlike, and the streak is black or dark brownish black. In many shale beds, particularly fissile shale, the parting surfaces have a lustrous sheen produced by a very thin crust of gypsum, and commonly the surfaces of joints and parting planes are stained with thin films of ocher, both probably derived from decomposition of pyrite. The weathered surfaces of some shales are covered with yellowish-gray clayey residuum.

In thin sections, bedding is expressed by minutely thin translucent lentils as much as a millimeter in thickness composed of mineral grains contained in an opaque matrix. The extremely thinly laminate structure of the shale is developed from the planar arrangement of the lentils, and minute banding is produced where the lentils are crowded within narrow more-or-less continuous zones. Some of the black-shale beds have visible laminations and persistent zones, rarely exceeding several millimeters in thickness, that contain minute lenses and nodules of relatively light-colored calcareous phosphatic rock.

Fissility is the most pronounced structural feature of the black shale when moderately weathered. Some beds of the shale can be split into broad sheets less than 2 mm thick and others can be crumbled into paper-thin flakes, but unweathered shale resists crumbling and breaks with conchoidal fracture across bedding laminae. In most of the natural outcrops of shale, subtle differences of color, bedding, and nodule distribution are masked by weathering. In many of the moderately weathered shale units the only discernible variation is in the relative fissilities of the different parts.

The dark-gray shale beds contain less organic material than black-shale beds. The quantities of calcite, quartz, apatite, and pyrite vary in the shales of different colors (table 4). Comparison of X-ray diffraction intensities from clay minerals in gray and black-shale samples of the Little Osage shale member of the Fort Scott limestone at locality LO–100, Fort Scott, Kans., suggests that illites are present in slightly greater amounts in black shale than in gray shale. Accordingly, gray shale has slightly greater amounts of kaolin than black shale (table 4).

Phosphatic shale yields appreciable quantities of oil by destructive distillation, in contrast with carbonaceous shale. Runnels and others (1952, p. 177–179) reported yields of oil ranging from a few to as much as 12 gallons per ton, and 14 samples of phosphatic shale (table 5),

TABLE 4.—*Relative abundance of minerals in shale from different parts of the Little Osage shale member in limestone quarry, Fort Scott, Bourbon County, Kans.*

Mineral	More abundant in—	Less abundant in—	Least abundant in—
Apatite	Black shale [1]	Dark-gray shale [2]	Light-gray shale.[3]
Calcite	Light-gray shale	do	Black shale.
Illite	Black shale	Light- and dark-gray shale.	
Kaolin	Light-gray shale	Dark-gray and black shale.	
Quartz	Light- and dark-gray shale.	Black shale	

[1] Black shale in lower part of unit.
[2] Massive dark-gray shale in upper part of unit.
[3] Irregular light-gray laminae contained in dark-gray shale.

collected for this investigation, yielded quantities of oil ranging from 0.2 to 14.6 gallons per ton. Although these phosphatic shale beds yield far less oil than the oil shale of the Green River formation in Colorado, they can be considered oil shale.

Phosphatic nodules seem to be randomly distributed within some phosphatic shale units and to occur in zones of abundant nodules locally, although these zones are generally discontinuous. The nodules are estimated to range from less than 1 percent to about 5 percent by volume.

The diameter of most phosphatic nodules is between ½ to 1 inch; the minimum dimension observed was about a quarter of an inch and the maximum about 6 inches. Most are spheroidal but many are lens shaped or are irregular in shape because of coalescence of more than one lens. Surfaces of the nodules are smooth and many are slickensided; the striae of the slickensides are perpendicular to normal bedding of the enclosing shale. Some of the laminations and parting planes of the enclosing shale bend around the edges of phosphatic nodules and others are truncated along the edges of the phosphatic nodules.

TABLE 5.—*Description of sample-collecting*

[Uranium determinations by R. Moore, Joseph Budinsky, D. L. Schafer, J. P. Schuch, Wendell Tucker Schuch; phosphate determinations by Wendell

Locality on pl. 1	Location					Description (includes bed, member and formation names)
	Sec.	Town-ship	Range	County	State	
MA-19	NE¼ 16	20 N.	18 E.	Mayes	Okla	Shale, black, carbonaceous
MA-29	NW¼ 3	23 N.	19 E.	do	do	Shale, gray, platy, micaceous
MA-30	NE¼ 13	23 N.	19 E.	do	do	Shale, black, fissile, carbonaceous, micaceous.
R-82	NW¼NE¼ 9	32 S.	25 E.	Cherokee	Kans	Riverton coal bed; grab sample
						Shale, dark-gray, platy to massive, carbonaceous, unweathered; grab sample.
R-91	NE¼SW¼ 23	29 N.	33 W.	Jasper	Mo	Riverton coal bed
						Underclay
						Shale, black, fissile
						Siltstone, gray, massive
S-40	NE¼ 3	26 N.	21 E.	Craig	Okla	Shale, dark-gray, carbonaceous; contains large ironstone nodules.
						Ironstone nodules, 0.8 ft in diameter.
						Shale, dark-gray; overlies Spaniard limestone, which is not exposed here.
SC-16	6	16 N.	18 E.	Wagoner	do	Shale, dark-gray, platy, carbonaceous.
						Shale, black, fissile
						Ironstone nodules, rare, lens-shaped, large (2 in.).
						Shale, black, fissile, phosphatic; overlies Sam Creek limestone, which is not exposed here.
						Phosphatic nodules, rare, spheroidal.
SC-39	Center 21	27 N.	21 E.	Craig	do	Shale, dark-gray, fissile to platy, carbonaceous, micaceous; overlies Sam Creek limestone, which is not exposed here.
D-20	SE¼ 33	21 N.	18 E.	Mayes	do	Shale, black, fissile, carbonaceous
D-28	NE. cor. 5	23 N.	19 E.	do	do	Shale, yellowish-brown, thin-bedded.
						Shale, brownish-black, fissile, carbonaceous.
						Drywood coal bed
D-31	NE¼ 10	25 N.	19 E.	Craig	do	Drywood? coal bed
						Shale, medium-gray; contains abundant ironstone concretions.
						Shale, dark-gray, platy, carbonaceous.
D-38	SE¼ 27	27 N.	20 E.	do	do	Bluejacket sandstone member
						Shale, dark-gray, platy, soft, weathered.
						Shale, black, fissile, carbonaceous
						Shale, black, platy to blocky; contains pyritized pelecypod shells.
						Drywood coal bed
D-81	Center W. line 24	32 S.	24 E.	Cherokee	Kans	Shale, dark-gray, fissile to platy, carbonaceous, weathered; grab sample.
D-202	NE¼SW¼ 5	35 N.	32 W.	Vernon	Mo	Bluejacket sandstone member: siltstone, yellowish-gray, thinly bedded, micaceous; contains coaly laminae.
D-210	SE¼ 11	35 N.	32 W.	do	do	Shale, black, fissile, carbonaceous, soft, micaceous.
						Drywood coal bed
						Underclay
D-220	NW¼SW¼ 6	35 N.	32 W.	Vernon	Mo	Sandstone
						Shale, black, platy, carbonaceous
						Rowe coal bed
I-21	7	21 N.	18 E.	Mayes	Okla	Shale, black; contains scattered ironstone and phosphatic nodules; grab sample.
						Phosphatic nodules

See footnote at end of table.

localities with analytical data

and C. G. Angelo; radiation measurements (eU) by B. A. McCall, C. G. Angelo, Mary Finch, and J. P. Tucker; oil yield by Wendell Tucker; all of U.S. Geol. Survey]

Group or formation	Thickness (feet)	Laboratory No.	U (percent)	eU (percent)	Radiation measured in field (milliroentgen per hour)	P_2O_5 (percent)	Oil (gallons per ton)
McAlester formation	5.0	236015	0.0005	0.002	0.02		
do	2.0	146086	<.001	.002			
do	2.5	146087	.001	.002	.025		
Cherokee group		[1] 146990	.0007				
do		146984	<.001	.003	.02		
do	.5						
do	6.0						
do	5.0	147954	.0011	.003	.02		
do	3.0±						
Savanna formation	5.0	[1] 146101	.002	.004	.02		0.2
do	.3	[1] 147241	.002	<.001		3.1	
do	7.0±				.02		
do	6.0	146071	.001	.002	.03		
do	2.5	236013	.0027	.003	.03		
do		236014	.003	.002		.5	
do	3.0	236012	.0007	.002	.04		
do		146612	.006	.006		11.4	
do	1.0	146100	<.001	.002			
do	1.0	236016	.0022	.004			
do	3.5	146084	.001	.002	.02		
do	.5	146085	.004	.004	.03		
do							
do							
do	4.0						
do	1.5	146088	.001	.002	.03		
Boggy formation	1.0±						
Savanna formation	5.5						
do	4.0	146097	.004	.005	.035		
do	1.0	146098	.001	.003	.035		
do	.2	146099	.002	.003	.04		
do	6.0	146983	<.001	.002	.015		
Boggy formation	8.0	147955	.0009	.003			
Savanna formation	1.0	147956	.0011	.003	.015		
do	.2						
do	2.4						
Cherokee group	8.0						
do	2.0	147957	.0013	.003	.015		
do	.5						
Boggy formation	9.0	236017	.0005	.002	.03		
do		146615	.002	.001		19.0	

TABLE 5.—*Description of sample-collecting*

Locality on pl. 1	Location					Description (includes bed, member and formation names)
	Sec.	Township	Range	County	State	
T-4	Between 12 and 13	21 N.	16 E.	Rogers	Okla	Chelsea sandstone member: Sandstone, yellowish-brown, crossbedded, medium-grained; irregularly channeling base. Basal 5.5 ft of 20-ft bluff well exposed.
						Shale, dark-gray, fissile; grab sample from shale lens at base of Chelsea sandstone.
						Tiawah limestone member
						Shale, black, fissile, carbonaceous; upper 2.4 ft of 3.6-ft unit.
						Shale, black, fissile, phosphatic; lower 1.2 ft of 3.6-ft unit.
						Phosphatic nodules (estimated <2 percent of the rock).
T-15	2	16 N.	15 E.	Wagoner	do	Shale, black, fissile, phosphatic; deeply weathered; 1.0-ft channel sample of 4.0-ft black-shale unit underlying the Tiawah limestone member.
T-27	NE¼ 3	23 N.	18 E.	Mayes	do	Shale, black, fissile, phosphatic
						Phosphatic nodules; estimated to be 3 percent of the rock.
T-32	SW¼ 5	25 N.	19 E.	Craig	do	Weir-Pittsburg? coal
T-33	NW. cor. 32	26 N.	19 E.	do	do	Tiawah limestone member
						Shale, light brownish- to medium-gray, platy.
						Shale, dark-gray, fissile, carbonaceous.
						Limestone, dark-gray, fossiliferous; one bed.
						Shale, black, phosphatic; abundant nodules.
						Shale, black, platy, phosphatic; 0.2-ft channel sample from zone of relatively abundant nodules (1.7-ft bed described above).
						Phosphatic nodules from 1.7-ft shale bed.
T-45	NW¼ 25	27 N.	19 E.	do	do	Tiawah limestone member
						Shale, black, fissile, phosphatic
						Shale, black, platy to blocky, phosphatic; phosphatic nodules, estimated to be 5 percent of the rock, are small and mostly lens shaped.
						Tebo coal bed
T-77	SE¼ 6	32 N.	33 W.	Barton	Mo	Shale, black, phosphatic, fresh; contains few small nodules.
						Aggregate of pyritized shells and coalified wood.
						Tebo coal
T-90	SW. cor. 13	28 S.	25 E.	Crawford	Kans	Tiawah limestone member
						Shale, black, platy, phosphatic; sample includes phosphatic lenses and nodules.
T-170	25	32 S.	23 E.	Cherokee	do	Sandstone and claystone
						Shale, black, fissile
						Covered interval
						Tiawah limestone
M-41	SE¼SW¼ 18	28 N.	21 E.	Craig	Okla	Shale, dark-gray, to black, fissile, phosphatic.
						Phosphatic nodules, medium-gray, spheroidal
						Phosphatic nodules, dark-gray, spheroidal.
						Mineral coal bed
M-70	SW¼NW¼ 14	27 S.	25 E.	Bourbon	Kans	Shale, black, fissile, phosphatic
						Phosphatic nodules, dark-brownish-gray; punky appearance.
						Mineral coal bed
F-230	SW¼SW¼ 18	34 N.	32 W.	Vernon	Mo	Shale, black, carbonaceous
						Ironstone nodules, abundant, large (4 in. in diameter), flat.
						Limestone, dark-gray, fossiliferous.
						Fleming coal bed

See footnote at end of table.

localities with analytical data—Continued

Group or formation	Thickness (feet)	Laboratory No.	U (percent)	eU (percent)	Radiation measured in field (milliroentgen per hour)	P_2O_5 (percent)	Oil (gallons per ton)
Senora formation	5.5	148068	0.0001				
do	1.0	236006	.0008	0.003			
do	5.5						
do	2.4	146048	.002	.003			<0.2
do	1.2	236005	.0038	.004			
do		146608	.008	.010		30.7	
do	1.0	146605	.002	.002	0.03	.1	
do	4.0	146083	.002	.004	.03		
do		147131	.012	.013		24.3	
do	.5	[1]146616	.001		.015		
do	.3						
do	8.0	[1]146090	<.001	.002	.03		
do	2.0	[1]146091	.001	.002	.02		
do	.3						
do	1.7	146092	.003	.004	.035		
do	.2	254099	.006	.006	.05	4.1	
do		254100	.008	.008		24.9	
do	.3						
do	1.0	146995	.002	.003	.03	.6	
do	1.0	146991	.002	.005	.03		
do	.5	[1]146985	.001		.03		
do	1.9	[1]147012	.004	.004	.05	1.7	
do	.01						
do	.6	[1]146989	.002	.005	.02		
do	0.4						
do	1.0	147021	.008	.006		10.1	
do	1.2						
do	.5	147952	.004	.004			
do	.5						
do	.5±						
do	3.0+				.01		
do		147135	.012	.014		33.0	
do		[1]147242	.012			32.1	
do	1.0+						
Cherokee group	.4	147412	.005	.006	.02	5.1	
do		147411	.023				
do	1.1						
do	2.5	147958	.0011	.003			
do		147974	.007	.006		.9	
do	2.8						
do	1.5						

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TABLE 5.—*Description of sample-collecting*

Locality on pl. 1	Location					Description (includes bed, member and formation names)
	Sec.	Township	Range	County	State	
V-3	SE¼SE¼ 1	22 N.	16 E.	Rogers	Okla	Verdigris limestone member
						Claystone, light-gray, earthy, limy.
						Shale, light-gray, carbonaceous in part.
						Shale, black, fissile, phosphatic
						Phosphatic nodules, light-olive-gray; generally small (<1 in. in diameter).
						Shale, black, fissile, phosphatic; contains few nodules.
V-7	22	17 N.	14 E.	Tulsa	do	Shale, dark-gray, platy; contains limestone nodules.
						Limestone nodules, large
						Shale, black, blocky, hard
						Shale, black, fissile, phosphatic
						Phosphatic nodules, dark gray; oblate spheroids; contain abundant pyrite.
						Shale, black
						Limestone, medium-gray; one bed
V-14	NW¼NE¼ 7	16 N.	15 E.	Wagoner	do	Shale, black, fissile, phosphatic
V-18	SE¼ 33	20 N.	15 E.	Rogers	do	Verdigris limestone member
						Shale, yellowish-gray; thin, uneven beds.
						Shale, black, fissile, phosphatic
						Phosphatic nodules, large (1.6 ft in diameter); flat; concentrated at base of shale unit.
V-24	SW¼SE¼ 14	24 N.	17 E.	do	do	Verdigris limestone member
						Shale, black, fissile, phosphatic
						Phosphatic nodules, brownish-gray, silty, spheroidal shape; estimated 3 percent of the rock.
V-25	32	24 N.	17 E.	Rogers	Okla	Verdigris limestone member
						Covered interval
						Shale, black, fissile, phosphatic; contains estimated 2 percent nodules.
						Phosphatic nodules, dark-gray; lens shape.
						Phosphatic nodules, dark-gray; spheroidal shape.
V-43	NE¼SW¼ 29	28 N.	20 E.	Craig	do	Verdigris limestone member
						Shale, gray, contains ironstone and carbonaceous laminae.
						Shale, black, platy, phosphatic, soft; deeply weathered.
						Phosphatic nodules, olive-gray; soft, chalky texture; lens shaped, estimated 5 percent of the rock.
V-51	NE¼ 22	25 N.	17 E.	Nowata	do	Shale, black, platy, weathered
						Phosphatic nodules, dark-gray, small, rare.
V-80	SE¼NW¼ 24	28 S.	25 E.	Crawford	Kans	Verdigris limestone member
						Shale, gray, fissile
						Shale, black, platy, phosphatic; deeply weathered.
V-83	15	31 S.	23 E.	do	do	Verdigris limestone member
						Claystone, gray, soft
						Shale, black, platy, soft
						Shale, black, platy, soft; contains limestone nodules.
						Shale, black, fissile, phosphatic; abundant nodules.
						Phosphatic nodules, medium dark-gray; spheroidal shape.
						Phosphatic nodules, olive-gray; lens shaped.
						Phosphatic nodules, dark-gray; spheroidal.
						Phosphatic nodules, medium dark-gray, granular texture; contain pyrite.

