Uranium and Other Trace Elements in Devonian and Mississippian Black Shales in the Central Midcontinent Area

GEOLOGICAL SURVEY BULLETIN 1107-E

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

Uranium and Other Trace Elements in Devonian and Mississippian Black Shales in the Central Midcontinent Area

By E. R. LANDIS

CONTRIBUTIONS TO THE GEOLOGY OF URANIUM

GEOLOGICAL SURVEY BULLETIN 1107-E

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

---

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1962

UNITED STATES DEPARTMENT OF THE INTERIOR

STEWART L. UDALL, *Secretary*

GEOLOGICAL SURVEY

Thomas B. Nolan, *Director*

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington 25, D.C.

CONTENTS

ILLUSTRATIONS

[Plates are in pocket]

TABLES

URANIUM AND OTHER TRACE ELEMENTS IN DEVONIAN AND MISSISSIPPIAN BLACK SHALES IN THE CENTRAL MIDCONTINENT AREA

By E. R. Landis

ABSTRACT

Marine black and dark-gray shales of Late Devonian and Early Mississippian age occupy a prominent position in the stratigraphic column in the central midcontinent region because of their areal extent and relation to widespread unconformities of economic interest. These rock units, the Woodford and Chattanooga shales and the Arkansas novaculite, have been recognized over large parts of Kansas, Oklahoma, Arkansas, and Missouri, and are partial or total equivalents of each other.

The Woodford shale was examined at 10 localities in Oklahoma. Uranium content of the samples ranges from less than 0.001 to 0.014 percent, but the modal, median, and arithmetic mean values of the Woodford samples as a whole and the samples of the shale only are 0.001, 0.002, and 0.003 percent uranium, respectively. These values are probably representative of most of the Woodford except the phosphatic nodules that are present in some parts of the formation. The samples of phosphatic nodules and laminae have an average uranium content of 0.006 percent. The Chattanooga shale was examined and sampled at 7 outcrop localities in Oklahoma, 10 in Arkansas, and 1 in Missouri, and samples of cores from 2 drill holes in Kansas were also collected. A total of 95 samples, of which 83 were shale samples, was collected, and the uranium content ranged from less than 0.001 to 0.55 percent. Only one sample contained more than 0.013 percent uranium; that was a selected sample of highly radioactive organic-rich material. No samples of shale contained more than 0.012 percent uranium, and the modal and median values of the Chattanooga samples as a whole are 0.002 percent uranium. The Arkansas novaculite was sampled at 15 localities in Arkansas and Oklahoma. Only one sample contained more than 0.004 percent uranium, and it was from a locality in Garland County, Ark., where the Arkansas novaculite has been contact metamorphosed. The average uranium value of all samples from the formation is 0.001 percent; this is believed to be representative of the uranium content of the formation in the report area. Despite the low uranium contents of these formations as a whole, at one locality the Chattanooga shale contains as much as 0.005 percent uranium in an interval 10.1 feet thick, and the Woodford contains as much as 0.005 percent uranium in intervals up to 20 feet thick. In general, if rock of this grade ever becomes of economic interest, the small amount of overburden on the black shale of the Woodford would make it more amenable to large-scale surface-mining methods than the Chattanooga.

Selected shale samples were analyzed for organic-carbon content and oil yield. A positive relation of organic-carbon content to uranium content is suggested. A few samples contained enough oil for specific-gravity determination. The number of samples is not sufficient to allow evaluation of the relation, but in these samples the larger the uranium content, the higher the specific gravity of the oil.

INTRODUCTION

During 1954 and 1955 an investigation of the radioactivity and uranium content of Devonian and Early Mississippian black shales in the central midcontinent region was carried on as a part of the Geological Survey's program of investigating uranium-bearing carbonaceous rocks. The investigation was conducted on behalf of the Division of Raw Materials of the U.S. Atomic Energy Commission.

FIELDWORK

In the summer of 1954 V. E. Swanson made a brief reconnaissance study of the uranium content of these shales and in the summer of 1955 responsibility for the project was assumed by the author. During the course of investigation 52 outcrop localities were examined (fig. 32) and 251 samples were collected for radioactivity and uranium-content determination (table 1). Also shown in figure 32 and table 1 are locations and analyses of samples of cores from two wells. A suite of radioactivity logs was also examined and evaluated (Landis, 1955).

PREVIOUS WORK

The radioactivity of ancient and recent sediments has been of interest to geologists and other scientists for many years because of the information to be gained about relative and absolute ages, depositional environments, geochemical cycles, and the possibilities of using the relation of relative radioactivity to lithology for interpretation and correlation of stratigraphic sequences penetrated in drill holes. In 1944, Russell gave a list of radioactivity determinations on sedimentary rocks which included some samples from the area of this report, and he described the relation between radioactivity and rock type. The relation of radioactivity, organic content, and sedimentation was further discussed by Russell in 1945. During a trace-elements reconnaissance in the central and southwestern States, Slaughter and Clabaugh (written communication, 1945) examined and sampled several exposures of the Chattanooga shale in northeastern Oklahoma and southwestern Missouri, the Woodford shale in south-central Oklahoma, and the Arkansas novaculite in southeastern Oklahoma and west-central Arkansas. Gott (written communication, 1948) made a gamma-ray log study of sedimentary rocks in parts of Oklahoma and Kansas with primary objectives of locating potential ore-bearing horizons, eliminating unpromising areas, and collecting basic data for the calibration of gamma-ray logs in terms of equivalent uranium content.

ACKNOWLEDGMENTS

Many Geological Survey colleagues supplied analyses, data, and guidance to the author at various times during the project. Discussions during the early phases of the project with N. F. Williams, Director, Arkansas Geological and Conservation Commission, were helpful.

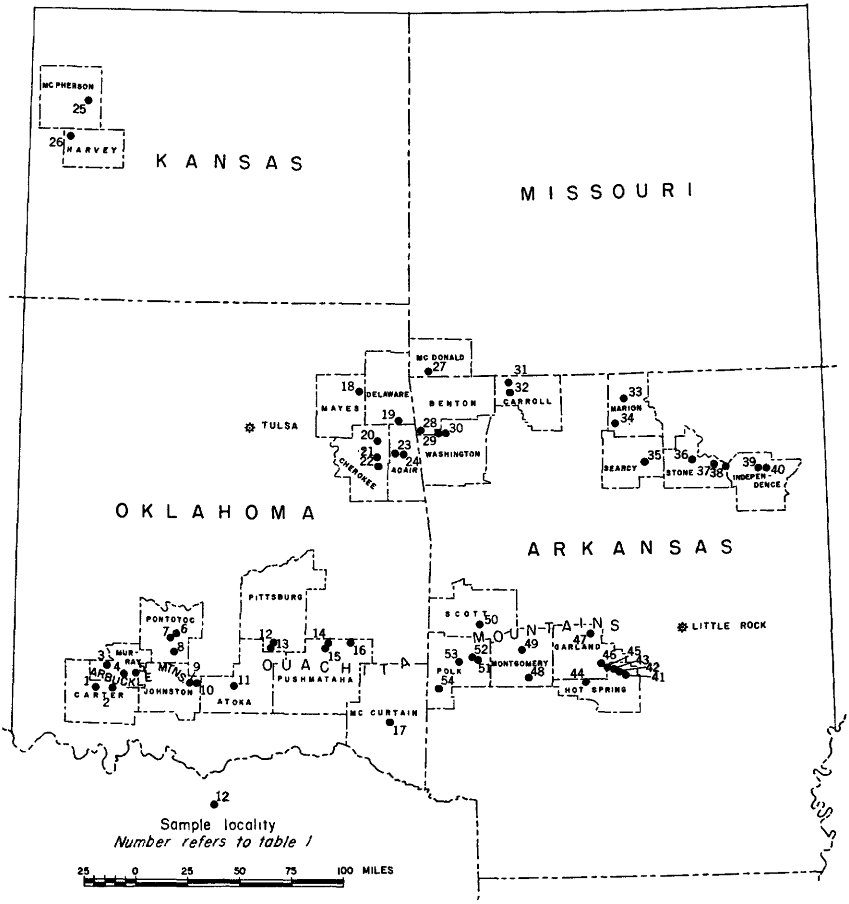

FIGURE 32.—Index map of sample localities.

Samples from two cores were collected with the permission and assistance of the Kansas Geological Survey. V. E. Swanson, U.S. Geological Survey, initiated the study and supplied much of the basic data and some interpretation.

STRATIGRAPHY

In the central midcontinent region the marine black and dark-gray shales of Late Devonian and Early Mississippian age occupy a prominent position in the stratigraphic column because of their areal extent and relation to widespread unconformities of economic interest. These rock units, the Chattanooga and Woodford shales and the Arkansas novaculite, have been recognized over large parts of Kansas, Oklahoma, Arkansas, and Missouri, and are partial or total equivalents of each other. An excellent summary of the stratigraphic relations of these units is given by Miser (1944).