See footnote at end of table.

localities with analytical data—Continued

Group or formation	Thickness (feet)	Laboratory No.	U (percent)	eU (percent)	Radiation measured in field (milliroentgen per hour)	P_2O_5 (percent)	Oil (gallons per ton)
Senora formation	3.0+						
do	.3	147415	0.001	0.001			
do	.5						
do	.8	236003	.0100	.009		10.8	
do		147119	.015	.015		30.4	
do	2.1	147413	.002	.003			
do	2.2	146057	.002	.002			
do		147112	.002	.002		2.1	
do	2.0	146058	.001	.002			
do	2.2	146059	.005	.003			
do		147123	.009	.009		26.9	
do	2.0						
do	4.0+						
do	5.0	236010	.0025	.004	0.03		
do	3.0+						
do	1.0						
do	3.7	146075	.002	.002			
do		146614	.012	.012		22.4	
do	.5+						
do	2.0	146080	.002	.003	.04		1.2
do		147129	.011	.010		31.8	
Senora formation	3.0						
do	1.5						
do	1.0	146081	.001	.003	.03		
do		147130	.012	.011		27.3	
do		[1] 147238	.011	.013		30.2	
do	3.5±						
do	.5						
do	1.0	146103	<.001	.002	.04		
do		147134	.012	.014		33.8	
do	2.0	147916	.002	.004			
do		147880	.011	.009		24.4	
do	1.5+						
do	2.0						
do	3.6	147013	.005	.003	.04	1.5	
do	.8						
do	2.8						
do	2.5						
do	.5						
do	2.7	147014	.004	.003	.03	.8	
do		147164	.021	.015		26.5	
do		147165	.012	.012		24.4	
do		147166	.021	.021		18.5	
do		[1] 147250	.017	.017		27.5	

TABLE 5.—*Description of sample-collecting*

Locality on pl. 1	Location					Description (includes bed, member and formation names)
	Sec.	Township	Range	County	State	
V-90	NW¼ 16	22 N.	16 E.	Rogers	Okla	Verdigris limestone member
						Shale, black, fissile, phosphatic; deeply weathered.
						Phosphatic nodules from upper 1.0 ft of unit; small, abundant in thin zones.
						Phosphatic nodules from lower 0.7 ft of unit; 3 in. in diameter.
V-110	SE¼ 12	24 N.	16 E.	do	do	Verdigris limestone member
						Shale, light yellowish-gray, earthy, limy.
						Shale, dark-gray to black, fissile, carbonaceous.
						Shale, black, platy, phosphatic
						Phosphatic nodules, dark-gray to black; mostly irregularly shaped.
V-160	NE¼NW¼ 27	30 S.	24 E.	Crawford	Kans	Shale, black, platy; contains widely scattered large limestone nodules.
						Croweburg coal bed
V-180	SW¼SW¼ 26	33 S.	21 E.	Labette	Kans	Verdigris limestone member
						Shale, black, platy, phosphatic; grab sample.
						Phosphatic nodules, dark-gray to black, irregularly shaped; prolate, coalesced, and spheroids.
V-240	SW¼SW¼ 7	34 N.	32 W.	Vernon	Mo	Verdigris limestone member
						Shale, black, blocky
						Shale, black, platy
						Limestone, dark-gray
						Shale, black, blocky; contains phosphatic nodules and large ironstone concretions.
						Phosphatic nodules
						Ironstone concretions
K-35	34	26 N.	18 E.	Craig	Okla	Breezy Hill limestone member
						Shale, light-gray, with yellow ironstone laminae.
						Shale, black, fissile, carbonaceous; soft.
						Iron Post coal bed
E-5	11	21 N.	15 E.	Rogers	do	Blackjack Creek limestone member.
						Excello shale member:
						Shale, grayish-yellow, earthy; soft
						Shale, grayish-brown, deeply weathered.
						Shale, brown, fissile
						Shale, black, fissile, phosphatic
						Phosphatic nodules, brownish-black; contain finely divided pyrite.
						Shale, black, blocky, phosphatic; hard.
E-6	34	17 N.	14 E.	Tulsa	do	Excello shale member:
						Shale, black, fissile, phosphatic; deeply weathered.
						Phosphatic nodules, olive-gray; spheroidal shape.
						Limestone
						Shale, black, fissile, deeply weathered.
						Phosphatic nodules, yellowish-brown; large, lens shaped.
						Shale, black, platy, phosphatic, deeply weathered.
E-10	27	18 N.	14 E.	do	do	Excello shale member:
						Shale, black, fissile, phosphatic
						Phosphatic nodules; rare, various shapes.
						Shale, black, blocky, phosphatic
						Phosphatic nodules, rare

See footnote at end of table.

localities with analytical data—Continued

Group or formation	Thickness (feet)	Laboratory No.	U (percent)	eU (percent)	Radiation measured in field (milliroentgen per hour)	P_2O_5 (percent)	Oil (gallons per ton)
Senora formation	0.5						
do	1.7	147928	0.001	0.003	0.02		
do		147890	.019	.015		30.3	
do		147891	.014	.012		32.2	
do	2.5						
do	.6	147930	.001	.002			
do	.5	147931	.001	.002	.02		
do	1.5	147932	.002	.002	.02		
do		147893	.014	.014		27.8	
do	1.7						
do	.5	147951	.0020	.002	.1		
do	2.0±						
do	2.0±	147953	.0031	.004	.1		
do		147973	.030	.024		22.9	
do	2.2						
do	1.0	147959	.0027	.003			
do	1.0	147960	.0018	.003			
do	.2						
do	5.0	147961	.0035	.004			
do		147975	.016	.013		25.8	
do		147976	.003	.003		.7	
do	3.4						
do	.7						
do	1.3	[1] 146094	.001	.003	.03		
do	1.5				.02		
Fort Scott limestone	3.0+						
Senora formation	.5	146053	.001	.002			
do	.2	146052	.003	.003			
do	2.3	146051	.003	.002	.02		
do	.5	236008	.0032	.002	.06		
do		147121	.021	.023		24.9	
do	2.0	236007	.0052	.006			
do	1.7	146054	.003	.004			
do		[1] 147234	.017	.017		32.0	
do	1.2						
do	.8	146055	.004	.003	.003		
do		[1] 147235	.012	.013		32.1	
do	.7	146056	.003	.003			
do	2.4	147907	.005	.004			
do		147871	.012	.010		26.8	
do	1.7	147908	.008	.010			
do		147872	.028	.021		24.2	

TABLE 5.—*Description of sample-collecting*

Locality on pl. 1	Location					Description (includes bed, member and formation names)
	Sec.	Township	Range	County	State	
E-13	NE¼NE¼ 24	20 N.	14 E.	Rogers	Okla	Blackjack Creek limestone member. Excello shale member: Shale, black, fissile, phosphatic Phosphatic nodules; rare; small Shale, black, platy, phosphatic Phosphatic nodules, rare, small
E-17	NW¼ 5	19 N.	15 E.	Wagoner	do	Blackjack Creek limestone member. Excello shale member: Shale, dark-gray, fissile Shale, black, fissile, phosphatic Phosphatic nodules; 1/10 in. to 2 in. in diameter. Shale, black, fissile, limy, fossiliferous. Iron Post coal bed
E-20	31	20 N.	15 E.	Rogers	do	Excello shale member: Shale, grayish-yellow, soft, limy, phosphatic. Phosphatic nodules; medium-gray; abundant (estimated 3 to 6 percent), spheroidal and lens shaped. Shale, black, fissile, phosphatic Phosphatic nodules, dark-gray, abundant (estimated 3 to 6 percent), lens shaped. Shale, black, blocky, phosphatic Phosphatic nodules, medium-gray, small (½ in. in diameter).
E-26	3	23 N.	16 E.	do	do	Excello shale member: Shale, black, fissile Covered interval
E-30	25	26 N.	18 E.	Craig	do	Excello shale member: Shale, black, fissile, phosphatic Phosphatic nodules, medium-gray, abundant (estimated 5 percent). Shale, black, fissile, phosphatic Phosphatic nodules, medium-gray, rare (estimated 3 percent), lens shaped.
E-34	13	26 N.	18 E.	do	do	Blackjack Creek limestone member. Excello shale member; black, fissile, phosphatic, nodules are rare (estimated 2 percent). Phosphatic nodules, dark-gray, 0.5 in. in diameter, spheroidal shaped. Phosphatic nodules, dark-gray, large (3.0 in. in diameter), lens shape. Breezy Hill limestone member
E-42	4	28 N.	20 E.	do	do	Excello shale member; black, platy.
E-44	SW¼ 7	28 N.	20 E.	do	do	Excello shale member: Shale, black, fissile, phosphatic, fresh. Phosphatic nodules, dark-gray, spheroidal; contain pyrite. Phosphatic nodules, dark-gray, concentrically layered. Phosphatic nodules, dark-gray, lens shaped. Shale, black, platy; contains relatively few phosphate nodules.
E-49	SW¼ 35	34 S.	20 E.	Labette	Kans	Excello: Shale, black, fissile, phosphatic Phosphatic nodules, dark-gray with black nuclei, small (½ in. in diameter), mostly spheroidal.

localities with analytical data—Continued

Group or formation	Thickness (feet)	Laboratory No.	U (percent)	eU (percent)	Radiation measured in field (milliroentgen per hour)	P_2O_5 (percent)	Oil (gallons per ton)
Fort Scott limestone----	10.0+	----------	----------	----------	----------	----------	----------
Senora formation-------	1.6	146066	0.003	0.003	0.03	----------	----------
-----do----------------	----------	146610	.017	.016	----------	23.0	----------
-----do----------------	3.0	146067	.005	.004	.045	----------	----------
-----do----------------	----------	146611	.022	.025	----------	22.1	----------
Fort Scott limestone----	1.0+	----------	----------	----------	----------	----------	----------
Senora formation-------	2.1	----------	----------	----------	----------	----------	----------
-----do----------------	1.9	146072	.002	<.001	----------	----------	----------
-----do----------------	----------	146613	.022	.023	----------	24.3	----------
-----do----------------	.5	146073	.004	.004	----------	----------	----------
-----do----------------	1.5	146074	.002	.003	----------	----------	----------
-----do----------------	.3	147909	.001	.003	----------	----------	----------
-----do----------------	----------	147873	.012	.010	----------	24.4	----------
-----do----------------	1.5	147910	.001	.002	----------	----------	----------
-----do----------------	----------	147874	.024	.021	----------	28.5	----------
-----do----------------	1.0	147911	.002	.004	----------	----------	----------
-----do----------------	----------	147875	.014	.012	----------	29.2	----------
-----do----------------	4.0	146082	.002	.003	----------	----------	8.1
-----do----------------	3.0	----------	----------	----------	----------	----------	----------
-----do----------------	1.0	147912	.001	.003	.03	----------	----------
-----do----------------	----------	147876	.013	.009	----------	26.0	----------
-----do----------------	1.0	147913	.002	.004	.03	----------	----------
-----do----------------	----------	147877	.013	.012	----------	16.8	----------
Fort Scott limestone----	5.0	----------	----------	----------	----------	----------	----------
Senora formation-------	3.0	146093	.002	.002	----------	----------	----------
-----do----------------	----------	147132	.016	.014	----------	29.2	----------
-----do----------------	----------	147133	.009	.010	----------	22.8	----------
-----do----------------	7.0	----------	----------	----------	----------	----------	----------
-----do----------------	1.3	146102	.001	.002	----------	----------	----------
-----do----------------	4.0	146606	.003	.004	.03	1.1	----------
-----do----------------	----------	147137	.010	.009	----------	21.4	----------
-----do----------------	----------	147138	.008	.010	----------	26.8	----------
-----do----------------	----------	147139	.009	.008	----------	22.8	----------
-----do----------------	1.0	146607	.003	.004	----------	2.1	----------
Cherokee group--------	1.5	146976	.003	.004	0.04	----------	----------
-----do----------------	----------	147144	.013	.013	----------	26.3	----------

TABLE 5.—*Description of sample-collecting*

Locality on pl. 1	Location					Description (includes bed, member and formation names)
	Sec.	Township	Range	County	State	
E-50	SE¼NE¼ 16	33 S.	21 E.	Labette	Kans	Excello, shale, black, fissile and platy, phosphatic, contains abundant nodules.
E-55	NE¼ 19	25 S.	25 E.	Bourbon	do	Excello: Shale, dark-gray, fissile, phosphatic. Phosphatic nodules, olive-gray, large, rare. Shale, black, platy, phosphatic Phosphatic nodules, medium dark-gray, lens shaped.
E-60	31	26 N.	18 E.	Craig	Okla	Excello: Shale, black, platy, phosphatic Phosphatic nodules, abundant (estimated 3 to 5 percent). Shale, black, blocky, phosphatic Phosphatic nodules large, mostly lens shaped, abundant (estimated 5 percent).
E-67	NE¼SE¼ 27	25 S.	25 E.	Bourbon	Kans	Excello, shale, black, platy, abundant phosphatic nodules. Mulky coal bed
E-69	Center of N.	27 S.	25 E.	do	do	Blackjack Creek limestone member. Excello, shale, black, fissile, phosphatic, nodules are flat, small, rare; nodules are included in sample. Mulky coal
E-70	33	21 N.	15 E.	Rogers	Okla	Excello: Clay, grayish-yellow, earthy Shale, black, fissile Phosphatic nodules, grayish-brown, large (1 to 2 in. in diameter), rare. Shale, black, platy Shale, black, phosphatic Phosphatic nodules, black, abundant (estimated 5 percent). Shale, black, platy, phosphatic Phosphatic nodules, light-gray, rare.
E-72	NW. cor. 27	26 S.	25 E.	Bourbon	Kans	Excello: Shale, dark-gray, fissile; phosphatic nodules rare, concentrated at base. Shale, black, platy, phosphatic Shale phospatic; contains abundant pyrite, many pryitized molluscan shells. Phosphatic nodules, olive-gray, lens shaped; contains abundant pyrite. Mulky coal bed
E-74	NW¼SW¼5	28 S.	25 E.	Crawford	Kans	Excello: Shale, black, blocky Phosphatic nodules, brownish-black, lens shaped and coalesced-spheroidal shape; contains abundant pyrite. Shale, black, fissile; contains rare phosphatic nodules. Mulky coal bed
E-79	NE¼ 10	29 S.	25 E.	do	do	Excello, shale, black, fissile, deeply weathered. Phosphatic nodules, light-olive-gray; contain abundant pyrite, spheroidal. Phosphatic nodules, light-olive-gray, lens shaped.
E-80	13	22 N.	15 E.	Rogers	Okla	Excello shale member: Shale, black, platy; contains rare phosphatic nodules. Shale, black, blocky, phosphatic Phosphatic nodules, black; contain abundant pyrite.

See footnote at end of table.

localities with analytical data—Continued

Group or formation	Thickness (feet)	Laboratory No.	U (percent)	eU (percent)	Radiation measured in field (milliroentgen per hour)	P_2O_5 (percent)	Oil (gallons per ton)
Cherokee group	2.2	146977	0.003	0.005			
do	1.0	242689	.002	.003			
do		242696	.008	.008		22.3	
do	1.5	242690	.006	.006			
do		242697	.021	.023		20.7	
Senora formation	2.0	147917	.001	.003	0.025		
do		147881	.013	.011		26.3	
do	2.0	147918	.003	.003	.025		
do		147882	.011	.013		22.4	
Cherokee group	4.5	147003	.010	.008	.04	4.4	
do	.9	[1] 146987	.007	.005	.04		
Fort Scott limestone	8.0+						
Cherokee group	2.0	147004	.006	.006	.04	5.4	
do	.9						
Senora formation	.7	147923	.001	.003			
do	.3	147919	.001	.003	.03		
do		147883	.011	.009		23.6	
do	1.0	147920	.001	.003	.03		
do	1.0	147921	.001	.003	.30		
do		147994	.012	.011		26.2	
do	1.6	147922	.002	.002			
do		147885	.015	.013		27.8	
Cherokee group	1.1				.02		
do	2.8	147006	.005	.005	.06	4.7	
do	.3						
do		[1] 147246	.022	.020		27.1	
do	1.4	[1] 146988	.001	.001	.02		
do	2.0	147007	.001	.003		.5	
do		147156	.014	.012		24.0	
do	1.0	147008	.003	.004	.06	1.4	
do	.7						
do	1.0+						
do		[1] 147248	.012			28.4	
do		[1] 147249	.015			23.7	
Senora formation	2.0	147924	.001	.003			
do	2.5	147925	.001	.003			
do		147886	.021	.021		24.4	

628210 O—62——5

TABLE 5.—*Description of sample-collecting*

Locality on pl. 1	Location					Description (includes bed, member and formation names)
	Sec.	Township	Range	County	State	
E-84	SW¼SW¼ 16	31 S.	23 E.	Crawford	Kans.	Excello, shale, black, fissile, phosphatic nodules abundant in upper half of unit, rare in lower half.
						Phosphatic nodules, dark-gray, spheroidal; contain pyrite.
						Phosphatic nodules, dark brownish-gray; spheroidal; contain abundant pyrite.
						Phosphatic nodules, brownish-gray, lens shaped.
						Phosphatic nodules, dark-gray, lens shaped; contain abundant pyrite.
E-100	12	24 N.	16 E.	Rogers	Okla.	Excello shale member, medium-gray, blocky, phosphatic, deeply weathered.
						Phosphatic nodules, dark-gray.
						Locality Nos. E-101A through FS-125 are all in the same general locality as shown on pl. 4.
E-101A	NE¼ 19	25 S.	25 E.	Bourbon	Kans.	Mulky coal bed, upper part.
E-101B	NE¼ 19	25 S.	25 E.	do	do	Mulky coal bed, lower part.
FS-103	NE¼ 19	25 S.	25 E.	do	do	Excello: (see also pl. 4) Shale, black.
FS-104	NE¼ 19	25 S.	25 E.	do	do	Shale, gray.
						Phosphatic nodules.
FS-120	NE¼ 19	25 S.	25 E.	do	do	Shale, black, phosphatic, fresh, hard.
FS-121	NE¼ 19	25 S.	25 E.	do	do	do.
FS-122	NE¼ 19	25 S.	25 E.	do	do	do.
FS-123	NE¼ 19	25 S.	25 E.	do	do	do.
FS-124	NE¼ 19	25 S.	25 E.	do	do	do.
FS-125	NE¼ 19	25 S.	25 E.	do	do	do.
						Limestone nodules in lowermost part of Excello; large (approximately 1 ft in diameter).
E-120	36	28 N.	19 E.	Craig	Okla.	Excello shale member: Shale, black, platy, phosphatic.
						Phosphatic nodules, spheroidal, rare.
						Shale, black, platy.
						Phosphatic nodules, abundant (estimated >5 percent of the rock).
E-140	35	29 N.	19 E.	do	do	Excello shale member: Shale, black, fissile, phosphatic.
						Phosphatic nodules, black, small, rare.
						Shale, black, platy, phosphatic.
						Phosphatic nodules, medium-gray, abundant (>5 percent), spherical.
						Shale, black, platy, phosphatic.
						Phosphatic nodules, black, large (1 to 2 in. in diameter).
E-146	NE¼NW¼ 16	25 S.	25 E.	Bourbon	Kans.	Excello: Shale, black, fissile, deeply weathered.
						Phosphatic nodules, rare, spherical.
						Shale, black, platy, phosphatic, soft, weathered; sample includes small lens-shaped nodules.
						Mulky coal bed.
E-250	SE¼NW¼ 7	34 N.	32 W.	Vernon	Mo.	Excello formation: Shale, black, fissile.
						Phosphatic nodules, rare, mostly lens shaped.
						Shale, black, platy, hard.
						Phosphatic nodules, abundant (estimated 3 to 5 percent).
E-270	SE¼NW¼ 30	40 N.	31 W.	Bates	do	Excello formation; mottled olive-gray and medium dark-gray, platy, contains large limestone nodules.
						Phosphatic nodules, light olive-gray, lens shaped, rare.