TABLE 1.—*Description, radioactivity, and uranium content of samples*

[Analysts: C. G. Angelo, H. E. Bivens, Joseph Budinsky, Grafton Daniels, R. Daywitt, Mary Finch, S. P. Furman, J. Goode, C. Johnson, J. Johnson, B. A. McCall, P. Moore, R. Moore, J. W. Patton, J. P. Schuch, D. Stockwell, Wendell Tucker, and James Wahlberg, U.S. Geological Survey]

Locality (fig. 32)	Rock unit	Location	Sample	Percent equivalent uranium	Percent uranium	Description
			Oklahoma			
			CARTER COUNTY			
1	Woodford shale (pl. 3).	SE¼SE¼ sec. 30 and NE¼NE¼ sec. 31, T. 2 S., R. 1 E.	[1] 209224	0.002	0.003	Black shale, channel sample 0.4 ft thick.
			[1] 209225	.002	.003	Black shale, channel sample 0.5 ft thick.
			[1] 209226	.002	.003	Black shale, channel sample 0.4 ft thick.
			[1] 209222	.002	<.001	Do.
			[1] 209223	.003	.001	Black shale, channel sample 1.4 ft thick.
			[1] 209227	.007	.008	Phosphatic nodules, weathered; from whole exposure.
2	do	NE¼ sec. 25, T. 2 S., R. 2 E.	[1] 209228	.010	.008	Channel sample, 1 ft of black brittle shale; location in formation unknown; near base of about 15 ft exposure.
			147349	.001	.0015	Channel sample, 2 in. of black, very hard shale; about middle of exposure.
			147348	.006	.0068	Brown carbonaceous shale, <½ in. thick, immediately overlies sample 147349.
			147383	.003	.002	Channel sample, 3 in. thick; black fissile shale containing phosphatic nodules; overlies sample 147348.
			147332	.007	.0069	Phosphatic nodules from sample 147383.
			147388	.001	.001	Selected sample, black shale, from same unit as sample 147349.
			147515	.002	.003	Phosphatic nodules from sample 147388.
			MURRAY COUNTY			
3	Woodford shale (pl. 3).	SW¼ sec. 13, T. 1 S., R. 1 E.	[1] 209214	0.004	0.002	Channel sample, 1.1 ft of badly weathered brown shale.
			[1] 209215	.006	.005	Channel sample, 0.5 ft weathered brown shale.
			[1] 209216	.005	.006	Channel sample, 0.8 ft weathered black shale.
			[1] 209217	.007	.007	Channel sample, 0.4 ft weathered black shale.
			[1] 209218	.010	.008	Channel sample, 0.6 ft black shale.
			[1] 209219	.006	.005	Channel sample, 0.7 ft black shale.
			[1] 209220	.005	.003	Channel sample, 0.4 ft black shale.
			[1] 209221	.005	.003	Channel sample, 0.7 ft black shale.
4	Caney shale	NE¼ sec. 1, T. 2 S., R. 2 E.	147204	.002	.001	Grab sample, dark-gray shale; location in formation uncertain.

See footnotes at end of table.

TABLE 1.—*Description, radioactivity, and uranium content of samples*—Continued

Locality (fig. 32)	Rock unit	Location	Sample	Percent equivalent uranium	Percent uranium	Description
			Oklahoma—Continued			
			MURRAY COUNTY—continued			
5	Woodford shale (pl. 3).	SE¼ sec. 35, T. 1 S., R. 3 E.	147384	0.002	0.001	Grab sample, light-gray calcareous glauconitic shale.
			147333	.008	.0058	White phosphatic nodules from sample 147384.
			147371	.004	.004	Chip sample, 4-ft black shale.
			147372	.003	.003	Chip sample, 0.1-ft black shale, 0.6 ft below top of sample 147371.
			147205	.007	.007	Chip sample, 4 ft black shale.
			147211	.004	.004	Channel sample, 1 ft black shale.
			147206	.006	.006	Chip sample, 5 ft black shale.
			147207	.005	.005	Do.
			147208	.004	.004	Grab sample, 5 ft black shale.
			147209	.005	.005	Do.
			147210	.003	.002	Chip sample, 5 ft black shale.
			147334	.004	.0024	Selected sample, phosphatic layer.
			PONTOTOC COUNTY			
6	Woodford shale (pl. 3).	NE ¼ sec. 27, T. 3 N., R. 6 E.	[1] 209245	0.005	0.002	Channel sample, 1 ft weathered brown shale.
			[1] 209246	.005	.002	Do.
			[1] 209247	.002	<.001	Channel sample, 1 ft black shale.
			[1] 209248	.003	.001	Do.
			[1] 209249	.002	<.001	Do.
			[1] 209250	.002	.001	Do.
			[1] 209251	.001	.001	Do.
			[1] 209252	.002	<.001	Do.
			[1] 209253	.001	.001	Do.
			[1] 209254	.001	<.001	Do.
			[1] 209255	.002	.001	Do.
			[1] 209256	.002	<.001	Do.
7	-----do-------------	NE ¼ sec. 33, T. 3 N., R. 6 E.	[1] 209229	.003	.005	Channel sample, 1-ft weathered dark-gray shale.
			[1] 209230	.003	.003	Do.
			[1] 209231	.003	.003	Do.
			[1] 209232	.002	.003	Channel sample, 0.5-ft dark-gray shale.
			[1] 209233	.004	.006	Do.
			[1] 209234	.004	.008	Do.
			[1] 209235	.004	.006	Channel sample, 2-ft dark-gray shale.
			[1] 209236	.003	.001	Do.
			[1] 209237	<.001	<.001	Do.
			[1] 209238	.006	.002	Do.
			[1] 209239	.003	.002	Do.
			[1] 209240	.005	.002	Do.
			[1] 209241	.006	.002	Do.
			[1] 209242	.005	.002	Do.
			[1] 209243	.004	.001	Grab sample, 3.5-ft dark-gray shale.
			147526	.005	.001	Selected sample, weathered carbonaceous limestone concretion.
			147527	.005	.005	Do.

See footnotes at end of table.

TABLE 1.—*Description, radioactivity, and uranium content of samples*—Continued

Locality (fig. 32)	Rock unit	Location	Sample	Percent equivalent uranium	Percent uranium	Description
		Oklahoma—Continued				
		PONTOTOC COUNTY—continued				
7	Woodford shale (pl. 3).	NE¼ sec. 33, T. 3 N., R. 6E.	147528	0.005	0.001	Selected sample, same as sample 147527 except not as weathered.
8	-----do-------------	SW¼ sec. 1, T. 1 N. R. 6E.	147353	.002	.002	Chip sample 5-ft weathered gray-brown shale.
			147354	.002	.0008	Chip sample, 5-ft weathered dark-gray shale.
			147517	.002	.001	White phosphatic nodules from 147354.
			147373	.002	.001	Chip sample, 5-ft weathered dark-gray shale.
		JOHNSTON COUNTY				
9	Woodford shale (pl. 3).	SE¼ sec. 27, T. 2S., R. 8 E.	147342	0.014	0.0127	White to gray phosphatic nodules weathered from outcrop; spherical type.
			147341	.007	.0075	White to gray phosphatic nodules weathered from outcrop; flat, elongate type.
			147391	.004	.005	Channel sample, 1-ft weathered gray shale.
10	-----do-------------	Center south line sec. 26, T. 2 S., R. 8 E.	147392	.004	.003	Chip sample, 2-ft fresh dark-gray to black shale.
		ATOKA COUNTY				
11	Arkansas novaculite (middle division; see pl. 5).	SW¼ sec. 13, T. 2 S., R. 11 E.	148201	0.002	0.001	Chip sample, 5-ft red and green shale.
			148202	.002	.002	Chip sample, 11.5-ft red, green, and black shale (interbedded novaculite excluded from sample).
			148203	.002	*.003	Channel sample, 0.7-ft black fissile shale.
			148204	<.001	.001	Channel sample, 0.5-ft black fissile shale.
		PITTSBURG COUNTY				
12	Caney shale (pl. 3)--	NW¼ sec. 4, T. 2 N., R. 15 E.	147355	0.002	0.0008	Chip sample, 3.9-ft light-greenish-gray shale.
			147385	.002	.001	Channel sample, 0.2-ft light-greenish-gray glauconitic clay shale.
			147336	.003	.0024	White phosphatic nodules from sample 147385.

See footnotes at end of table.