See footnote at end of table.

localities with analytical data—Continued

Group or formation	Thickness (feet)	Laboratory No.	U (percent)	eU (percent)	Radiation measured in field (milliroentgen per hour)	P_2O_5 (percent)	Oil (gallons per ton)
Cherokee group	5.1	147015	0.002	0.004	0.048	1.7	
do		147167	.016			27.2	
do		[1] 147251	.016	.013		23.7	
do		[1] 147252	.011	.009		25.4	
do		[1] 147253	.015			20.9	
Senora formation	2.5	147929	.001	.003	.02		
do		147892	.021	.019		27.3	
Cherokee group	0.2	[1] 242714	.010				
do	.9	[1] 242713	.0006				
do	1.0	148034	.0088	.008	.09	3.4	
do	1.9	148035	.0022	.003		1.5	
do		148028	.0093	.010		22.7	
do	.9	148038	.0093	.009		5.3	
do	1.2	148039	.0061	.006		4.6	
do	1.0	148040	.0060	.007		3.2	
do	1.5	148041	.0049	.004		3.3	
do	1.4	148042	.0042	.005		2.2	
do	1.2	148043	.0047	.005		2.7	
do		148030	.0014	.002		1.5	
Senora formation	2.5	147933	.001	.002	.02		
do		147894	.009	.008		23.4	
do	2.5	147934	.001	.003	.02		
do		147895	.012	.011		26.6	
do	1.6	147938	.001	.003	.02		
do		147899	.012	.013		25.3	
do	2.0	147939	.001	.002	.02		
do		147900	.013	.008		24.4	
do	4.0	147940	.001	.003	.02		
do		147901	.015	.010		23.1	
Cherokee group	1.3	148060	.002	.003			
do		148033	.015	.016		23.9	
do	1.0	148061	.005	.006	.035	4.2	
do	1.1						
do	2.0	147962	.0028	.003	.035		
do		147977	.012	.010		23.6	
do	2.0	147963	.0024	.003	.035		
do		147978	.010	.009		21.4	
do	1.2	242685	.003	.008	.06		
do		242692	.018	.017		27.6	

TABLE 5.—*Description of sample-collecting*

Locality on pl. 1	Location: Sec.	Location: Township	Location: Range	Location: County	Location: State	Description (includes bed, member and formation names)
E-300	NE¼NE¼ 5	39 N.	29 W.	Bates	Mo.	Excello formation; light-yellowish-gray, indistinct laminae, soft, deeply weathered; grab sample.
						Phosphatic nodules, yellowish-gray, deeply weathered.
LO-13	NE¼ 24	20 N.	14 E.	Rogers	Okla.	Little Osage shale member:
						Shale, black, platy
						Shale, black, fissile; contains large nodules in two zones.
LO-36	30	26 N.	18 E.	Craig	do	Little Osage shale member; black, platy, fresh; grab sample.
						Phosphatic nodules, grayish-black, mostly spheroidal; contain abundant pyrite.
LO-40	26	26 N.	17 E.	Nowata	do	Little Osage shale member:
						Shale, black, platy; contains abundant phosphatic laminae.
						Phosphatic nodules, dark-gray, small.
						Shale, black, platy, phosphatic
						Phosphatic nodules, dark-gray, spheroidal.
LO-51	NW¼ 9	32 S.	21 E.	Labette	Kans.	Higginsville limestone member:
						Covered interval: probably Little Osage shale.
						Little Osage shale member; black, fissile, phosphatic, nodules abundant (estimated 5 percent).
						Phosphatic nodules, olive-gray, granular textured, lens shaped.
						Phosphatic nodules, grayish-black, spheroidal; no pyrite visible.
						Phosphatic nodules, grayish-black, spheroidal; contain pyrite.
LO-55	NE¼ 19	25 S.	25 E.	Bourbon	do	Little Osage shale member; dark-gray to black; contains laminations and lentils of medium gray phosphatic material; lenses and laminae are 1 mm or less thick.
						Selected sample in which no phosphatic material is visible.
LO-66	NE¼SE¼ 27	25 S.	25 E.	do	do	Little Osage shale member; black, platy, phosphatic; contains abundant small, lens-shaped nodules.
						Summit coal bed
LO-76	SW¼SE¼ 10	28 S.	24 E.	Crawford	do	Little Osage shale member; black, platy.
						Phosphatic nodules, dark-gray, small, rare.
LO-80	13	22 N.	15 E.	Rogers	Okla.	Little Osage shale member:
						Shale, black, platy, phosphatic
						Phosphatic nodules, large (1½ in. in diameter), spheroidal.
						Shale, black, fissile, phosphatic, soft, deeply weathered.
						Phosphatic nodules, black, spheroidal, small (½ in. in diameter).
						Higginsville limestone member
LO-85	NW¼ 19	30 S.	24 E.	Crawford	Kans.	Little Osage shale member; black, platy, grab sample.
						Phosphatic nodules, medium-dark-gray, spheroidal.
						Phosphatic nodules, olive-gray, lens shaped.
FS-100A	NE¼ 19	25 S.	25 E.	Burbon	do	Higginsville limestone member
FS-100B	NE¼ 19	25 S.	25 E.	do	do	Little Osage shale member:
						Shale, medium-gray, limy
FS-100C	NE¼ 19	25 S.	25 E.	do	do	Shale, black, platy, phosphatic
FS-100D	NE¼ 19	25 S.	25 E.	do	do	Phosphatic nodules, rare
FS-100E	NE¼ 19	25 S.	25 E.	do	do	Limestone, mottled, dark-gray, shaly.

See footnote at end of table.

localities with analytical data—Continued

Group or formation	Thickness (feet)	Laboratory No.	U (percent)	eU (percent)	Radiation measured in field (milliroentgen per hour)	P_2O_5 (percent)	Oil (gallons per ton)
Cherokee group		242688	0.002	0.005	0.04		
do		242695	.013	.012		27.9	
Fort Scott limestone	2.2	146068	.001	.003			
do	1.5	146069	.004	.003			
do	9.0	146095	.002	.003	.03		
do		[1] 147239	.019	.019		25.9	
do	3.0	147914	.002	.004			
do		147878	.016	.014		30.4	
do	3.0	147915	.002	.003	.02		
do		147879	.019	.018		32.4	
do	1.0+						
do	3.5						
do	2.5	146978	.003	.004	.03		
do		147145	.010	.006		21.2	
do		147146	.011	.012		22.9	
do		147147	.016	.015		26.8	
do	2.0+	242698	.017	.014		16.26	
do	1.0	242699	.003	.004		1.38	
do	2.2	147002	.008	.007	.05	2.5	
do	.1	242708	.001	.001			
do	2.0+	147011	.002	.003	.04	.3	
do		147160	.013	.012		24.0	
do	2.5	147926	.001	.003			
do		147887	.018	.018		26.8	
do	2.5	147927	.002	.004			
do		147888	.060	.056		28.5	
do	14.0						
do	.5	[1] 147016	.002	.003	.025	.6	
do		147168	.011	.011		25.3	
do		147169	.009	.008		23.1	
do	2.8	148065	.0009	.002			
do	.8	148037	.0011	.002		<.1	
do	2.8	[1] 148036	.0028	.004		1.1	
do		148029	.021	.020		17.6	
do	.35	148064	.0018	.003			

TABLE 5.—*Description of sample-collecting*

Locality on pl. 1	Location: Sec.	Location: Township	Location: Range	Location: County	Location: State	Description (includes bed, member and formation names)
						Little Osage shale member—Con.
FS-100F	NE¼ 19	25 S.	25 E.	do	do	Summit coal bed
FS-100G	NE¼ 19	25 S.	25 E.	do	do	Claystone, gray, limy
FS-100H	NE¼ 19	25 S.	25 E.	do	do	Blackjack Creek limestone member.
LO-130	24	28 N.	19 E.	Craig	Okla	Little Osage shale member:
						Shale, black, fissile, phosphatic
						Phosphatic nodules, spheroidal, rare small.
						Shale, black, platy, phosphatic
						Phosphatic nodules, dark-gray to black, abundant (estimated 5 percent of the rock).
						Shale, black, platy
						Phosphatic nodules, dark-gray to black, abundant (5 percent).
LO-150	SW¼ 6	29 N.	19 E.	do	do	Little Osage shale member:
						Shale, black, fissile, phosphatic
						Phosphatic nodules, small, rare, deeply weathered.
						Shale, black, platy, phosphatic
						Phosphatic nodules, black, large; contain pyrite.
						Shale, black, platy, phosphatic
						Phosphatie nodules, black, small, abundant; contain pyrite.
LO-260	SW¼SE¼ 19	40 N.	31 W.	Bates	Mo	Claystone, black, soft; contains plant fossils.
						Shale, medium-gray, silty, limy, carbonaceous.
						Coal bed; channel sample
						Underclay
						Covered interval
						Higginsville limestone member
						Little Osage shale member; black, blocky; contains pyrite-rich laminae.
						Phosphatic nodules, abundant in lower part of unit.
LO-270	SE¼NW¼ 30	40 N.	31 W.	do	do	Little Osage shale member:
						Shale, medium-gray, fissile; deeply weathered.
						Shale, black, fissile; phosphatic nodules rare.
						Shale, black, platy; phosphatic nodules abundant.
						Phosphatic nodules
LO-290	Center of 21	40 N.	29 W.	Bates	Mo	Little Osage shale member; shale, black, fissile, phosphatic.
						Phosphatic nodules, light bluish-gray, oblate spheroidal shape, small.
LO-300	Center N½ E. sec. line 5	39 N.	29 W.	do	do	Little Osage shale member; black, fissile, abundant phosphatic nodules.
						Phosphatic nodules, bluish-gray, earthy textured, lens shaped.
FS-126	NE¼ 19	25 S.	25 E.	Bourbon	Kans	Shale, black
						Locality numbers FS-130 through FS-145 are all in the same general locality as shown on pl. 4.
FS-130	SW¼ 17	25 S.	25 E.	do	do	Shale, dark-gray
FS-131	SW¼ 17	25 S.	25 E.	do	do	Shale, black
FS-131$_1$	SW¼ 17	25 S.	25 E.	do	do	Phosphatic nodules, lenses
FS-131P	SW¼ 17	25 S.	25 E.	do	do	Phosphatic nodules, spheroidal; contain nodular pyrite.
FS-132	SW¼ 17	25 S.	25 E.	do	do	Summit coalbed
FS-133	SW¼ 17	25 S.	25 E.	do	do	Shale, black
FS-134	SW¼ 17	25 S.	25 E.	do	do	do
FS-135	SW¼ 17	25 S.	25 E.	do	do	do
FS-136	SW¼ 17	25 S.	25 E.	do	do	do
FS-137	SW¼ 17	25 S.	25 E.	do	do	do
FS-138	SW¼ 17	25 S.	25 E.	do	do	do
FS-139	SW¼ 17	25 S.	25 E.	do	do	do
FS-140	SW¼ 17	25 S.	25 E.	do	do	do
FS-141	SW¼ 17	25 S.	25 E.	do	do	Shale, dark-gray
FS-142	SW¼ 17	25 S.	25 E.	do	do	Shale, black
FS-143	SW¼ 17	25 S.	25 E.	do	do	do
FS-144	SW¼ 17	25 S.	25 E.	do	do	do

localities with analytical data—Continued

Group or formation	Thickness (feet)	Laboratory No.	U (percent)	eU (percent)	Radiation measured in field (milliroentgen per hour)	P_2O_5 (percent)	Oil (gallons per ton)
Fort Scott limestone	0.4	242715	0.0006				
do	4.1	148063	.0001	0.002			
do	5.6	148062	.0013	.002			
do	2.0	147935	.001	.003			
do		147896	.019	.017		31.1	
do	3.0	147936	.002	.003			
do		147897	.016	.014		30.7	
do	2.0	147937	.005	.007			
do		147898	.029	.022		32.0	
do	3.0	147941	.001	.003			
do		147902	.010	.012		26.4	
do	3.0	147942	.001	.003			
do		147903	.017	.015		31.2	
do	3.0	147943	.004	.006			
do		147904	.032	.030		31.0	
Labette shale	2.7	147964	.0008	.001			
do	.5	147965	.0011	.001			
do	.3	147966	.0028	.002			
do	.5						
do	3.0						
Fort Scott limestone	14.0						
do	3.0	147967	.0029	.003			
do		147979	.013	.013		19.2	
do	1.0	147968	.0015	.003			
do	1.5	147969	.0048	.005			
do	.5	147970	.0040	.005			
do		147980	.017	.018		26.5	
do	3.0	242686	.006	.008	0.04		
do		242693	.009	.014		21.2	
do	1.6	242687	.004	.007	.04		
do		242694	.018	.018		27.3	
do	1.2	148044	.0054	.005		4.2	
do	1.0	148045	.0009	.002		<.1	
do	2.5	148046	.0034	.004		1.2	
do		148031	.0154	.015		17.8	
do		148032	.0150	.013		22.6	
do	.4	242716	.0005	.001			
do	2.5	148047	.0046	.0005		3.6	
do	2.5	148048	.0041	.004		2.2	
do	2.5	148049	.0043	.004		1.5	
do	2.5	148050	.0044	.004		2.0	
do	2.5	148051	.0041	.005		2.1	
do	2.5	148052	.0047	.004		3.0	
do	2.5	148053	.0040	.004		2.4	12.7
do	2.4	148054	.0028	.003		1.1	
do	1.0	148055	.0010	.003		<.1	
do	2.4	148056	.0032	.004		1.6	
do	2.4	148057	.0025	.004		1.5	
do	2.4	148058	.0045	.006		4.9	

TABLE 5.—*Description of sample-collecting*

Locality on pl. 1	Location					Description (includes bed, member and formation names)
	Sec.	Township	Range	County	State	
FS-145	SW¼ 17	25 S.	25 E.	Bourbon	Kans.	Limestone; includes pyritized molluscs.
A-2	SE¼ 35	26 N.	16 E.	Nowata	Okla.	Anna shale member:
						Shale, black, fissile, phosphatic; sample from basal part of 6.2-ft exposure.
						Phosphatic nodules, small, rare; contain sharks' teeth:
						Spheroidal nodules, dark-gray.
						Spheroidal nodules, olive-gray.
						Limestone.
						Limestone, ocherous, decalcified, earthy.
						Siltstone, medium-gray, thin bedded, platy, micaceous; contains few thin (¼ in.) ironstone laminae; 8.0-ft channel sample taken 15 ft below top of formation.
A-37	33	27 N.	17 E.	do	do	Anna shale member; black, fissile, phosphatic, deeply weathered; grab sample.
						Phosphatic nodules, medium-dark-gray.
A-46	SE¼ 33	29 N.	18 E.	Craig	do	Anna shale:
						Shale, medium-gray; gradational with unit below.
						Shale, black, fissile, soft, weathered; phosphatic nodules rare.
						Shale, black, fissile, hard, phosphatic.
						Phosphatic nodules, dark-gray, spheroidal shaped, rare.
						Shale, black, fissile, soft, limy, deeply weathered, contains limestone nodules and lenses.
A-60	SW¼ 26	21 S.	25 E.	Linn	Kans.	Anna shale member; black, platy, abundant fossils
						Phosphatic nodules, dark-olive-gray, spheroidal; most abundant near top of unit; orbiculoidal brachiopods common as nuclei.
A-61	Center W. line 18	23 S.	25 E.	do	do	Myrick Station limestone member.
						Anna shale member; black, fissile, phosphatic.
						Phosphatic nodules, olive-black, concentrically laminated, oblate spheroid shape, abundant (estimated 5 percent of the rock).
A-62	SW¼NW¼ 24	25 S.	24 E.	Bourbon	do	Myrick Station limestone member.
						Anna shale member, black, platy, phosphatic, contains coalified wood fragments.
						Phosphatic nodules, dark-brownish-gray, oblate spheroid shape, abundant (estimated 5 percent of the rock); orbiculoidal brachiopods common as nuclei.
A-75	NE¼SW¼ 7	27 S.	24 E.	do	do	Myrick Station limestone member.
						Anna shale member:
						Shale, drak-gray, fissile; contains minute phosphatic pelecypod shells and rare phosphatic nodules.
						Phosphatic nodules, olive-gray, small irregular shape.
						Shale, black, fissile, and blocky, phosphatic; contains coaly laminae.
						Phosphatic nodules, dark-gray, lens shaped, abundant (estimated 2 to 5 percent).
						Phosphatic nodules, dark-gray, irregular shape.

See footnote at end of table.

localities with analytical data—Continued

Group or formation	Thickness (feet)	Laboratory No.	U (percent)	eU (percent)	Radiation measured in field (milliroentgen per hour)	P_2O_5 (percent)	Oil (gallons per ton)
Fort Scott limestone	0.3	148059	0.0034	0.003	----------	2.2	----------
Pawnee limestone	1.5	146045	.004	.004	0.03	----------	----------
do	----------	147117	.018	.018	----------	31.6	----------
do	----------	147118	.016	.016	----------	29.5	----------
do	2.0	----------	----------	----------	----------	----------	----------
do	.5	148066	.0014	.002	----------	----------	----------
Labette shale	8.0	148067	.0001	----------	.02	----------	----------
Pawnee limestone	.5	146096	.002	.003	.03	----------	----------
do	----------	[1] 147240	.022	.024	----------	32.0	----------
do	1.5	----------	----------	----------	----------	----------	----------
do	1.5	146972	.002	.003	.03	----------	----------
do	1.3	146992	.001	.003	.04	----------	----------
do	----------	147140	.026	.028	----------	30.2	----------
do	1.0	146973	.006	.003	----------	----------	----------
do	.8+	146999	004	.004	.035	2.3	14.6
do	----------	147152	.014	.013	----------	28.0	6.7
do	2.0+	----------	----------	----------	----------	----------	----------
do	2.0+	147000	.006	.006	.035	1.9	----------
do	----------	147153	.021	.021	----------	30.3	----------
do	2.0+	----------	----------	----------	----------	----------	----------
do	1.5	[1] 147001	.002	.003	.04	<.1	----------
do	----------	147654	.018	.017	----------	26.7	----------
do	5.0+	----------	----------	----------	----------	----------	----------
do	.5	147009	.002	.004	----------	.9	----------
do	----------	147157	.022	----------	----------	27.4	----------
do	1.0	147010	.003	.003	.04	.9	----------
do	----------	147158	.021	.018	----------	26.7	----------
do	----------	[1] 147247	.028	.030	----------	30.9	----------

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TABLE 5.—*Description of sample-collecting*

Locality on pl. 1	Location					Description (includes bed, member and formation names)
	Sec.	Township	Range	County	State	
A-86	SW¼ 20	30 S.	22 E.	Crawford	Kans	Myrick Station limestone member.
						Anna shale, black, platy, soft, phosphatic.
						Phosphatic nodules, dark olive-gray with black cores; spheroidal and coalesced-oblate forms.
						Claystone, yellow, deeply weathered.
MC-87	Center N. line 23	30 S.	21 E.	do	do	Laberdie limestone member
						Mine Creek shale, dark-gray, fissile and blocky, soft.
						Myrick Station limestone
LN-22	17	25 N.	16 E.	Nowata	Okla	Worland limestone member
						Covered interval (probably Lake Neosho shale).
						Lake Neosho shale member:
						Shale, black, fissile, phosphatic
						Phosphatic nodules, brownish-gray with black cores, spheroidal.
						Shale, dark-gray, blocky; contains molluscan shell casts.
LN-48	SW¼SE¼ 26	34 S.	17 E.	Labette	Kans	Worland limestone member
						Lake Neosho shale member:
						Claystone, yellowish-gray
						Shale, black, fissile, phosphatic
						Phosphatic nodules, olive-gray, oblate spheroidal.
LN-63	Center E. line 30	25 S.	23 E.	Bourbon	do	Worland limestone member
						Lake Neosho shale member, medium-gray, deeply weathered, phosphatic.
						Phosphatic nodules, light-olive-gray, spheroidal.
LN-88	Center W. line 36	29 S.	20 E.	Neosho	do	Worland limestone member
						Covered interval (probably Lake Neosho shale member).
						Lake Neosho shale member, black platy, hard, weathered, phosphatic.
						Phosphatic nodules; abundant in upper 1.0 ft of unit, rare in lower part:
						Olive-gray, spheroidal
						Light-olive-gray, lens-shaped
PF-1	SW¼ 30	28 N.	16 E.	Nowata	Okla	Idenbro limestone member
						Claystone, light-greenish-gray, limy; contains phosphatic and limestone nodules.
PF-59	Center of 5	21 S.	25 E.	Linn	Kans	Shale, medium-gray; contains abundant clay-ironstone concretions.
						Idenbro limestone member
						Shale, dark-gray, platy and fissile
						Phosphatic nodules, olive-gray, small, rare.
Mi-8	NW¼SW¼ 35	18 N.	12 E.	Tulsa	Okla	Shale, black, platy; contains large (approximately 2 in. in diameter) limestone nodules.
						Limestone nodules
						Shale, grayish-black, platy
						Dawson coal bed

See footnote at end of table.

localities with analytical data—Con.