TABLE 1.—*Description, radioactivity, and uranium content of samples*—Continued

Locality (fig. 32)	Rock unit	Location	Sample	Percent equivalent uranium	Percent uranium	Description
			Oklahoma—Continued			
			PITTSBURG COUNTY—continued			
12	Woodford chert	NW¼ sec. 4, T. 2N., R. 15 E.	147389	0.002	0.001	Channel sample, 1.8-ft black fissile shale.
			147335	.006	.0064	White phosphatic nodules from sample 147389.
			147386	.001	.001	Chip sample, 3.2-ft weathered, flaggy, black shale.
			147337	.005	.0045	White phosphatic nodules from sample 147386.
			147387	.001	.001	Chip sample, 3.2-ft fissile black shale.
			147338	.008	.0060	White phosphatic nodules from sample 147387.
			147356	.001	.0006	Channel sample, 1-ft flaggy, black shale.
			147214	.004	.002	Channel sample 1-ft fissile black shale.
			147215	<.001	<.001	Channel sample, 0.5-ft flaggy black shale.
			147421	.006	.007	White phosphatic nodules from sample 147215.
13	Caney shale	Center east line, sec. 5 T. 2 N., R. 15 E.	147212	.002	.001	Chip sample, represents 15-ft greenish-gray shale.
			147213	.003	.001	Channel sample, 0.5-ft weathered gray shale.
			PUSHMATAHA COUNTY			
14	Stanley shale (see pl. 5).	SW¼ sec. 4, T. 2 N., R. 19 E.†	148196	0.004	0.001	Chip sample, 5-ft greenish-gray shale.
	Arkansas novaculite (middle division?)	do	148197	.001	.001	Channel sample, 0.2-ft greenish-gray shale.
15	Arkansas novaculite (middle division?; see pl. 5).	NW¼ sec. 9, T. 2 N., R. 19 E.	148198	.001	.001	Channel sample, 0.8-ft greenish-gray shale.
16	Stanley shale (see pl. 5).	NE¼(?) sec. 8, T. 2 N., R. 21 E.	148199	.001	.001	Chip sample, 5-ft greenish-gray shale.
	Arkansas novaculite (upper division).		148200	.002	.002	Channel sample, 0.3-ft black fissile shale.
			McCURTAIN COUNTY			
17	Arkansas novaculite (middle division; see pl. 5).	SW¼ sec. 31, T. 5 S., R. 25 E.	148192	0.002	0.001	Channel sample, 0.5-ft black fissile shale.
			148191	.002	.001	Chip sample, 5-ft dark-gray to black fissile shale; a few thin novaculite beds.
			MAYES COUNTY			
18	Chattanooga shale (see pl. 4).	SW¼ sec. 12, T. 22 N., R. 21 E.	[1]140072	0.005	0.002	Chip sample, 10-ft black shale.

See footnotes at end of table.

TABLE 1.—*Description, radioactivity, and uranium content of samples*—Continued

Locality (fig. 32)	Rock unit	Location	Sample	Percent equivalent uranium	Percent uranium	Description
			Oklahoma—Continued			
			DELAWARE COUNTY			
19	Chattanooga shale (see pl. 4).	NW¼ sec. 25, T. 20 N., R. 24 E.	[1]140078	0.006	0.004	Channel sample, 3-ft black shale.
			[1]140077	.006	.004	Do.
			[1]140076	.005	.003	Do.
			[1]140075	.005	.003	Do.
			[1]140074	.004	.002	Do.
			[1]140073	.005	.003	Do.
			CHEROKEE COUNTY			
20	Chattanooga shale (see pl. 4).	NW¼ sec. 24, T. 18 N., R. 22 E.	[1]140084	0.005	0.002	Chip sample, 30-ft black shale.
			[1]140085	.007	.004	Grab sample, black shale from lower 2 ft of formation.
			147217	.004	.002	Channel sample, 1-ft dark-gray to black shale.
			147218	.004	.002	Channel sample, 1-ft black shale.
			147358	<.001	.0008	Pyrite layer, 1/16-in. thick.
			147219	.004	.002	Channel sample, 1-ft black shale.
			147220	.004	.002	Do.
			147221	.004	.002	Do.
			147222	.004	.002	Do.
			147223	.004	.002	Do.
			147224	.004	.002	Channel sample, 0.4-ft black shale.
			147529	.001	<.001	Channel sample, 0.1-ft black cone-in-cone limestone lentil.
			147225	.004	.002	Channel sample, 1-ft black shale.
			147226	.004	.002	Channel sample, 1.3-ft black shale.
			147519	.001	.001	Channel sample, 0.2-ft black, cone-in-cone limestone layer.
			147227	.004	.002	Channel sample, 1-ft black shale.
			147228	.004	.002	Do.
			147229	.004	.002	Do.
			147230	.004	.002	Do.
			147345	.003	.002	Do.
			147231	.004	.002	Do.
			147359	.002	.0020	Do.
			147232	.004	.002	Do.
			147360	.004	.0026	Do.
			147233	.004	.002	Do.
			147374	.004	.001	Do.
			147172	.004	.004	Do.
			147173	.005	.005	Do.
			147174	.004	.005	Do.
			147375	.004	.003	Do.
			147175	.005	.006	Do.
			147176	.005	.007	Do.
			147177	.006	.006	Do.
			147178	.006	.004	Do.
			147179	.006	.005	Do.
			147180	.006	.004	Channel sample, 1.1-ft black shale.
	Sylamore sandstone member of Chattanooga shale.	-----do------------	147393	.013	.013	Selected sample, 0.02-ft very phosphatic shaly sandstone.

See footnotes at end of table.

TABLE 1.—*Description, radioactivity, and uranium content of samples*—Continued

Locality (fig. 32)	Rock unit	Location	Sample	Percent equivalent uranium	Percent uranium	Description
		Oklahoma—Continued				
		CHEROKEE COUNTY—continued				
20	Sylamore sandstone member of Chattanooga shale.	NW¼ sec. 24, T. 18 N., R. 22 E.	147524	0.001	0.001	Channel sample, 0.3-ft light-gray, iron-stained sandstone.
			147523	.006	.006	Selected sample, dark-gray to black; soft irregular blebs of phosphatic material from sample 147524.
			147339	.007	.0088	Selected sample, black rounded phosphatic nodules from sample 147524.
21	Chattanooga shale (see pl. 4).	SE¼ sec. 12, T. 17 N., R. 22 E.	[1] 140080	.006	.001	Channel sample, 0.7-ft medium-olive-gray shale.
			[1] 140081	.005	.002	Channel sample, 2.5-ft black shale.
			[1] 140082	.006	.003	Channel sample, 1.5-ft black shale.
			[1] 140083	.007	.006	Channel sample, 1.2-ft black shale.
22	-----do-------------	Center west line sec. 13, T. 17 N., R. 23 E.	[1] 140089	.001	<.001	Grab sample, phosphatic nodules in gray shale.
			[1] 140090	.003	.001	Channel sample, 4-ft black shale.
		ADAIR COUNTY				
23	Chattanooga shale (see pl. 4).	Center west line sec. 7, T. 17 N., R. 24 E.	[1] 140088	0.004	0.003	Chip sample, 12-ft black shale.
24	-----do-------------	Center west line sec. 11, T. 17 N., R. 24 E.	[1] 140087	.004	.002	Grab sample, black shale.
		Kansas				
		McPHERSON COUNTY				
25	Chattanooga shale--	Sec. 20, T. 19 S., R. 1 W	148225–55	0.004	0.002	These are maxima of 28 channel samples of thin units from 13 ft of core from Derby Oil Co. No. 3 Lacquement well. All dark-gray shale with a faint greenish cast.
		HARVEY COUNTY				
26	Chattanooga shale--	SE ¼ sec. 17, T. 22 S., R. 3 W.	148151–63	0.004	.004	These are maxima of 13 channel samples of thin units from 2.3 ft of core from Derby Oil Co. No. 1 Sperling well. All medium-gray to black shale with a greenish cast.
	Sylamore(?) sandstone member of Chattanooga shale.	-----do-------------	148150	<.001	.001	Grab sample representative of 0.2-ft sandstone at base of core.

See footnotes at end of table.