Group or formation	Thickness (feet)	Laboratory No.	U (percent)	eU (percent)	Radiation measured in field (milliroentgen per hour)	P_2O_5 (percent)	Oil (gallons per ton)
Pawnee limestone	.5+						
do	1.5	147017	0.004	0.004	0.035	1.0	
do		147170	.030	.030		33.9	
do	.5						
do	19.0+						
do	4.0	[1] 147018	.002	.003	.02	.1	
do	4.0+						
Altamont limestone	2.0+						
do	2.5						
do	3.0	146076	.002	.004	.035		
do		147127	.014	.016		18.6	
do	5.0	[1] 146994	.001	.002		.2	
do	1.8						
do	.8						
do	1.0	146975	.003	.005	.04		
do		147143	.024	.022		26.1	
do	2.0+						
do	.9	146982	.002	.003	.02		
do		[1] 147245	.019	.020		30.4	
do	1.5						
do	1.0						
do	1.9	147019	.005	.004	.09	1.4	
do		[1] 147254	.050	.050		34.0	
do		147171	.032	.032		26.8	
Lenapah limestone	4.0+						
do	1.0	146602	.002	.003		.3	
Holdenville formation	20.0+						
Lenapah limestone	.5						
do	1.0	146981	.003	.003	.03		12.0
do		[1] 147244	.023	.022		23.9	
Seminole formation	2.0	146603	.002	.003		.2	
do		[1] 147236	.002	<.001		.6	
do	9.0						
do	1.0+						

TABLE 5.—*Description of sample-collecting*

Locality on pl. 1	Location					Description (includes bed, member and formation names)
	Sec.	Town-ship	Range	County	State	
Mi-12	NW¼ 13	20 N.	12 E.	Tulsa	Okla	Shale, black, fissile
						Shale, black, fissile, contains abundant nodules (estimated 5 percent).
						Shale, black, fissile
						Shale, black, fissile, phosphatic
						Phosphatic nodules
						Grab sample of shale unit above; collected 100 ft east of above samples.
						Limonitic (appearance of ocher) material from joint surfaces of shale.
						Shale, black, platy
						Limestone
						Shale, black
						Checkerboard limestone member
Mi-54	SE¼NW¼ 29	29 S.	17 E.	Wilson	Kans	Muncie Creek shale member, gray, phosphatic, grab sample.
						Phosphatic nodules, grayish-brown; weathered to punky texture.
						Coal bed; grab sample
Mi-89	SE¼ 17	32 S.	19 E.	Labette	do	Shale, black, fissile, phosphatic
						Phosphatic nodules, grayish-black, abundant; weathered to punky texture.
						Shale, dark-gray, platy
						Limestone (may be correlative of Checkerboard limestone in Oklahoma).

[1] Semiquantitative spectrographic analysis of sample given in table 10.

Many spheroidal nodules have nuclei which are commonly shell fragments, whole *Orbiculoidea*, fish scales, spines, teeth, and pyrite or marcasite, but nuclei are generally absent in lens-shaped nodules. Interiors of most nodules are of uniform color, but some have faintly visible concentric alternation of light and dark layers. Most nodules are black, but some are olive gray, yellowish gray, and dark brownish gray, with the more weathered nodules generally lighter colored.

Runnels and others (1953, p. 104), in a mineralogical study of phosphate nodules principally from the same zones reported in this investigation, concluded: "The phosphatic nodules in Pennsylvanian black shales collected from 11 localities in eastern Kansas have an average composition of 30.2 percent P_2O_5, 0.017 percent U_3O_8, and 3.2 percent F. These are combined in a form tentatively identified as a carbonate-bearing fluoapatite mineral."

LIMESTONE AND GRAY SHALE

The black phosphatic shale beds of principal interest in this investigation—the Excello, the Little Osage, the shale below the Verdigris limestone member, the Lake Neosho shale member, and the Anna shale member—are all overlain by limestone caprocks. The limestone and the underlying black shale in some places are separated by a thin

localities with analytical data—Continued

Group or formation	Thickness (feet)	Laboratory No.	U (percent)	eU (percent)	Radiation measured in field (milliroentgen per hour)	P_2O_5 (percent)	Oil (gallons per ton)
Coffeyville formation	0.6	146993	0.002	0.003			3.6
do	.7	146969	.001	.002	0.01	0.3	
do	.8	146064	.004	.004			
do	1.6	146065	.006	.005	.06		8.9
do		147125	.023	.025		28.0	
do		146970	.008	.009	.05		
do		146971	.006	.010			
do	2.0						
do	.6						
do	3.0					.01	
do	3.0+						
Iola formation		[1] 146996	.003	.004	.04	.3	
do		[1] 147243	.022	.024		28.4	
Chanute formation		[1] 146986	.001	.001	.03		
Pleasanton group	6.0	147020	.002	.004	.04	1.1	
do		[1] 147255	.013	.012		32.9	
do	8.0						
do	1.0+						

transitional bed of gray limy nodular shale. The limestone is hard and very finely to coarsely crystalline and commonly contains abundant well-preserved mollusks, crinoid fragments, fusulinids, and corals.

Limestone beds other than the black-shale caprocks are also present. The texture of the limestone both in different beds and within certain units ranges from coquinoid to lithographic, with grains ranging from coarse-clastic limestone grains and algal fragments to cryptocrystalline calcite. Molluscan shell fragments, crinoid plates, and columnals are abundant. Limestone units may be 1 foot or more than 40 feet thick and may have several individual beds each less than a foot thick, or may consist of a single bed several feet thick.

Many limestone units are overlain by massive gray claystone and thin even-bedded gray clay shale. The shale is sparingly fossiliferous and contains ironstone and limestone concretions and, locally, irregularly shaped sandstone stringers.

COLLECTION OF SAMPLES FOR LABORATORY TESTS

Radioactivity at outcrops was tested by means of hand-borne Geiger-Mueller and scintillation counters, and channel samples were collected for laboratory determination of total radioactivity, and uranium, phosphate, and trace-element contents. Small random channel samples were taken to represent the total thickness of units of sandstone, gray shale, and limestone, but complete channel samples of the thin black-shale units were taken wherever possible, and, at many localities where minute lithologic differences between the top and bottom of a shale unit were noted, two or more vertically continuous channel samples were taken from a single black-shale unit.

Most of the shale samples are of phosphatic shale beds. A solution of ammonium molybdate acidized with nitric acid was used (Oakes, 1938) to test for phosphate in the field and to distinguish phosphatic nodules from other type nodules. The phosphatic nodules were removed from the shale and submitted separately for uranium and phosphate analyses. This was done not only to determine uranium content of the phosphatic nodules alone, but also to maintain uniformity of sampling from place to place. For example, a standard channel sample consists of a column 1 foot by 1 inch square and a single phosphatic nodule 1 inch in diameter added to the sample would comprise nearly 10 percent of the sample, whereas the actual nodule content in the rock might be less than half that amount. As individual nodules within the shale unit were expected to vary in uranium content, each collection of nodules included as many as several dozen nodules.

Results of field measurements of radioactivity are listed in table 5, expressed in milliroentgens per hour (mr/hr) obtained from either Geiger-Mueller or scintillation counter readings. Radioactivity measurements of samples were made in the laboratory and are expressed in table 5 in terms of equivalent uranium (percent eU). Values obtained by fluorometric testing of samples (percent U) are listed in table 5.

RADIOACTIVITY AND URANIUM CONTENT OF BLACK SHALE

RADIOACTIVITY

The black-shale units are the most radioactive rocks examined. Radioactivities range from 0.001 to 0.009 percent equivalent uranium; the most common value for the carbonaceous shale is 0.002 percent equivalent uranium; for phosphatic shale the most common value is 0.003 percent equivalent uranium.

The Excello, which is generally about 4 feet thick on the surface, was studied and sampled in greater detail than any other black-shale unit (pls. 2 and 3). The radioactivity of more than 50 outcrop samples of the Excello, not including phosphatic nodules, is most commonly 0.003 percent equivalent uranium and is estimated to be nearly 0.004 percent equivalent uranium for the shale with nodules included.

Because the Excello is easily identified on gamma-ray logs, it was chosen for comparison of radioactivity of black shale on the surface with that of the same bed in the subsurface.

The order of magnitude of radioactivity in the Excello throughout a subsurface area of more than 20,000 square miles is shown on figure 1. The data, expressed in terms of equivalent uranium, were calculated from gamma-ray well logs and are estimates of the amount of radioactivity reaching the inside of casing walls of wells. Because the calculations do not take into account the effects of casing thickness and diameter, fluid content in the borehole, type and thickness of cement, and other factors, most of which reduce the measure of true radioactivity of the rocks, the individual values cannot be considered

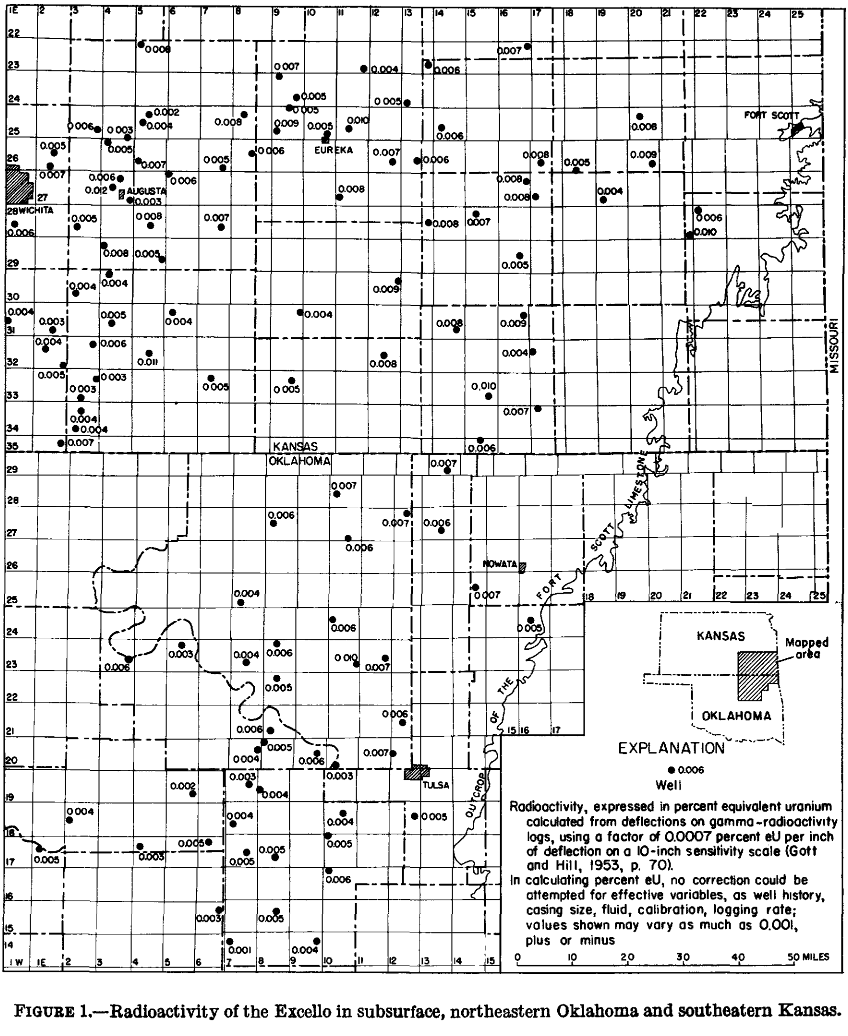

FIGURE 1.—Radioactivity of the Excello in subsurface, northeastern Oklahoma and southeatern Kansas.

quantitatively, but the calculated values suggest that the level of radioactivity of the Excello in the subsurface is generally higher than on the outcrop. The Little Osage, Anna, and other black-shale units, which are equally widely distributed in the subsurface, also have higher calculated percentages of equivalent uranium than determined in surface samples.

Most samples of black and dark-gray shale have larger values of equivalent uranium than of uranium as chemically determined. Of 100 samples of shale, only 7 contain more uranium than equivalent uranium, 22 have equal values, and 71 contain less uranium than equivalent uranium, but in most of the latter, the excess of equivalent uranium over uranium is not more than 0.002 percent. This excess may be due in part to radiation from potassium which is present in quantities ranging from 2 to as much as 5 percent of the shale.

URANIUM CONTENT

More than 180 samples of shale were collected at nearly 100 localities in Oklahoma, Kansas, and Missouri. Results of chemical analyses for uranium are listed in table 3 and are summarized for the phosphatic shale samples in table 4. Samples are averaged in table 6 and samples containing less than 0.001 percent uranium were considered to contain no uranium, and each shale sample was stripped of its phosphatic nodules before analysis for uranium. Samples collected in two quarries near Fort Scott, Kans., (pl. 4, indicated as "FS" loc. Nos. in table 5) were not included in table 6 because the nodules would not break out from the relatively unweathered samples of shale collected at that locality; these are discussed elsewhere.

Most of the samples of carbonaceous shale from 5 shale units contain 0.001 percent uranium or less, but 2 values of 0.004 percent uranium were obtained from beds of black fissile shale above the Drywood coal bed. The remaining values of 0.003 percent uranium or more are for samples of phosphatic shale; thus, the phosphatic shale is decidedly more uraniferous. The range of uranium content of the phosphatic shale units is 0.001 to 0.010 percent, and the average uranium content is 0.003 percent.

A few phosphatic nodules were found in a shale unit above the Sam Creek limestone and in a shale unit above the Inola limestone. These two units could be described as carbonaceous shale which is locally and partially phosphatic. Analytical data of samples from these units are included with the data for phosphatic shale units in table 6; however, the low relative phosphate content (19.0 and 11.4 percent) of the nodules and relatively low uranium content (0.0005 and 0.0007 percent) in comparison with other phosphatic shale units suggests that these units are transitional with carbonaceous black shale.

TABLE 6.—*Range and average, in percent, of uranium and phosphate contents of phosphatic shale from rocks of Des Moines age in northeastern Oklahoma, southeastern Kansas, and western Missouri*

Shale unit	Number of samples		Uranium content of shale		Uranium content of phosphatic nodules		P_2O_5 content of phosphatic nodules	
	Shale	Nodules	Range	Average	Range	Average	Range	Average
Marmaton group								
Perry Farm shale member of the Lenapah limestone	2	1	0.002–0.003	0.002	------------	0.023	--------	24
Lake Neosho shale member of the Altamont limestone	5	5	.001–.005	.003	0.014–0.050	.028	19–34	27
Anna shale member of the Pawnee limestone	11	11	.001–.006	.003	.014–.030	.021	27–34	30
Little Osage shale member of the Fort Scott limestone	26	22	.001–.008	.003	.009–.060	.018	18–32	26
Cherokee group (or Krebs and Cabaniss groups)								
Excello	55	46	0.001–0.010	0.003	0.008–0.028	0.015	17–32	25
Shale beneath the Verdigris limestone member	18	16	.001–.010	.003	.001–.030	.016	19–34	27
Shale above the Mineral coal bed	1	2	------------	.005	.012–.023	---------	32–33	---------
Shale beneath the Tiawah limestone member	11	3	.001–.008	.003	.008–.012	.009	24–31	27
Shale above the Inola limestone member of the Boggy formation (locally phosphatic in part)	1	1	------------	.0005	------------	.002	--------	19
Shale above the Sam Creek limestone member of the Savanna formation (locally phosphatic in part)	1	1	------------	.0007	------------	.006	--------	11

Most of the shale samples described in table 3 were collected from eight units of phosphatic shale in the upper part of the Cherokee or Cabaniss groups and in the Marmaton group. Recalculating the averages by using weighted averages of uranium content for total bed thicknesses, the averages would generally be reduced by insignificant amounts; by including uranium of the phosphatic nodules with that of the shale, assuming that the phosphatic nodules make up 5 percent by weight of the shale, uranium content averages of the shale samples would generally be increased about 0.001 percent.

The percentage of uranium in black shale differs markedly within very short horizontal and vertical distances, dependent on phosphate distribution. A sample, prepared by handpicking under magnification, of barely discernible laminae, mostly 1 mm or less in thickness, of medium- to dark-gray phosphatic shale contained in a matrix of dark-gray to black shale (loc. LO–55, Little Osage shale member), contains 0.017 percent uranium and 16.26 percent P_2O_5, values that approach those of the phosphatic nodules, whereas the darker matrix contains

0.003 percent uranium and 1.38 percent P_2O_5. Coincidence between radioactivity and the phosphatic laminae is shown on an autoradiograph of a polished hand specimen of this shale (fig. 2). The phosphatic laminae appear as bright narrow horizontal bands; the differences in uranium content of the various phosphatic laminae and lenses are manifested by differing brightness of the bands. Because the sample of the phosphatic laminae analyzed for uranium includes material from many different laminae in unknown proportions, each probably having a different concentration of uranium, the value of 0.017 percent uranium can be regarded only as an approximate average of the uranium content of the phosphatic laminae.

Plate 4 shows the lateral differences of uranium content of shale beds and the nodules therefrom as sampled at closely spaced intervals

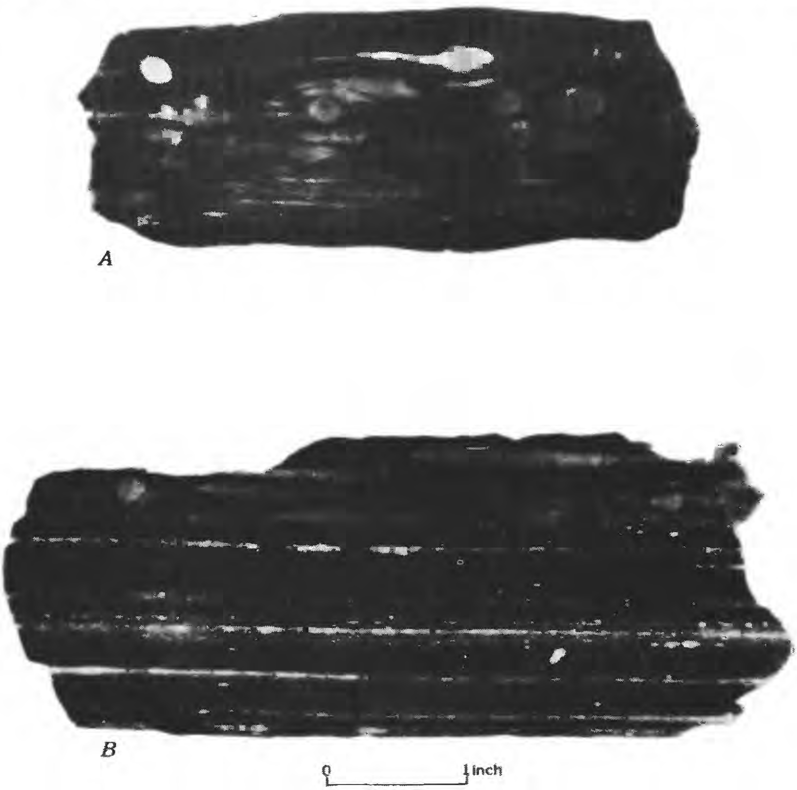

FIGURE 2.—Autoradiographs of phosphatic shale showing loci of radioactivity within black shale. *A*, Hand specimen from black-shale unit 1 foot thick underlying the Tiawah limestone member, loc. T–90, Crawford County, Kans., comprises sample 147021, which includes phosphatic lenses and nodules: 0.008 percent uranium, 10.1 percent P_2O_5. Dark areas in some of the ellipsoidal nodules are occupied by pyritic cores. *B*, Black shale from the Little Osage shale member, loc. LO–55, Bourbon County, Kans. Dark spot above and to the left of the flaw on film is a pyrite nodule; bright narrow bands and lens-shaped light areas are phosphatic laminae comprising sample 242698: 0.017 percent uranium, 16.26 percent phosphate; broad dark bands comprise sample 242699: 0.003 percent uranium, 1.38 percent phosphate.

in limestone quarries near Fort Scott, Kans., with the uranium content of rocks that lie above and below the black-shale beds. Because the black shale in the newly cut quarries is fresh and tough, complete separation of the nodules from the shales was not possible, and the nodules, as they were cut in the channel samples, were included together with the enclosing shale.

The ratio of uranium to phosphate in each sample of shale is shown on figure 3. The trend line (percent $U=0.0024+0.0007\ P_2O_5$) was determined by the conventional method of least squares. The data shown indicate a linear relation between uranium content and phosphate content.

Local increase of radioactivity was noted along several tens of feet of outcrop of the black shale that overlies the Checkerboard limestone of the Missouri series (loc. Mi–12, Tulsa County, Okla.; pl. 1). Considerable surface weathering was indicated by abundant fractures with prominent ocher stains on the fracture surfaces. A sample of the ocher contains 0.006 percent uranium and 0.010 percent equivalent uranium; these values suggest that redistribution of uranium or radium by weathering processes has taken place. The shale adjacent to the ocher contains 0.008 percent uranium, twice the amount obtained for shale collected 100 feet away at the same stratigraphic position.

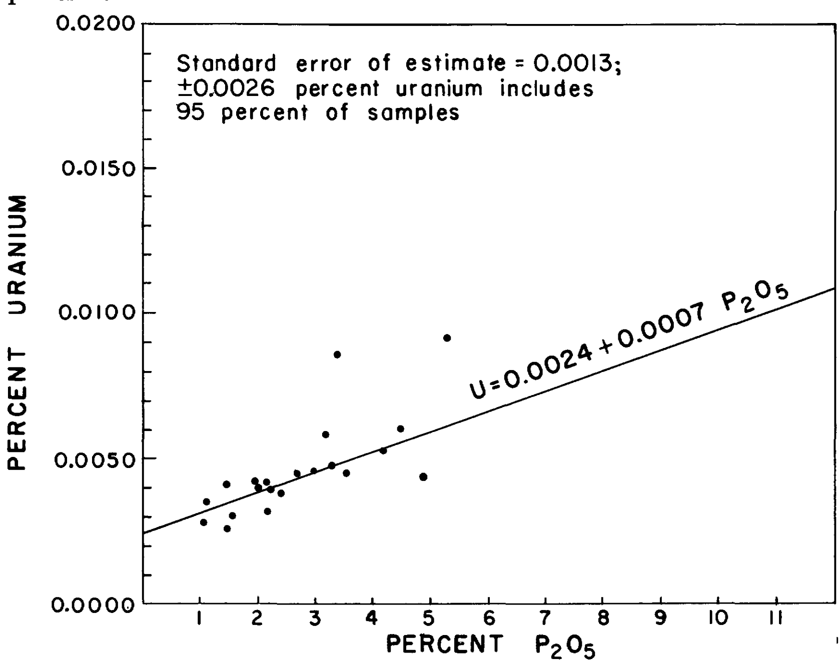

FIGURE 3.—Scatter diagram showing relation of uranium to phosphate in 21 samples of black shale from limestone quarries near Fort Scott, Kans.

URANIUM AND PHOSPHATE CONTENT OF NODULES

URANIUM AND PHOSPHATE DISTRIBUTION

The averages of uranium and phosphate content of nodules from each of eight nodule-bearing black-shale units in the Des Moines series are shown in table 4. The uranium content of 118 samples of phosphatic nodules and other phosphatic materials from shale units of the Missouri series as well as the Des Moines series ranges from 0.002 to 0.060 percent, the average uranium content is 0.016 percent, and the average equivalent uranium content is 0.016 percent. The P_2O_5 content of these samples ranges from 11.4 to 34.0 percent, and the average P_2O_5 content is 26.3 percent.

The uranium content in nodules collected from shale beds in the Marmaton group generally is a little greater than the uranium content in nodules from shale units in the Cherokee group or in the Cabaniss group, as shown in the following tabulation:

Unit	Average uranium content (percent)	Maximum uranium content (percent)
Marmaton group		
Little Osage shale member	0.018	0.060
Anna shale member	.021	.031
Lake Neosho shale member	.028	.050
Cherokee and Cabaniss groups		
Excello	0.015	0.028
Shale below Verdigris limestone member	.016	.030

The phosphate content of nodules from these shale units is much the same; the averages range from 26.4 to 29.7 percent P_2O_5, and the maxima range from 32 to 34 percent P_2O_5.

Whereas figure 3 shows the uranium and phosphate content of shale samples with included phosphate nodules, figure 4 shows uranium and phosphate content of nodules that have been separated from shale. The slopes of the two trend lines (0.0007 and 0.0006) are almost identical, although the shale trend line lies slightly above the nodule trend line. The uranium-phosphate relation in shale is similar to that in nodules with the uranium to phosphate ratio slightly higher for the shale.

The spread of dots in figure 4 is much greater than in figure 3, and the standard error of estimate for figure 4 is more than six times greater than that for figure 3. An important difference in the 2 sets of samples is the fact that the samples used in figure 3 are from 2

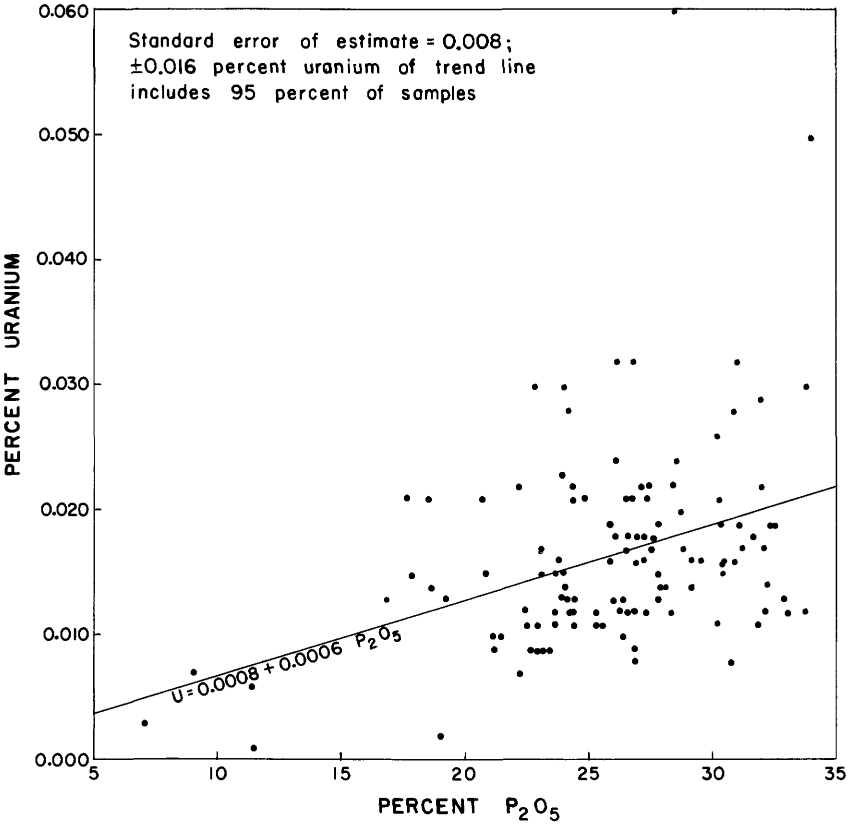

FIGURE 4.—Scatter diagram showing relation of uranium to phosphate in 118 samples of phosphatic nodules

freshly exposed outcrops, but the samples for figure 4 are from outcrops that were weathered to varying degrees.

The results of uranium and phosphate content analyses of nodules, which were collected from thin zones and sorted according to relative color and to shapes, are shown in table 7. The results indicate that spheroidal nodules ("round" in table 7) and nodules whose colors on freshly broken surfaces are darker, even though the differences are as small as olive gray contrasted with light olive gray or dark gray contrasted with medium gray, generally contain greater amounts of uranium and phosphate than lens-shaped ("flat") and lighter-colored nodules ("light") from the same unit and locality. On the basis of the comparisons shown in table 7, the spheroidal nodules or darker nodules might be expected to contain 0.001 to 0.007 percent more uranium and 1 to 7 percent more P_2O_5 than the lens-shaped or lighter colored nodules from the same outcrop. Weathering probably accounts for much of the light coloring and some loss of uranium and phosphate.

TABLE 7.—*Uranium and phosphate content of phosphatic nodules selected on basis of shape and color*

Locality	Laboratory No.	Relative color	Shape	U (percent)	P_2O_5 (percent)
A-2	147117	Dark	Round	0.018	31.6
	147118	Light	do	.016	29.5
E-34	147132	Dark	Round	.016	29.2
	147133	do	Flat	.009	22.8
M-41	147135	Light	Round	.012	33.0
	[1] 147242	Dark	do	.012	32.1
E-44	147138	do	do	.008	26.9
	147139	do	Flat	.009	22.8
LO-51	147145	Light	do	.010	21.2
	147146	Dark	Round	.011	22.9
	147147	do	do	.016	26.8
E-55	242696	Light	do	.008	22.3
	242697	Dark	Flat	.021	20.7
A-75	147158	do	do	.021	26.7
	[1] 147247	do	Round	.028	30.9
E-79	[1] 147248	Light	do	.012	28.4
	[1] 147249	do	Flat	.015	23.7
V-83	147164	Dark	Round	.021	26.5
	[1] 147250	do	Flat	.017	27.5
	147165	Light	do	.012	24.4
	147166	Dark	Round	.021	18.5
E-84	147167	do	do	.016	27.2
	[1] 147251	Light	do	.016	23.7
	[1] 147252	do	Flat	.011	25.4
	[1] 147253	Dark	do	.015	20.9
LN-88	[1] 147254	do	Round	.050	34.0
	147171	Light	Flat	.032	26.8

[1] Semiquantitative spectrographic analyses given in table 10.

THE PHOSPHORITE MINERAL

Runnels, Schleicher, and Van Nortwick (1953) collected and analyzed nodules from Pennsylvanian black-shale beds at 11 localities in Kansas. The shale units of 10 of the 11 localities are the same units as some sampled for this report, and as previously noted (p. 40), they tentatively identified a carbonate-bearing fluorapatite as the main nodule mineral. Their analyses closely correspond with analyses of sedimentary phosphate identified as carbonate-fluorapatite by Altschuler and others (1958). The carbonate-fluorapatite mineral differs from fluorapatite by a deficit of phosphate and an excess of fluorine in addition to the presence of carbonate.

Altschuler and others (1958) on the basis of analytical studies contend that most of the uranium in marine phosphorite was originally emplaced in the tetravalent state, and that it was structurally fixed as a proxy for divalent calcium. Krumbein and Garrels (1952, fig. 8), in reconstructing chemical sedimentary environments, indicate that phosphorite, organic matter, and uranium were deposited in a reducing environment and at a pH ranging from 7.0 to 7.8. They show pyrite was coprecipitated in the same pH range, but at the lowest Eh values (about minus 0.2 and less). Iron sulfide, tentatively identified as pyrite, is abundant in many of the collected phosphatic nodules and forms the nuclei of some nodules. Pyrite, if present in the ironstone nodules or limestone concretions of the carbonaceous black shale, is not megascopically prominent. The phosphatic black-shale beds probably were deposited in an environment of lower Eh-pH than that of the carbonaceous black-shale beds although both must have formed in a slightly alkaline reducing environment. Uranium probably is associated with phosphate in the black-shale beds by virtue of its ability to substitute for calcium in the carbonate-fluorapatite structure.

URANIUM CONTENT OF OTHER SEDIMENTARY ROCKS

COAL AND UNDERCLAY

Coal generally is very weakly radioactive. Few of the coals tested at the outcrop with a Geiger-Mueller counter were radioactive above background count, and, therefore, coal samples were collected for chemical analysis at only a few localities. The majority of these contain no more than 0.002 percent uranium.

The limestone quarry near Fort Scott, Kans. (pl. 4), proved to be an excellent locality for study of coal beds and adjacent sedimentary rocks. Here the Mulky coal was well exposed beneath the phosphatic Excello shale member, as was the Summit coal beneath the phosphatic Little Osage shale member. A channel sample from the upper 0.2 foot of the Mulky coal (pl. 4; loc. E–101, table 8) contains 0.01 percent uranium, and a channel sample of the lower 0.9 foot contains only 0.0006 percent uranium.

At a nearby locality (E–67, table 8) three channel samples were taken in the Mulky coal. Here also the uppermost sample contained the most uranium. The germanium content of the ash is less than the uranium content in the uppermost sample and greater than the uranium content of the lower two samples. The germanium content of the coal is less in the upper sample at locality E–101 than in the lower sample.

The uppermost layers of the Mulky coal at localities E–101 and E–67 contain much more uranium than the lower layers. At locality E–101 some germanium may have been lost from the upper part of the coal with the increase in uranium, for according to Stadnichenko and others (1953, p. 1): "Usually the top and bottom layers of a coal bed show the highest concentrations of germanium."

The Summit coal bed, where exposed in the quarry, near Fort Scott, is only 2 to 4 inches thick and is separated from the overlying Little Osage shale member by an irregularly bedded zone of limestone, limy claystone, and pyrite concretions. (See inset, pl. 4.) Channel

TABLE 8.—*Uranium and germanium content of the ash of coal from Bourbon County, Kans.*

[Analyses by Grafton Daniels, B. A. McCall, D. L. Schafer, and R. P. Cox, U.S. Geological Survey]

Locality	Location			Description	Thickness (feet)	Laboratory No.	eU (percent)	U in ash (percent)	Ge in ash (percent)	Ash (percent)
	Sec.	Township	Range							
LO-66	SE¼ 27	25 S.	25 E.	Summit coal, bright, bony	0.1	242708	0.002	0.002	[1] 0.001	49.7
E-67	SE¼ 27	25 S.	25 E.	Excello basal part overlying the Mulky coal	.15	242709	.001	.001	[1] .001	78.2
				Mulky coal:						
				Upper part	.15	242710	.003	.018	[1] .015	14.9
				Middle part	.5	242711	.001	.006	[2] .06	8.0
				Lower part	.5	242712	.001	.003	[2] .06	6.2
				Total bed, sampled within 100 ft of parts listed above.	.9	[3] 146987	.005	.073	[1] .015	9.7
E-72	NW. cor. 27	26 S.	25 E.	Mulky coal	1.4	[3] 146988	.001	.016	[1] .03	8.3
E-101	NE¼ 19	25 S.	25 E.	Mulky coal:						
				Upper part	.2	[3] 242714	.007	.085	[2] .009	11.8
				Lower part	.9	[3] 242713	.001	.007	[2] .07	8.0
FS-100	NE¼ 19	25 S.	25 E.	Summit coal	.4	242715	.002	.001	[1] .001	58.2
FS-132	SW¼ 17	25 S.	25 E.	Summit coal	.4	242716	.001	.001	[1] .001	48.2

[1] Semiquantitative spectrographic analysis.
[2] Quantitative spectrographic analysis.
[3] Complete semiquantitative analyses given in table 10.

samples of the Summit coal contain much less uranium (0.0005–0.0006 percent) than the upper sample of the Mulky coal (0.010 percent); however, a channel sample from the limy pyritic zone separating the Summit coal from the Little Osage shale member contains 0.0034 percent uranium, a quantity that is relatively great for limestone or gray shale, and thus the pyritic limy zone seems to substitute for the upper part of the coal as an enriched zone.

A hypothesis of diagenetic accumulation can account for the concentration of uranium in the uppermost part of the Mulky coal bed at localities E–67 and E–101. The coal probably originated in brackish-water swamps located near the shoreline. Very little uranium was available in the stagnant brackish water or was inherent to the plant material which collected in the swamp and formed most of the coal; however, with the invasion of sea water prior to the deposition of the phosphatic black shale a new source of uranium became available. At this time the unconsolidated organic material of the swamp would be covered by the same sea from which the uraniferous phosphate nodules were precipitated, and uranium could have been precipitated by humic material in the upper part of the swamp deposit. Uranium also may have been precipitated with pyrite locally where lime mud was collecting. Such occurrences would be limited to localities where the sea water was temporarily deficient in phosphate, and as the precipitating phosphorite was a much more effective uranium-fixing agent, only small concentrations of uranium would collect in the swamp material.

The laboratory tests of Szalay (1954) and Moore (1954), which indicate that woody and lignitic material can extract uranium from aqueous solution, indicate a mechanism for this diagenetic hypothesis. An alternative explanation, involving this same mechanism, could be that the uranium was epigenetically concentrated by extraction from downward-moving water; however, the lack of good permeability in the black shale discounts the probability of such a secondary redistribution of uranium.

GRAY SHALE, SILTSTONE, AND SANDSTONE

Gray shale and siltstone have small but measurable amounts of radioactivity, generally on the order of 0.001 to 0.002 percent equivalent uranium, but samples usually contain less than 0.001 percent uranium. A channel sample of sandstone from the base of a channel deposit of the Chelsea sandstone member of the Senora formation in Rogers County, Okla. (loc. T–4, table 3), contains 0.0001 percent uranium and has no measurable radioactivity.

LIMESTONE

Limestone and limy claystone of the Fort Scott limestone, typical of much of the limy rock in the area, contain 0.0013 and 0.0001 percent uranium respectively in samples collected near Fort Scott, Kans. (pl. 4), and exhibit a radioactivity of 0.002 percent equivalent uranium. With the exception of sample 145 (pl. 4), which contains 0.0034 percent uranium and has been discussed previously (p. 51), no limestone beds more radioactive than this were found, and no other limestone samples were taken.

URANIUM CONTENT OF ASPHALT AND OIL FROM SEEPS

The uranium content of the ash of 73 samples of asphalt from Oklahoma and Missouri was reported in 1957 by W. J. Hail. This information is summarized as follows:

Location	Number of samples	Average U in ash	Average ash in oil	Average oil in sample
		Percent	*Percent*	*Percent*
Oklahoma (all samples)	39	0. 015	2. 27	3. 16
Oklahoma (from rocks of Pennsylvanian age only)	13	. 009	2. 24	3. 73
Missouri (all samples)	34	. 018	1. 25	3. 4
Missouri (not including samples from locality near Ellis)	31	. 006	1. 31	3. 1

The relatively high average uranium content (0.018 percent) in the ash of the oil extracted from rocks in Missouri is the result of high values obtained from three samples. These samples were collected from an abandoned quarry in oil-impregenated sandstone of the Bluejacket sandstone member near Ellis, Mo. The average uranium content of ash of the oil extracted from the three samples is 0.141 percent uranium, and one of these (lab. No. 91576), which was collected by N. W. Bass and H. J. Hyden in 1953, contains 0.40 percent uranium in the ash of the extracted oil, and it is the richest of the 73 samples from Oklahoma and Missouri reported by Hail.

The quarry is located in the SW¼SE¼ sec. 10, T. 35 N., R. 32 W., Vernon County, Mo. The topography is that of rounded sandstone hills of very low relief. The area is drained by streams which flow north into the Marmaton River and east into Dry Wood Creek. The regional strike is northeast, but the dip of the beds to the northwest is so slight as to be obscured by local thickening and thinning of lithologic units. The quarry was filled with water at the time it was visited in March 1956, and the top and base of the sandstone were obscured by agricultural development. The approximate thicknesses of lithologic units, based on measurements at the quarry and along the southern-

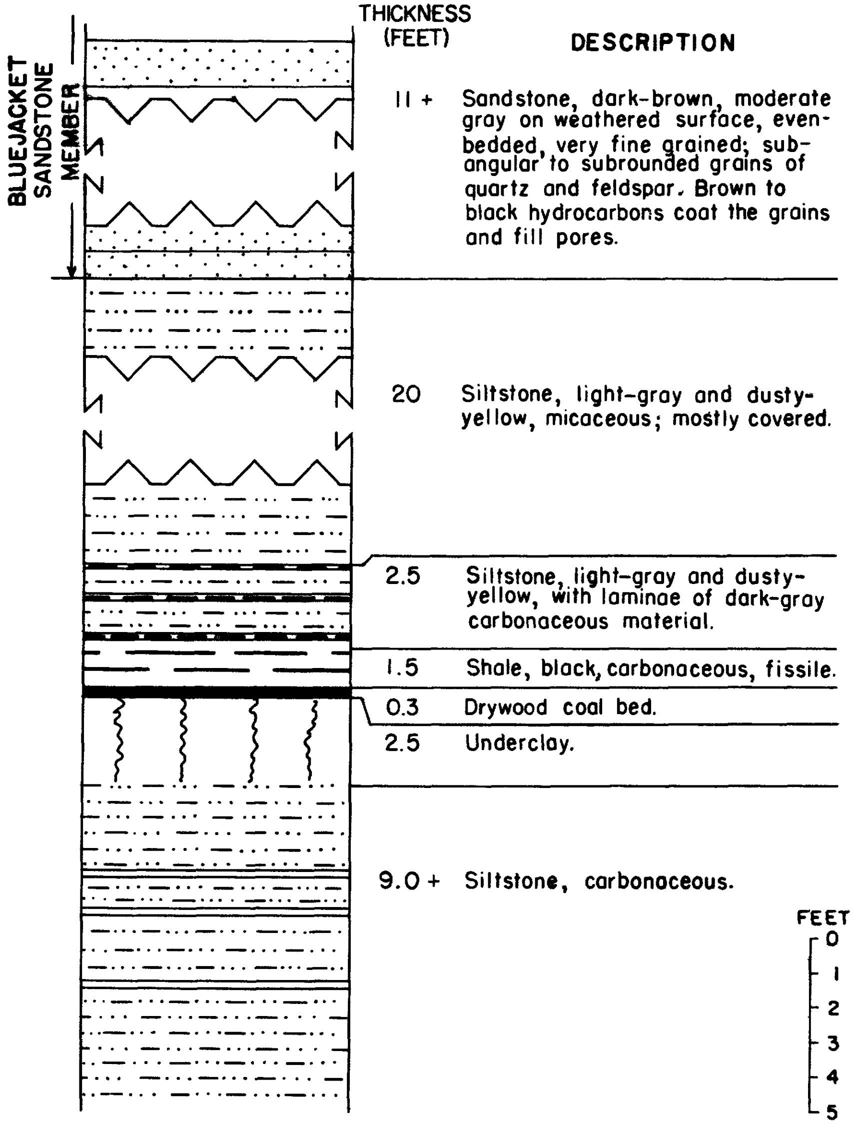

FIGURE 5.—Generalized description of the Cherokee group near the base of the Bluejacket sandstone member in the vicinity of Ellis, Vernon County, Mo.

most quarter of a mile of the east section-line road of sec. 11, T. 35 N., R. 32 W., is shown on figure 5.