TABLE 1.—*Description, radioactivity, and uranium content of samples*—Continued

Locality (fig. 32)	Rock unit	Location	Sample	Percent equivalent uranium	Percent uranium	Description
			Missouri			
			MCDONALD COUNTY			
27	Chattanooga shale (see pl. 4).	NE cor. sec. 15, T. 21 N., R. 33 W.	[2] 24948	0.002	0.001	Channel sample, 1.08-ft siltstone.
			[2] 24949	.003	.001	Channel sample, 2-ft shale.
			[2] 24950	.003	.001	Channel sample, 2.3-ft shale.
			[2] 24951	.003	.001	Channel sample, 2-ft siltstone and shale.
			[2] 24952	.003	.001	Channel sample, 1.98-ft shale.
			[2] 24953	.003	.002	Channel sample, 2-ft siltstone and shale.
			[2] 24954	.004	.001	Channel sample, 1.85-ft shale.
			Arkansas			
			BENTON COUNTY			
28	Chattanooga shale (see pl. 4).	SW¼ sec. 32, T. 17 N., R. 33 W.	[1] 228908	0.006	0.004	Channel sample 2-ft black shale.
			WASHINGTON COUNTY			
29	Fayetteville shale	NW¼ sec. 5, T. 16 N., R. 32 W.	[1] 140067	0.003	0.001	Channel sample, 5-ft black shale.
30	Chattanooga shale (see pl. 4).	NE¼ sec. 31, T. 17 N., R. 31 W.	[2] 24943	.003	.002	Channel sample, 1.83-ft black shale.
			[2] 24944	.004	.003	Channel sample, 2-ft black shale.
			[2] 24941	.004	.003	Grab sample, 0.5-ft fresh black shale.
	Sylamore sandstone member of Chattanooga shale.	do	[2] 24942	.005	.004	Channel sample, 0.5-ft sandstone containing phosphatic nodules.
			CARROLL COUNTY			
31	Chattanooga shale (see pl. 4).	SW¼ sec. 5, T. 20 N., R. 26 W.	[2] 24955	0.004	0.001	Channel sample, 2-ft black shale.
			[2] 24956	.003	.002	Do.
			[2] 24957	.004	.002	Do.
32	do	NE¼ sec. 15, T. 20 N., R. 26 W.	[1] 140069	.004	.001	Channel sample, 1-ft greenish-gray shale, slightly sandy in upper 0.1-ft.
			[1] 140070	.004	.001	Channel sample, 1-ft black shale.
			[1] 140071	.004	.001	Channel sample, 0.5-ft black shale.

See footnotes at end of table.

TABLE 1.—*Description, radioactivity, and uranium content of samples*—Continued

Locality (fig. 32)	Rock unit	Location	Sample	Percent equivalent uranium	Percent uranium	Description
			Arkansas—Continued			
			MARION COUNTY			
33	Sylamore sandstone member of Chattanooga shale (see pl. 4).	SW¼ sec. 11, T. 19 N., R. 17 W.	[1]228906	0.25	0.55	Selected sample, spore-rich black shale containing much opaque organic material.
			147380	.011	.008	Selected sample, black shale, no obvious organic material or spores; from point 0.3 ft below top of shale.
			[1]228904	.007	.005	Channel sample, 0.9 ft black shale; full thickness of black shale lens.
			147381	.013	.007	Selected sample, gray to black shale in lowest 0.5 ft of shale.
			[1]228905	.008	.006	Channel sample, 1.3 ft black shale; about 12 ft from sample 228904, full thickness of black-shale lens.
			[1]231720	.016	.012	Channel sample, 0.9 ft black shale; contains 0.1 ft spore-rich, organic-rich layer.
			[1]231713	.008	.008	Selected sample, coalified plant material; no spores present.
34	do	SW¼ sec. 26, T. 18 N., R. 18 W.	[1]231714	.004	.003	Grab sample, 0.4 ft weathered black shale.
			[1]231715	.010	.009	Grab sample, 0.5 ft weathered black shale lens in sandstone.
			SEARCY COUNTY			
35	Fayetteville shale	NW¼ sec. 31, T. 15 N., R. 15 W.	[1]140065	0.004	0.001	Channel sample, 0.8 ft black shale.
			[1]140066	.003	.001	Channel sample, 1 ft black shale.
			STONE COUNTY			
36	Sylamore sandstone member of Chattanooga shale (see pl. 4).	NW¼ sec. 21, T. 15 N., R. 11 W.	147423	0.002	0.002	Chip sample, 0.8 ft phosphatic gray sandstone.
			147347	.004	.003	Channel sample, 0.3 ft light-greenish-gray phosphatic clay shale.
			147200	.005	.004	Chip sample, representative of a total of 1.3 ft of black shale in 2.5 ft of alternating black shale and sandstone.

See footnotes at end of table.