The petroliferous rock near Ellis, Mo., is, of course, far too lean in uranium to be considered as a commercial source in itself: the richest sample of extracted oil (Hail's lab. No. 91576) would contain only 0.003 percent uranium, and the sandstone sample would contain only 0.00016 percent uranium. The oil extracted from this rock is of interest in that it contains more uranium than other oil or natural asphalt of the Tri-State area, and it thus may be associated with uranium enrichment in adjacent sedimentary materials.

Examination of the rocks in the vicinity of the Ellis quarry failed to expose any unusually radioactive sedimentary material, and the two samples of petroliferous rock collected subsequently to sample 91576 contained oil of lesser uranium content:

Laboratory No.	Oil in rock	Ash in oil	Uranium in ash
	Percent	*Percent*	*Percent*
91576	5. 38	0. 75	0. 40
207078	4. 08	. 70	. 013
224923	4. 47	. 40	. 011

A sample of petroliferous sandstone from the Little Cabin sandstone member of former usage was collected from an exposure in the wall of a sinkhole in the NW¼NE¼ sec. 9, T. 32 S., R. 25 E., Cherokee County, Kans. This sample contains 1.54 percent oil in the rock, 0.053 percent ash in the oil, and 0.013 percent uranium in the ash of the oil. The uranium content in the ash is relatively high; on the other hand, the percentage of ash in the oil is unusually low.

This sandstone is underlain by a 1-foot thick bed of coal, the Riverton coal, a sample of which contains 0.001 percent uranium in its ash and 6.9 percent ash. The coal is in turn underlain by a dark-gray to black carbonaceous shale; a sample of this shale contains less than 0.001 percent uranium. At the sample locality the Little Cabin sandstone member is 14 feet above the eroded top of limestone of Mississippian age. The rocks of Pennsylvanian age rest with angular discordance on those of Mississippian age and the possible sources for uranium in the oil are numerous.

Two oil samples reported by Erickson and others as collected from oil seeps along the Front Range of Colorado (1952, table 3, nos. 3 and 4) contained 0.48 and 0.39 percent uranium in ash, or 0.0041 and 0.0050 percent uranium in extracted oil. Ore-grade uranium has been discovered in the vicinity of these seeps, and the early sample from the Ellis, Mo., quarry contained approximately the same amount of uranium (0.40 percent uranium in ash, 0.0030 percent uranium in extracted oil). The samples collected from the Ellis quarry for this report, however, failed to confirm the high uranium content of the early sample. The early sample from the Ellis quarry is apparently anomalous and not indicative of any ore-grade uranium.

RADIOACTIVITY ASSOCIATED WITH THE OIL FIELD AT NOWATA, OKLA.

Radioactivity associated with oil fields is a subject of recurrent interest. As early as 1904 (Burton) it was mentioned in the literature. In the 1920's and 1930's, radioactivity of oil-field fluids was a subject of active interest in the U.S.S.R. (Bogoyavlenskii, 1929; Nikitin, 1932). Vernadskii and Khlopin (1932), in summarizing the investigations of the brines from Soviet oil fields, concluded that the oil-field brines contain more radium than the average subsurface or surface water: the average concentration in Soviet oil field waters was reported as 3.8×10^{-11} percent by weight, and the maximum 1.46×10^{-8} percent by weight.

RADIOACTIVE PRECIPITATES

Abnormally high radioactivity associated with the oil fields in southeastern Kansas and northeastern Oklahoma has been noted in recent years. Gott and Hill (1953) found radium-bearing precipitates to be the source of the radioactivity in some oil fields of southeastern Kansas.

High radioactivity of sands used for water filtering in the Nowata oil field in northeastern Oklahoma was noticed in early 1955. Waterflood plants operating at many localities in this field include tanks filled with sand where water produced from the oil wells, with added new water from surface streams and wells, is filtered prior to injection into the oil reservoir. Reports that coal placed in some of these filters had collected a commercial grade of uranium appeared in many newspapers and magazine articles.

N. W. Bass and N. M. Denson of the U.S. Geological Survey in January 1955 examined localities in the Nowata oil field which had been reported as very radioactive. Analytical data on the most radioactive of their samples are:

Material	Location			Laboratory No.	Field No.	eU	U
	Sec.	T.	R.				
						Percent	*Percent*
Filter sand	N½NW¼ 6	25 N.	17 E.	224888	DO4-9	0.052	0.0003
Do	S½NE¼ 4	24 N.	17 E.	224890	DO4-10	.042	.0001
Pipe scale	N½NW¼ 6	25 N.	17 E.	224889	DO4-9′	.005	.003
Do	S½NE¼ 4	24 N.	17 E.	224891	DO4-10′	.008	.002

Twenty-one samples of oil-field waters were also collected by Denson and Bass in the Nowata oil field. Chemical analyses revealed little uranium in most samples. One sample contained 60 parts per billion uranium, 11 samples contained from 1 to 6 parts per billion uranium, and 9 samples contained less than 1 part per billion uranium, which indicates that the Nowata oil-field waters are far less than a high-grade source of uranium.

H. S. Stafford and R. T. Russell of the Atomic Energy Commission (written communication, 1955) reported on many solid and liquid materials from the Nowata oil field, and only two samples of filter sand contained appreciable uranium: 0.23 percent and 0.10 percent U_3O_8. The high radioactivity is associated with brine and is attributed to concentrations of radium apparently not closely associated with uranium.

High radioactivity has been noted at many other waterflood oil fields in northeastern Oklahoma. Samples obtained by John Demakeas, a prospector, were gathered from the NE¼ sec. 9, T. 18 N., R. 7 E., Cushing oil field, Creek County, Okla., and submitted to the Geological Survey for analyses. The following data are the results of analyses performed by John W. Rosholt and C. A. Horr.

Material	Laboratory No.	Field No.	eU	U	U (parts per billion)
			Percent	*Percent*	
Filter material	231278	S-1	0. 001	0. 0007	
Do	231279	S-2	. 001	. 0012	
Ditch precipitate	231280	S-3	. 88	. 0010	
Do	231281	S-4	1. 1	. 0006	
Water	231273	W-1			3. 0
Do	231274	W-2			2. 2
Do	23175	W-3			2. 1
Do	23176	W-4			2. 1
Do	23177	W-5			2. 4

Samples W-1 and S-4 were analyzed for Ra^{226}, Th^{228}, and Pb^{210}. Water sample W-1 contains 0.043×10^{-11} grams of Ra^{226} per liter of water. Assuming that the specific gravity of this water is 1, 0.043×10^{-11} grams of Ra per liter is equivalent to $.0043 \times 10^{-11}$ percent Ra by weight or three decimal places below the average Ra content reported by Vernadskii and Khlopin (1932).

Sample S-4 contains 1.79 percent equivalent Ra^{226}, 1.01 percent equivalent Th^{228}, and 0.41 percent equivalent Pb^{210}. These quantities of radioactive elements far exceed the amount necessary for equilibrium with uranium.

It is inferred that the radium, thorium, and lead in excess of equilibrium with the uranium content of this sample were precipitated from the produced water as it traversed the ditch. If all the Pb^{210} present in the sample was produced from Ra^{226} decay after precipitation of the Ra^{226}, if loss of radon after precipitation was negligible, and if no Pb^{210} was leached from the sample, the average age of the precipitate is 8 years.

In summary, it seems that abnormal radioactivity of precipitates from oil-field water in many fields in southeastern Kansas and northeastern Oklahoma is due principally to the presence of radium with only trace amounts of uranium.

URANIUM CONTENT OF OIL-FIELD FLUIDS

Ash from 2 samples of crude oil collected in January 1955 from the Nowata oil field contained 0.045 percent and 0.040 percent uranium, which are the 2 highest quantities reported by Hyden (1956) from among 118 samples of crude oil from Western States. The uranium content of the ash of 4 other samples collected at the same time (Hyden, 1956) in the Nowata oil field was smaller than the 2 mentioned above, but relatively high as compared with the average content of the ashes of 118 samples.

The Nowata oil field consists of a set of neighboring and, for the most part, contiguous oil pools (fig. 6). The major pools in this area are Chelsea, Alluwe, Coody's Bluff, Nowata, Claggett, and Delaware-Childers. Major production is from the Bartlesville sand, the subsurface equivalent of the Bluejacket sandstone member of the Boggy formation.

The Nowata oil field is one of the older fields in Oklahoma. Oil and gas leases in the Alluwe and Coody's Bluff area were awarded in 1888 by the Cherokee Nation to Edward Byrd; however, drilling and initial development started in the Chelsea area in 1904 when the Secretary of the Interior confirmed the validity of some of the leases (Powell and Eakin, 1952, p. 1, 4). Waterflooding was first tried as a method of increasing oil production in the Nowata oil field in 1935 (Powell and Eakin, 1952), with the five-point pattern of rows of alternate water-injection wells and producing wells being used.

In order to compare the uranium content of the crude oil and the water circulated in the field and to consider possible controls for the quantity of uranium in each of these fluids, samples of the produced oil, water, and the injection water were collected for analyses at seven water plants (fig. 6) where water that has been produced with the oil and separated from it is mixed with water from surface streams or from water wells, filtered, and stored in a clear-water tank for reinjection into the oil reservoir. One-gallon samples of water collected from the "clear-tank" at each of the seven water plants are shown in table 9 as injected water.

One-gallon samples of the oil which had been produced with the water were collected at each plant and one-gallon samples of produced water from storage or separator tanks near the waterplants. The samples from plants No. 2 and No. 3 are a mixture of water from wells that had been producing for less than 1 year and wells that had been

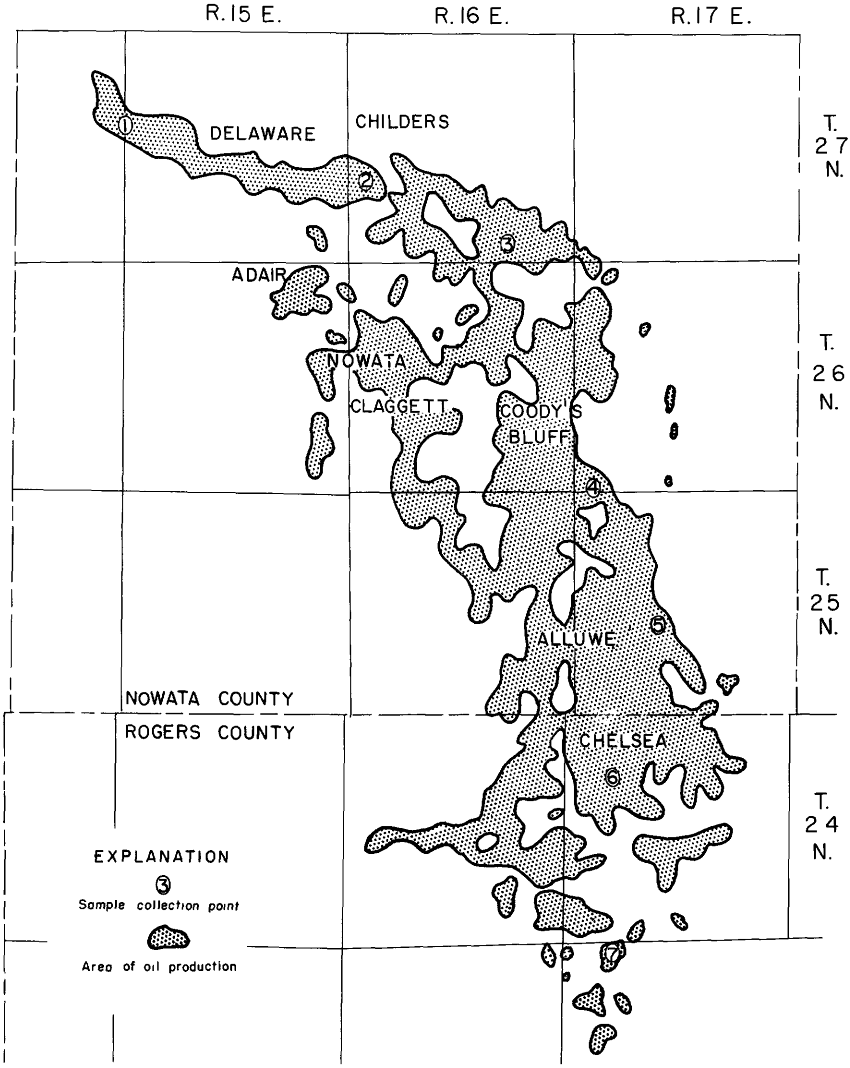

FIGURE 6.—Index map of oil and water sample locations in oil pools of the Nowata oilfield, Oklahoma.

producing many years, whereas that from other plants is only from old wells. Four samples of the commercial detergents used in the separation of the oil and water also were collected.

All the water samples were collected in one-pint plastic bottles, and 2 cc of concentrated nitric acid were added to each of these pint bottles immediately after sampling in order to inhibit the plating of uranium on the walls of the bottles.

The uranium content of samples of oil and the uranium content in samples of produced water is shown in table 10. The uranium con-

TABLE 9.—*Analyses showing ions present in produced and injected water from the Nowata oil field, Oklahoma*

[Analyses by R. P. Cox, R. F. Dufour, Mary Finch, Irving Frost, Wayne Mountjoy, and D. L. Skinner, U.S. Geol. Survey]

Locality on fig. 6	Laboratory No.	Type of water	pH	Analyses (parts per million)														
				U	Total solids	SiO_2	HCO_3	Cl	SO_4	Na	K	Ca	Mg	As	Ba	Li	Sr	Fe
1	235645	Produced	6.4	0.001	111,000	8.0	287	59,200	328	29,500	200	4,160	1,520	0.04	14	38	300	11
	235646	Injected	6.3	.001	115,000	11	58	62,200	274	35,000	260	4,450	1,510	.07	13	42	270	1
2	235643	Produced (old)	6.4	.003	95,800	5.0	428	51,800	1,590	25,000	120	3,670	814	.02	6	29	190	23
	235641	Produced (new)	6.3	.001	94,400	6.0	388	52,800	442	22,500	100	4,180	1,210	.02	1	34	190	50
	235639	Injected	7.6	.001	105,000	10	189	54,300	674	26,500	280	4,140	1,270	.48	2	39	160	1
3	237424	Produced (new)	6.8	.010	64,700	6.0	510	34,400	4,150	17,600	144	2,280	2,180	.02	1	16	43	25
	235626	Produced (old)	6.9	.001	74,900	5.0	406	25,400	0.1	12,200	30	1,500	1,030	.02	303	15	150	34
	235618	Injected	7.6	.001	360	4.0	138	105	37.0	70	3	40	4.6	.02	1	1	1	1
4	235623	Produced	6.8	.001	24,500	9.0	759	13,700	.1	7,200	28	810	320	.02	126	19	50	33
	235624	Injected	7.3	.001	10,400	13	396	6,260	21.0	3,000	10	510	150	.02	65	2	20	1
5	235628	Produced	7.2	.001	17,200	9.0	468	9,580	83.0	5,000	16	470	250	.02	18	5	30	1
	235629	Injected	7.2	.001	18,600	8.0	483	10,500	29.0	5,600	18	520	270	.02	56	4	30	1
6	235633	Produced	7.0	.001	19,100	10	620	10,800	39.0	5,800	16	460	200	.02	1	4	40	2
	235632	Injected	7.6	.001	6,000	9.0	308	3,320	38.0	1,750	6	180	77.0	.02	12	1	10	1
7	235637	Produced	7.1	.001	16,900	8.0	309	9,680	26.0	5,200	12	360	150	.02	22	3	20	1
	235636	Injected	7.5	.001	12,200	6.0	192	6,940	28.0	3,800	10	250	110	.02	15	2	10	1

TABLE 10—*Uranium content of produced oil and the difference in content of the produced water from the content of the injected water, Nowata oil field, Oklahoma*

[Analysed by D. Ferguson, U.S. Geol. Survey]

Locality on fig. 6	Laboratory No.	Produced oil		Produced water							Source of water added to recycled water prior to injection
		U in ash	U in oil [1] (ppm)	Increase or decrease in ppm [2]					pH	Change in pH [1]	
				U	SO_4	HCO_3	Cl	Total solids			
		Percent									
1	235644	0.0047	0.0019	0.000	+54.0	+229	−3,000	−4,000	6.4	+0.1	Arbuckle formation.
2	235640	.017	.0010	+.003	+916	+239	−2,500	−9,000	6.4	−1.2	Do.
2	(3)	(4)	(4)	.000	−232	+199	−1,500	−10,400	6.4	−1.3	Do.
3	[3] 237423	.052	.0047	+.009	+4,110	+352	+34,300	+64,400	6.8	−.8	River.
3	235621	.007	.0023	−.001	−37.0	+328	+24,300	+74,500	6.9	+.1	Do.
4	235622	.019	.0026	.000	−21.0	+363	+7,540	+14,100	6.8	−.5	Do.
5	235630	.023	.035	.000	−4.0	−15	−920	−500	7.2	.0	Do.
6	235634	.028	.014	.000	+1.0	+312	+7,480	+13,000	7.0	−.6	Do.
7	235638	.042	.011	.000	−2.0	+117	+2,740	+4,700	7.1	−.4	Do.

[1] Calculated from percentage of uranium in ash and percentage of ash in oil.
[2] Results of arithmetic subtraction of values for injected water from values for produced water.
[3] New water production.
[4] No oil production.

tent of the new water from Climax Molybdenum Co.'s Lowery flood (loc. 3, fig. 6) is the highest of the water samples and the uranium content in the ash of oil is greatest there. A water sample collected from the Lowery flood by Denson and Bass in January 1955 contains 60 parts per billion uranium (p. 57), and a water sample collected by the authors in October 1955 from a well in this area contains 10 parts per billion. Samples collected elsewhere by Denson and Bass and by the authors contain less than 10 parts per billion and most contain less than 1 part per billion. Materials from the Lowery flood area are thus shown to contain more uranium than those from other localities.

Samples from the Delaware flood (loc. 1, fig. 6) on the opposite end of the Delaware-Childers pool from the Lowery flood contain the least uranium in both water and ash of oil.

The results of the complete chemical analyses of the water samples are shown in table 10. The waters from localities 1 and 2 contain more dissolved material than the waters from the remaining localities, because water produced from rocks of the Arbuckle group of Ordovician age is injected as floodwater whereas surface water is injected at the remaining localities.

A sample of injected water was collected at the Lowery flood (loc. 3, fig. 6) on September 27, 1955, a few weeks after water injection was started and before production was rejuvenated. On October 11, 1955, samples of the produced water and of the produced oil were collected at a well where oil production had begun on October 1. These are considered samples of new production in contrast with the other samples from wells that had been producing much longer. The difference in dissolved content of the injected water at the Lowery flood and the produced water is obviously not a direct measurement of the changes incurred by a sample unit of water in traverse from injection point to production point; however, these differences are assumed to indicate such changes, at least qualitatively.

An association of uranium and sulfate in the waters is indicated by the high sulfate content of the two more uraniferous water samples (locs. 2 and 3, table 9). The barium content of these samples is low, but this probably is due to the relatively low solubility of barium sulfate in slightly acid solution rather than to a significant relation to uranium.

Circulation of Arbuckle water produces a decrease in total solid content (table 8) and circulation of river water generally causes a decrease of sulfate. At locality 2 where Arbuckle water is used, sulfate content increases directly with the increase in uranium content. The pH of the water varies so little that it apparently is not a major factor in the observed increase of uranium content.

The four samples of organic detergent, which is added in very small amounts to the injected water, contained 1, 3, 4, and 88 parts per billion uranium. Although the detergents did contain as much as 88 parts per billion uranium, the detergent was added in much too small a quantity to increase the uranium content of the injection water significantly; indeed the injection waters contain less uranium than the produced waters in all but one case.

In conclusion, the authors believe that the water- and oil-analyses data are inadequate to establish definitely a route of migration for uranium among the three host materials, crude oil, water, and rock, or to determine the ultimate source of the uranium. Minor amounts of uranium may be associated with a sulfate-bearing mineral in or adjacent to the Bartlesville sand in the vicinity of localities 2 and 3 (fig. 6) in the eastern part of the Delaware-Childers pool, and associations of uranium with sulfate-bearing minerals have been noted elsewhere. Dunham (written communication, 1955) described the occurrence of uranium in gypsum beds in the Brule formation of Eocene age in Nebraska, and he proposed that the gypsum and uranium were precipitated concomitantly. Pierce, Gott, and Mytton (written communication, 1955) found uranium associated with secondary anhydrite in the "Brown dolomite" in the Panhandle oil field of Texas. This uranium-sulfate association might also result from the occurrence of small amounts of uranium in association with pyrite in or adjacent to the reservoir rock.

J. W. Watkins and Robert Armstrong of the Bureau of Mines, U.S. Department of the Interior, made radiation surveys of two wells in the Climax-Brundred Waterflood Division, sec. 36, T. 27 N., R. 16 E., near the Lowery flood. The log shows a radioactive zone in the Bartlesville sand (fig. 7). The cores from the two Climax-Brundred waterflood division wells include a sandstone that is dark gray to black due to organic material in the interstices, possibly residual oil. Similar material has been found in the cuttings and cores of some wells in the Nowata oil field that is termed an asphaltic sandstone in the field. The cores from these wells were not available for examination, when the authors first saw the Bureau of Mines gamma-ray log; but examination of core material from two other nearby wells showed no visible uranium minerals.

Three types of organic material were identified by J. M. Schopf (written communication, 1956) in cores of the reservoir rock, the Bartlesville sand, from the Nowata oil field: asphalt, oil, and coal flakes. In addition, the Bartlesville sand contains lenses and laminae of dark-gray shale.

The coaly material includes microscopic-sized particles such as spores and large flakes exhibiting woody structure. The length of

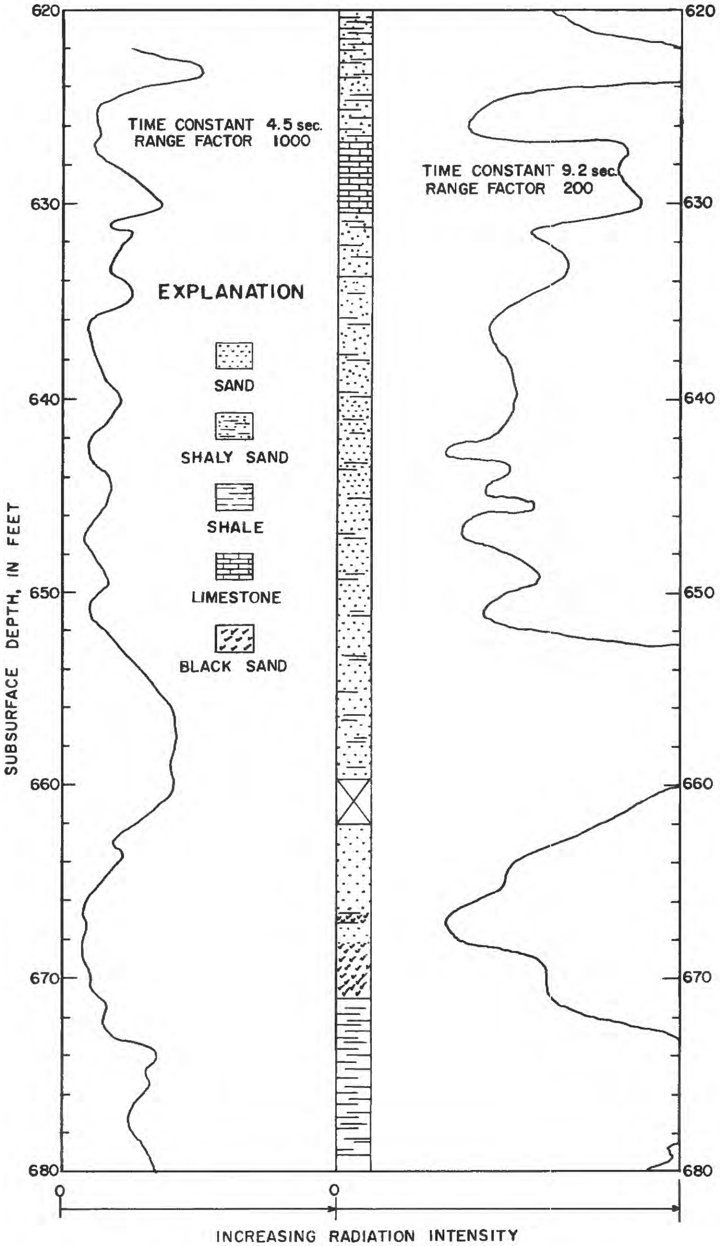

FIGURE 7.—Gamma-ray logs and stratigraphy of J. Condry well 12-P14, Climax-Brundred Waterflood Division, sec. 36, T. 27 N., R. 16 E., Nowata County, Okla. (after J. W. Watkins).

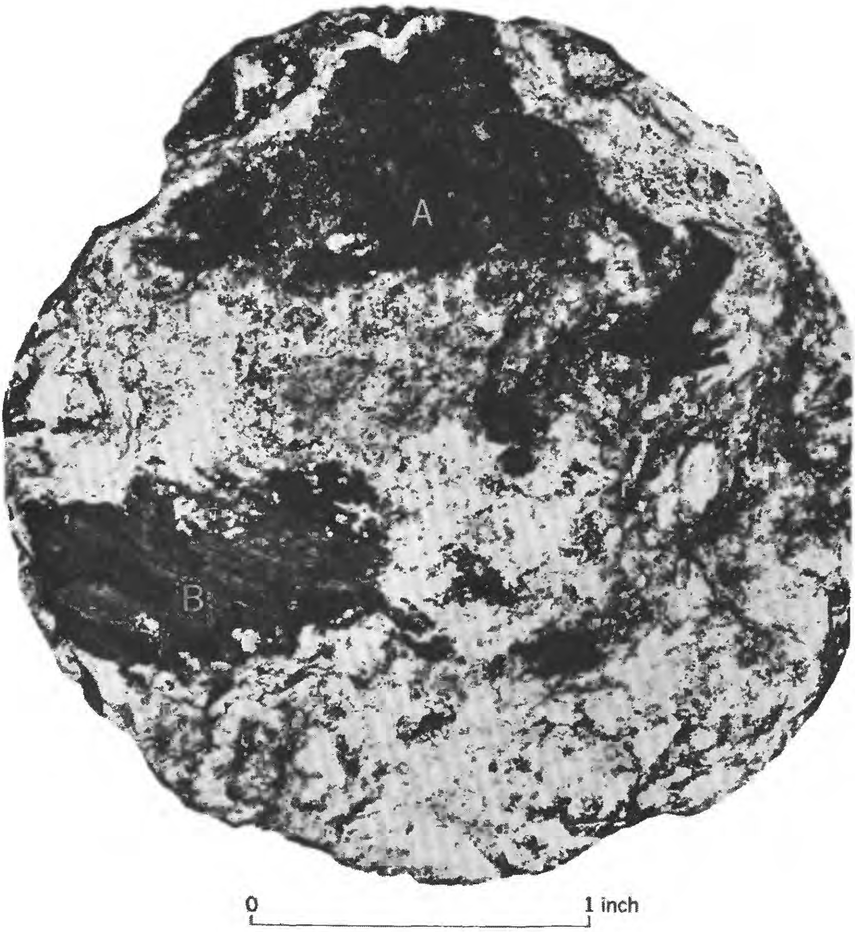

FIGURE 8.—Transverse section of core of Bartlesville sand from Phillips and Milam well M-11, sec. 28, T. 26 N., R. 15 E., Nowata County, Okla. Dark areas *A* and *B* are coal flakes. Coal flake marked *B* is coated with finely crystalline pyrite.

some of the flakes exceeds the diameter (2½ in.) of the core. A photograph of a transverse section of the core of reservoir rock in the Phillips and Milam well M-11 in Nowata County, Okla. (fig. 8), shows some of these coal flakes. A sample of very similar material was scraped from the core at a spot 3 feet above that which appears in the photograph, and the uranium content of the ash of this sample is 0.003 percent (table 11).

The uranium content of the organic materials in the cores (table 11) as calculated from the uranium in ash is small. The core description (fig. 7) indicates that a black shale immediately underlies the sandstone, at a depth of 671 feet. In other wells, black shale and coal or gray shale are found below the sand. At shale localities D-28 and D-38 (table 3) along the outcrop of the base of the Bluejacket sandstone member, samples of black carbonaceous shale and coal below the base of the Bluejacket were collected. The uranium content of the shale samples ranges from 0.001 to 0.004 percent, and the coal sample contains 0.002 percent uranium.

TABLE 11.—*Uranium content of the ash of organic materials in three cores from the Nowata oil field, Oklahoma*

[Analysed by D. Ferguson and C. G. Angelo, U.S. Geol. Survey]

Name of well	Location			Type of organic material	Laboratory No.	U in ash (percent)	eU of ash (percent)	Ash (percent)
	Section	Township	Range					
Climax Molybdenum Co. W. A. Lowery 13-W-6.	35	27 N.	16 E.	Asphalt	240501	0.0056	0.001	0.4750
				Extracted oil.	240500	.0160	.001	.0959
				Coal flakes.	240745	.0004	.001	30.67
Climax Molybdenum Co. F. Grimmett 00-10.	35	27 N.	16 E.	Asphalt	237167	.0018	.001	1.08
					243223	.0153	.001	.70
				Extracted oil.	237166	.0084	.003	1.29
Phillips & Milam M-11	28	26 N.	15 E.	Coal flakes.	240744	.003	.001	30.67

The black shale associated with the Bluejacket sandstone member probably contributed much uranium both to the oil in the Nowata oil field and to the brine. The black shale contains about 0.003 percent uranium, or one-eighth of the average concentration in ash of the Nowata oil, and if the shale contains equilibrium quantities of radium, it contains approximately 10×10^{-10} percent of radium, or 10,000 times the concentration that is present in an equivalent volume of an oil-field water sample (W-1). The ash of the oil samples contains from 1 to 14 times the concentration of uranium present in the black shale; but the largest amount of uranium in oil (0.035 ppm) is only 1/750 of the amount of uranium in oil by weight and this ratio is a little less than 1/2,000 for equal volumes of oil and shale.

Analytical data indicate that radium in precipitates from formational water is the principal source of the radioactivity in the Nowata oil field and other oil fields in Kansas and Oklahoma. Such radioactive precipitates may account for some of the radioactivity recorded by airborne equipment over some oil fields (Lundberg, 1952; Merrit, 1952). The Nowata oil field is unusual because of the relatively high uranium content in the ash of the oil. Two localities in the Delaware-Childers pool of the Nowata oil field are interesting because of relatively uraniferous water associated with the high sulfate content of the water, which suggests that some uranium may be associated with a soluble sulfate or sulfide mineral, such as gypsum or pyrite, in the Bartlesville sand.

The high uranium content in the ash of oil samples from the Nowata oil field may have been incorporated in the oil by mechanical or chemical action of the recycled water and may be in reworked shale and coal fragments from the Bartlesville sand.

DISTRIBUTION OF OTHER ELEMENTS

The results of semiquantitative spectrographic analyses of samples of phosphatic nodules, black and gray shale samples, coal ash, and crude-oil ash are given in table 12 and the distribution of the values is summarized by histograms on plate 5.

The range of values for most elements in the phosphatic nodules is accordant with the amount obtained in analyses summarized by Krauskopf (1955) for sedimentary phosphatic rocks from many sources. However, the amount of rare-earth elements in the phosphatic nodules collected for this report are high in comparison to the amount in phosphatic rocks from other areas. For example, these nodules are richer in rare-earth elements, but contain much smaller concentrations of the elements vanadium, chromium, nickel, zinc, titanium, copper, and cadmium, than do phosphorites from the Phosphoria formation of the Rocky Mountain area.

A parallel relation between the amount of rare earth and amount of phosphate is suggested by data (table 12) for nodules from widely separated stratigraphic units and localities. No other elements have this relation to phosphate. The strong concentrations of certain elements in shale and in coal and crude-oil ash are accordant with concentration ranges for these rocks from various sources listed by Krauskopf (1955). Germanium is commonly reported in coal ash and is present in detectible concentrations in the ash of crude oil from the Nowata oil field, Nowata County, Okla.

TABLE 12.—*Semiquantitative spectrographic analyses of phosphatic, limestone, and ironstone nodules, black shale, coal, and crude-oil ash from rocks of Pennsylvanian age in Kansas, Oklahoma, and Missouri*

Figures are reported in percentage to the nearest number in the series 7, 3, 1.5, 0.7, 0.3, 0.15. Sixty percent of the reported results may be expected to agree with the results of quantitative methods. × indicates looked for but not detected. Dashes (--) indicate not looked for.

[Analyses by Mona Frank, K. E. Valentine, and N. M. Conklin, U.S. Geol. Survey]

Element	Sensitivity limit	Locality, laboratory No., and rock type (see also table 3 and pl. 1)							
		E-6 147234 Phosphatic nodules	E-6 147235 Phosphatic nodules	Mi-8 147236 Limestone nodules	Mi-12 147237 Phosphatic nodules	V-25 147238 Phosphatic nodules	LO-36 147239 Phosphatic nodules	A-37 147240 Phosphatic nodules	S-40 147241 Ironstone nodules
	Percent								
Si	0.005	3.0	3	3	7	3	7	3	7
Al	.0001	1.5	1.5	.7	1.5	1.5	1.5	1.5	1.5
Fe	.0008	1.5	3	7	3	3	3	1.5	>10
Mg	.00003	.15	.15	3	.15	.07	.07	.07	1.5
Ca	.01	>10	>10	>10	>10	>10	>10	>10	1.5
Na	.01	.15	.15	.03	.15	.15	.15	.15	.03
K	.1	---	---	---	---	---	---	---	---
Ti	.0005	.015	.015	.015	.03	.015	.015	.15	.07
P	.07	>10	>10	.07	>10	>10	>10	>10	1.5
Mn	.0007	.0015	.0015	.03	.007	.003	.0015	.0015	.07
Ag	.00001	.0003	.00015	.00007	.00015	.00015	.00015	.00007	.00015
As	.01	---	---	---	---	---	---	---	---
B	.005	×	×	×	.007	×	.007	×	.015
Ba	.0005	.03	.03	.0015	.03	.007	.007	.007	.007
Be	.00005	.00007	×	×	.00007	.00015	.00007	.00007	.00007
Cd	.005	---	---	---	---	---	---	---	---
Ce	.03	.03	.03	×	.03	.03	.03	.03	×
Co	.001	×	.0015	×	×	.0015	×	×	×
Cr	.0006	.007	.003	.0007	.003	.007	.007	.007	.0007
Cu	.00005	.007	.007	.007	.007	.007	.007	.007	.0015
Dy	.006	.007	.007	×	.015	.007	.007	.015	×
Er	.003	.015	.015	×	.015	.007	.007	.0015	×
Ga	.001	×	.0015	×	.0015	×	×	.015	.003
Gd	.006	.007	.007	×	.007	.015	×	.03	×
Ge	.001	---	---	---	---	---	---	---	---
Ho	.001	---	---	---	---	---	---	---	---
La	.003	.03	.03	×	.03	.03	.03	.03	×
Mo	.0005	×	.0007	.0007	.0015	.003	.0015	×	.0007
Nd	.006	×	×	×	.007	×	×	.015	×
Ni	.001	.0015	.0015	.0015	.003	.003	.003	.0015	.003
Pb	.001	×	×	×	.0015	.0015	×	×	.0015
Ru	.008	×	×	×	×	×	×	×	.015
Sc	.0005	.0015	.0015	.0007	.0015	.0015	.0015	.0015	.0015
Sn	.001	×	×	×	×	×	×	×	×
Sr	.001	.07	.07	.007	.15	.015	.03	.03	.003
Tm	.001	---	---	---	---	---	---	---	---
V	.001	.0015	.0015	.0015	.0015	.0015	.0015	.0015	.0015
Y	.001	.07	.07	.0015	.07	.07	.07	.15	.015
Yb	.0001	.007	.007	.00015	.007	.007	.007	.007	.0007
Zn	.008	×	.007	×	.07	.007	.15	.03	.007
Zr	.0008	×	×	×	×	×	×	×	×

TABLE 12.—*Semiquantitative spectrographic analyses of phosphatic, limestone, and ironstone nodules, black shale, coal, and crude-oil ash from rocks of Pennsylvanian age in Kansas, Oklahoma, and Missouri*—Continued

Element	Sensitivity limit	Locality, laboratory No., and rock type (see also table 3 and pl. 1)							
		M-41 147242 Phosphatic nodules	Mi-54 147243 Phosphatic nodules	PF-59 147244 Phosphatic nodules	LN-63 147245 Phosphatic nodules	E-72 147246 Phosphatic nodules	A-75 147247 Phosphatic nodules	E-79 147248 Phosphatic nodules	E-79 147249 Phosphatic nodules
	Percent								
Si	0.005	1.5	3	3	3	7	3	3	7
Al	.0001	1.5	1.5	1.5	1.5	3	1.5	3	3
Fe	.0008	3	3	1.5	1.5	.7	.7	3	.7
Mg	.00003	.07	.07	.3	.07	.07	.07	.03	.03
Ca	.01	>10	>10	>10	>10	>10	>10	>10	>10
Na	.01	.15	.15	.15	.15	.07	.15	.07	.03
K	.1	---	---	---	---	---	---	---	---
Ti	.0005	.015	.015	.015	.015	.015	.015	.007	.015
P	.07	>10	>10	7	>10	>10	>10	>10	7
Mn	.0007	.007	.0015	.03	.0015	.0015	.0015	.0007	.0015
Ag	.00001	.00015	.00015	.00003	.00015	.00015	.000015	.00015	.00003
As	.01	---	---	---	---	---	---	---	---
B	.005	×	.007	.007	.007	.007	.007	×	.007
Ba	.0005	.015	.03	.015	.007	.0015	.03	.03	.007
Be	.00005	.00015	.00007	.00007	×	×	×	.00007	×
Cd	.005	---	---	---	---	---	---	---	---
Ce	.03	.03	.03	.03	.03	.03	.03	.03	.03
Co	.001	.0015	.0015	.0015	×	×	×	×	×
Cr	.0006	.0007	.003	.003	.003	.003	.003	.0015	.003
Cu	.00005	.007	.007	.003	.0015	.007	.007	.007	.003
Dy	.006	.007	.007	.007	.007	×	.007	×	×
Er	.003	.007	.007	.007	.007	.007	.007	×	.007
Ga	.001	×	.0015	.0015	×	.0015	.0015	.0015	.0015
Gd	.006	.007	.007	.007	.007	.007	.007	×	×
Ge	.001	---	---	---	---	---	---	---	---
Ho	.001	---	---	---	---	---	---	---	---
La	.003	.015	.07	.015	.03	.015	.03	.015	.015
Mo	.0005	×	×	×	×	.0015	.0007	.0015	×
Nd	.006	×	×	×	×	×	×	×	×
Ni	.001	.003	.003	.003	.003	.0015	.003	.003	.003
Pb	.001	×	.003	.003	.0015	×	.0015	.0015	×
Ru	.008	×	×	×	×	×	×	×	×
Sc	.0005	.0015	.0015	.0015	.0015	.0015	.0015	.0015	.0015
Sn	.001	×	×	×	×	×	×	×	×
Sr	.001	.07	.07	.07	.07	.03	.07	.07	.07
Tm	.001	---	---	---	---	---	---	---	---
V	.001	.0015	.0015	×	×	.0015	.0015	×	×
Y	.001	.07	.07	.015	.03	.07	.07	.03	.015
Yb	.0001	.007	.007	.0015	.003	.003	.007	.003	.0015
Zn	.008	×	.015	×	×	.007	.15	.07	.007
Zr	.0008	×	.0015	.0015	×	.0015	×	.0015	×

TABLE 12.—*Semiquantitative spectrographic analyses of phosphatic, limestone, and ironstone nodules, black shale, coal, and crude-oil ash from rocks of Pennsylvanian age in Kansas, Oklahoma, and Missouri*—Continued

Element	Sensitivity limit	Locality, laboratory No., and rock type (see also table 3 and pl. 1)							
		V–83 147250 Phosphatic nodules	E–84 147251 Phosphatic nodules	E–84 147252 Phosphatic nodules	E–84 147253 Phosphatic nodules	LN–88 147254 Phosphatic nodules	Mi–89 147255 Phosphatic nodules	T–33 146090 Black shale	T–33 146091 Black shale
	Percent								
Si	0.005	3	1.5	7	7	1.5	1.5	>10	>10
Al	.0001	3	1.5	3	3	1.5	.7	>10	>10
Fe	.0008	1.5	1.5	.7	7	1.5	1.5	7	7
Mg	.00003	.07	.15	.03	.07	.15	.07	.7	.7
Ca	.01	>10	>10	>10	>10	>10	>10	.7	.7
Na	.01	.15	.15	.07	.07	.15	.15	.15	.15
K	.1	---	---	---	---	---	---	3	3
Ti	.0005	.015	.007	.007	.015	.015	.015	.3	.3
P	.07	>10	7	7	7	>10	>10	×	×
Mn	.0007	.0007	.015	.0007	.0007	.0015	.0015	.015	.003
Ag	.00001	.00015	.000015	.000015	.00015	.00015	.00015	.00015	.00015
As	.01	---	---	---	---	---	---	---	---
B	.005	.007	×	×	.007	.007	.007	.015	.015
Ba	.0005	.007	.007	.003	.015	.003	.007	.07	.07
Be	.00005	.00007	×	×	×	.00007	.00007	.00015	.00015
Cd	.005	---	---	---	---	---	---	---	---
Ce	.03	.03	.03	.03	.03	.03	.03	×	×
Co	.001	×	×	×	×	.0015	×	.0015	.0015
Cr	.0006	.003	.0015	.0015	.0015	.003	.0015	.007	.007
Cu	.00005	.007	.003	.003	.015	.007	.007	.007	.007
Dy	.006	×	×	×	×	.007	.007	×	×
Er	.003	×	×	.003	.003	.007	.007	×	×
Ga	.001	.0015	×	×	.0015	×	×	.007	.007
Gd	.006	×	×	×	×	.007	.007	×	×
Ge	.001	---	---	---	---	---	---	---	---
Ho	.001	---	---	---	---	---	---	×	×
La	.003	.03	.015	.015	.015	.015	.03	.003	.003
Mo	.0005	.0015	.0007	×	.0015	.0015	.0007	.0007	.0007
Nd	.006	×	×	×	×	×	.007	---	---
Ni	.001	.003	.003	.003	.007	.003	.003	.015	.015
Pb	.001	×	×	×	×	.003	.0015	.0015	.0015
Ru	.008	×	×	×	×	×	×	×	×
Sc	.0005	.0015	.0015	.0015	.0015	.0015	.0015	.0015	.0015
Sn	.001	×	×	×	×	×	×	×	×
Sr	.001	.07	.07	.03	.03	.15	.15	.03	.03
Tm	.001	---	---	---	---	---	---	---	---
V	.001	×	×	.0015	×	.003	.0015	.007	.007
Y	.001	.03	.03	.015	.015	.07	.07	.003	.003
Yb	.0001	.003	.003	.0015	.0015	.007	.007	.0003	.0003
Zn	.008	.07	.07	.007	.015	.007	×	×	×
Zr	.0008	.0015	.0015	.0015	.0015	×	.0015	.0015	.0015

TABLE 12.—*Semiquantitative spectrographic analyses of phosphatic, limestone, and ironstone nodules, black shale, coal, and crude-oil ash from rocks of Pennsylvanian age in Kansas, Oklahoma, and Missouri*—Continued

Element	Sensitivity limit	Locality, laboratory No., and rock type (see also table 3 and pl. 1)							
		K-35 146094 Black shale	S-40 146101 Black shale	FS-103 148034 Black shale	LO-108 148036 Black shale	LN-22 146994 Black shale	Mi-54 146996 Black shale	A-62 147001 Black shale	T-77 147012 Black shale
	Percent								
Si	0.005	>10	>10	>10	>10	>10	>10	>10	>10
Al	.0001	>10	>10	7	7	7	10	7	7
Fe	.0008	3	7	1.5	1.5	3	7	3	3
Mg	.00003	.7	.7	.3	.3	.7	.7	.7	.7
Ca	.01	.7	.7	1.5	3	7	.7	.7	7
Na	.01	.15	.15	.3	.15	.7	.7	.3	.7
K	.1	7	3	3	1.5	3	3	3	3
Ti	.0005	.3	.3	.15	.15	.15	.3	.3	.3
P	.07	×	×	1.5	.3	×	×	×	.7
Mn	.0007	.0015	.07	.007	.007	.15	.007	.015	.015
Ag	.00001	.00015	.00015	.0003	.00015	.00007	.0003	.00015	.00015
As	.01	---	---	---	---	---	---	---	---
B	.005	.015	.015	.015	.03	.03	.03	.03	.03
Ba	.0005	.07	.07	.007	.007	.07	.15	.15	.07
Be	.00005	.00015	.00015	.00015	.00015	.00007	.00015	.00007	.00015
Cd	.005	---	---	---	---	---	---	---	---
Ce	.03	×	×	×	---	×	×	×	×
Co	.001	.0015	.0015	.003	.0015	.0015	.0015	.0015	.0015
Cr	.0006	.007	.007	.007	.007	.007	.03	.03	.015
Cu	.00005	.007	.007	.015	.015	.007	.07	.015	.015
Dy	.006	×	×	×	---	×	×	×	×
Er	.003	×	×	×	---	×	×	×	×
Ga	.001	.007	.007	.0015	.0015	.007	.007	.003	.007
Gd	.006	×	×	---	---	×	×	×	×
Ge	.001	---	---	---	---	---	---	---	---
Ho	.001	×	×	×	×	×	×	×	×
La	.003	.003	.003	×	×	.007	.003	.003	.007
Mo	.0005	.0007	.0007	.003	.003	×	.007	.003	.003
Nd	.006	---	---	---	---	---	---	---	---
Ni	.001	.015	.015	.015	.015	.015	.015	.015	.015
Pb	.001	.0015	.0015	.003	.0015	.003	.015	.007	.003
Ru	.008	×	×	×	×	×	×	×	×
Sc	.0005	.0015	.0015	.0015	.0015	.0015	.0015	.0015	.0015
Sn	.001	×	×	×	×	×	×	×	.0015
Sr	.001	.03	.03	.015	.015	.03	.03	.007	.03
Tm	.001	---	---	---	---	---	---	---	---
V	.001	.007	.007	.03	.03	.015	.07	.07	.015
Y	.001	.003	.003	.0015	.0015	.003	.003	.003	.003
Yb	.0001	.0003	.0003	.00015	.00015	.0003	.0003	.0003	.0003
Zn	.008	×	×	.07	.07	.015	.015	.015	.03
Zr	.0008	.0015	.0015	.007	.007	.0015	.003	.003	.003

TABLE 12.—*Semiquantitative spectrographic analyses of phosphatic, limestone, and ironstone nodules, black shale, coal, and crude-oil ash from rocks of Pennsylvanian age in Kansas, Oklahoma, and Missouri*—Continued

Element	Sensitivity limit	Locality, laboratory No., and rock type (see also table 3 and pl. 1)							
		LO-85 147016 Black shale	MC-87 147018 Black shale	T-32 146616 Coal	E-101 242713 Coal	E-101 242714 Coal	T-45 146985 Coal	Mi-54 146986 Coal	E-67 146987 Coal
	Percent								
Si	0.005	>10	>10	>10	---	---	>10	>10	>10
Al	.0001	7	>10	7	7	>10	7	7	7
Fe	.0008	1.5	3	>10	>10	7	>10	>10	7
Mg	.00003	.7	.7	.15	.7	1.5	.3	.7	.3
Ca	.01	1.5	.7	.7	7	7	.7	1.5	.7
Na	.01	.3	.7	.15	---	---	.3	.7	---
K	.1	3	3	.7	3	3	1.5	3	3
Ti	.0005	.3	.3	.3	.3	.3	.15	.3	.15
P	.07	.3	×	×	×	×	×	×	×
Mn	.0007	.007	.007	.015	.03	.07	.03	.015	.015
Ag	.00001	.0003	.00015	.0007	.0003	.0015	.0007	.0003	.0007
As	.01	---	---	.07	×	×	×	×	×
B	.005	.03	.03	.07	.03	.015	.03	.03	.03
Ba	.0005	.07	.07	.03	.03	.07	.03	.03	.07
Be	.00005	.00015	.00015	.00015	.0015	.0007	.0007	.00015	.0003
Cd	.005	---	---	×	×	×	×	×	.15
Ce	.03	×	×	×	×	×	.07	.03	.03
Co	.001	.0015	.0015	.015	.007	.007	.015	.003	.007
Cr	.0006	.03	.015	.007	.015	.15	.015	.015	.03
Cu	.00005	.03	.015	.03	.03	.03	.03	.03	.03
Dy	.006	×	×	×	×	×	×	×	×
Er	.003	×	×	×	×	×	×	×	×
Ga	.001	.007	.007	.007	tr.	tr.	.007	.007	.007
Gd	.006	×	×	×	×	×	×	×	×
Ge	.001	---	---	×	.07	.007	.07	.015	.015
Ho	.001	×	×	×	×	×	×	×	×
La	.003	.003	.007	×	tr.	×	.003	.003	.003
Mo	.0005	.0015	×	.007	.03	.3	.003	.003	.3
Nd	.006	---	---	×	×	×	.003	.003	.003
Ni	.001	.015	.03	.03	.07	.15	.07	.03	.07
Pb	.001	.0015	.003	.015	.07	.07	.07	.07	.03
Ru	.008	×	×	×	×	×	×	×	×
Sc	.0005	.0015	.0015	.0015	.003	.003	.0015	.0015	.0015
Sn	.001	.0015	×	×	×	×	.0015	.0015	.0015
Sr	.001	.03	.03	.07	.03	.03	.03	.03	.03
Tm	.001	---	---	×	×	×	×	×	×
V	.001	.015	.015	.003	.03	.3	.03	.03	.15
Y	.001	.003	.003	.007	.003	.003	.007	.007	.007
Yb	.0001	.0003	.0003	.0007	.0007	---	.0007	.0007	.0007
Zn	.008	.015	.007	×	.7	.7	.015	×	1.5
Zr	.0008	.003	.003	.007	.007	.015	.007	.007	.003

TABLE 12.—*Semiquantitative spectrographic analyses of phosphatic, limestone, and ironstone nodules, black shale, coal, and crude-oil ash from rocks of Pennsylvanian age in Kansas, Oklahoma, and Missouri*—Continued

Element	Sensitivity limit	Locality, laboratory No., and rock type (see also table 3 and pl. 1)							
		E-72 146988 Coal	T-77 146989 Coal	R-82 146990 Coal	3 235620 Crude oil ash	3 235621 Crude oil ash	4 235622 Crude oil ash	5 235630 Crude oil ash	6 235634 Crude oil ash
	Percent								
Si	0.005	>10	>10	>10	---	---	.3	---	---
Al	.0001	7	7	7	.3	.15	.7	.7	.3
Fe	.0008	>10	>10	>10	7	3	7	>10	7
Mg	.00003	.7	.3	.3	1.5	1.5	.7	.7	.7
Ca	.01	.7	.7	.7	7	>10	7	>10	>10
Na	.01	.3	.3	.15	7	>10	7	1.5	1.5
K	.1	1.5	1.5	.7	×	×	×	×	×
Ti	.0005	.3	.3	.3	.07	.03	.07	.03	.03
P	.07	×	×	×	×	×	×	×	×
Mn	.0007	.015	.015	.015	.15	.07	.07	.15	.15
Ag	.00001	.0007	.0007	.00015	.0015	×	.0015	.0007	.0007
As	.01	×	×	×	.3	×	.7	×	×
B	.005	.03	.03	.03	×	×	×	×	×
Ba	.0005	.03	.03	.03	3	.15	7	7	1.5
Be	.00005	.0007	.0003	.0015	.0007	×	.0015	.0015	.0007
Cd	.005	×	×	×	---	---	---	---	---
Ce	.03	.07	×	×	.03	×	.03	×	×
Co	.001	.003	.015	.003	.07	.03	.07	.03	.15
Cr	.0006	.015	.015	.015	.03	.007	.07	.03	.015
Cu	.00005	.03	.03	.015	.15	.15	.07	.3	1.5
Dy	.006	×	×	×	×	×	×	×	×
Er	.003	×	×	×	×	×	×	×	×
Ga	.001	.007	.007	.007	×	×	×	×	×
Gd	.006	×	×	×	×	×	×	×	×
Ge	.001	.03	.015	.07	.007	.003	.007	×	×
Ho	.001	×	×	×	---	---	---	---	---
La	.003	.003	.003	.003	.007	×	.007	.007	×
Mo	.0005	.015	.015	.0015	.007	.003	.007	.0015	.003
Nd	.006	.003	.003	.003	---	---	---	---	---
Ni	.001	.015	.03	.015	7	3	7	.7	3
Pb	.001	.07	.07	.03	.07	.07	.07	.15	.15
Ru	.008	×	×	×	×	×	×	×	×
Sc	.0005	.0015	.0015	.0015	.015	×	.07	.03	.03
Sn	.001	.0015	.0015	.0015	.015	×	.03	.007	.007
Sr	.001	.03	.03	.03	.7	.3	.7	1.5	1.5
Tm	.001	×	×	×	---	---	---	---	---
V	.001	.03	.03	.015	7	3	7	1.5	3
Y	.001	.007	.007	.007	.03	×	.03	.03	.015
Yb	.0001	.0007	.0007	.0007	.003	.0015	.003	.003	.007
Zn	.008	.03	.007	×	.15	×	.15	.07	.7
Zr	.0008	.003	.007	.003	.03	.03	.15	.15	.03

TABLE 12.—*Semiquantitative spectrographic analyses of phosphatic, limestone, and ironstone nodules, black shale, coal, and crude-oil ash from rocks of Pennsylvanian age in Kansas, Oklahoma, and Missouri*—Continued

Element	Sensitivity limit	Locality, laboratory No., and rock type (see also table 3 and pl. 1)				
		7 235638 Crude oil ash	2 235640 Crude oil ash	2 235642 Crude oil ash	1 235644 Crude oil ash	1 235647 Crude oil ash
	Percent					
Si	0.005	---	---	---	---	---
Al	.0001	.15	.3	.15	1.5	.15
Fe	.0008	3	3	7	>10	3
Mg	.00003	.7	.3	1.5	.3	1.5
Ca	.01	>10	7	>10	>10	3
Na	.01	3	3	>10	1.5	>10
K	.1	X	X	X	X	X
Ti	.0005	.03	.07	.015	.03	.03
P	.07	X	X	X	X	X
Mn	.0007	.15	.15	.3	.3	.03
Ag	.00001	.0003	.003	.003	.003	X
As	.01	X	X	X	X	X
B	.005	X	X	X	X	X
Ba	.0005	1.5	.07	.07	.7	.07
Be	.00005	.0007	X	.0007	.0015	X
Cd	.005	---	---	---	---	---
Ce	.03	X	X	X	X	X
Co	.001	.15	.15	.03	.03	.03
Cr	.0006	.015	.015	.03	.07	.015
Cu	.00005	.3	3	.7	.3	.3
Dy	.006	X	X	X	X	X
Er	.003	X	X	X	X	X
Ga	.001	X	X	X	X	X
Gd	.006	X	X	X	X	X
Ge	.001	X	X	.003	.007	X
Ho	.001	---	---	---	---	---
La	.003	X	X	X	.007	X
Mo	.0005	.003	.007	.003	.007	X
Nd	.006	---	---	---	---	---
Ni	.001	>10	>10	3	3	1.5
Pb	.001	.3	.7	.15	.07	.15
Ru	.008	X	X	X	X	X
Sc	.0005	.03	.007	.015	.07	.003
Sn	.001	X	.03	.015	.015	.007
Sr	.001	.3	.15	.7	1.5	.15
Tm	.001	---	---	---	---	---
V	.001	10	10	3	3	1.5
Y	.001	.015	X	.015	.03	X
Yb	.0001	.007	.015	.003	.003	.007
Zn	.008	X	1.5	.3	.3	.15
Zr	.0008	.07	.015	.03	.07	.15

SUMMARY AND CONCLUSIONS

No commercial concentration of uranium was found in rocks of Pennsylvanian age in Oklahoma, Kansas, or Missouri. Phosphatic black shale contains the most uranium of the sedimentary rocks tested, and the uranium content of these rocks is 0.010 percent to less than 0.001 percent, and the average is 0.003 percent. The uranium is associated with phosphate and is most concentrated in phosphatic laminae, lenses, and nodules. Phosphatic nodules separated from the shale contain 0.002 to 0.060 percent uranium and average 0.016 percent.

The phosphatic black shale probably was deposited in a slightly alkaline reducing environment, where uranium was fixed as a calcium substitute in a carbonate-fluorapatite mineral. The environment of deposition of the other rock types was not conducive to the concentration of uranium except probably for minor local concentrations in the top layer of beds of plant material that were covered by sea water and later compacted and metamorphosed to coal.

The ash of crude oil produced from a sandstone reservoir of Pennsylvanian age contains small amounts of uranium and other rare metals. These amounts are relatively large, however, compared to the quantities of these metals in the ash of other crude oils from other areas. Stratigraphically adjacent black shale or coal beds are probable sources of these metals. Relatively high radioactivity in the vicinity of some waterflooded oilfields in Oklahoma is due to the concentration of radium-bearing precipitates without appreciable uranium.

The quantities of uranium in the phosphatic shale are too small for present-day commercial mining for uranium, but its close association with coal and phosphate and the presence of other rare metals in the shale and coal beds may cause it to be of future interest.

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INDEX