TABLE 1.—*Description, radioactivity, and uranium content of samples*—Continued

Locality (fig. 32)	Rock unit	Location	Sample	Percent equivalent uranium	Percent uranium	Description
			Arkansas—Continued			
			STONE COUNTY—continued			
36	Sylamore sandstone member of Chattanooga shale (pl. 4).	NW¼ sec. 21, T. 15 N., R 11 W.	147346	0.006	0.006	Selected sample, greenish-gray shale from 0.3 ft interbedded phosphatic shale and sandstone.
			147422	.007	.007	Selected sample, sandstone from same unit as sample 147346.
			148164	.004	.003	Channel sample, 1.5 ft black shale.
			147382	.004	.002	Chip sample, 3.4 ft black shale.
37	Cason shale	NE¼ sec. 9, T. 14 N., R. 9 W.	148170	.003	.001	Channel sample, 1 ft gray-green clay shale.
			148171	.004	.001	Selected sample, from 1.3 ft black phosphatic, concretionary unit.
			147390	.008	.008	Selected sample, same material as sample 148171.
			148172	.007	.007	Selected sample, from same unit as sample 148171, except smaller rounded masses.
			148173	.003	.001	Channel sample, 0.7-ft medium- to dark-gray shale.
			148174	.003	.001	Channel sample, 2-ft black shale.
			148175	.003	.001	Channel sample, 1.3-ft brownish- to greenish-black shale.
			148176	.004	.002	Channel sample, 0.9-ft black shale.
			148177	<.001	.001	Grab sample, black phosphatic concretion.
38	Chattanooga shale (see pl. 4).	Sec. 5(?), T. 14 N., R. 8 W.	147201	.008	.007	Grab sample, badly weathered black shale from upper 2 ft of formation.
			INDEPENDENCE COUNTY			
39	Chattanooga shale (see pl. 4).	NE¼ sec. 23, T. 14 N., R. 6 W.	148169	0.003	0.002	Chip sample, 5-ft weathered black shale.
40	do	NW¼ sec. 24, T. 14 N., R. 6 W.	148165	.006	.003	Do.
			148167	.003	.002	Channel sample, 0.2-ft slightly silty dark-gray shale.
			148168	.004	.003	Chip sample, 2-ft silty dark-gray shale.
			148166	.003	.002	Channel sample, 0.2-ft silty dark-gray shale.

See footnotes at end of table.

TABLE 1.—*Description, radioactivity, and uranium content of samples*—Continued

Locality (fig. 32)	Rock unit	Location	Sample	Percent equivalent uranium	Percent uranium	Description
			Arkansas—Continued			
			HOT SPRING COUNTY			
41	Upper division of the Arkansas novaculite (see pl. 5).	NE¼ sec. 21, T. 3 S., R. 17 W.	147378	0.002	0.001	Grab sample, medium- to dark-gray shale.
	Middle(?) division of the Arkansas novaculite.	-----do-----------	147191	.002	.002	Channel sample, 1-ft dark-gray shale.
42	Middle division of the Arkansas novaculite (see pl. 5).	SW¼ sec. 12, T. 3 S., R. 18 W.†	147367	.004	.0011	Channel sample, 0.5-ft medium-gray and black shale.
			147379	.003	.002	Selected sample, black shale from same unit as sample 147367.
			147196	.003	.002	Grab sample, same as sample 147195 except more weathered.
			147195	.002	.002	Grab sample, dark-gray to black shale.
			147366	.004	.0018	Selected sample, black fissile shale about 0.04-ft thick immediately subjacent and superjacent to sample 147401.
			147401	.001	.002	Channel sample, 0.08-ft brown quartz sandstone.
			147365	.002	.0009	Chip sample, black nonfissile shale.
			147193	.001	.001	Grab sample, black nonfissile shale.
43	Stanley shale-------	N½ sec. 14, T. 3 S., R. 18 W.	[1] 140062	.002	.001	Chip samples, through 180 ft of black shale in the upper part of the Stanley shale.
44	Middle division of the Arkansas novaculite (see pl. 5).	NE¼ sec. 20, T. 4 S., R. 20 W.	148181	.003	.001	Chip sample, 12 ft of black shale with a minor amount of interbedded black novaculite.
			GARLAND COUNTY			
45	Stanley shale (see pl. 5).	SE ¼ sec. 10, T. 3 S., R. 18 W.	[1] 140061	0.003	<0.001	Channel sample, 12-ft dark-gray shale about 400 ft above base of formation.
	Middle division of the Arkansas novaculite.		[1] 140060	.001	<.001	Grab sample, gray shale near base of middle division.
46	Upper division of the Arkansas novaculite.	S½ sec. 8, T. 3 S., R. 18 W.	147400	.006	.004	Grab sample, metamorphosed novaculite; much black iron oxide.
			147425	<.001	<.001	Grab sample, metamorphosed novaculite; much red iron oxide.
			147426	.025	.027	Selected sample, represents about 4 in. across bedding; largely black iron-oxide latticework; metamorposed novaculite.

See footnotes at end of table.

TABLE 1.—*Description, radioactivity, and uranium content of samples*—Continued

Locality (fig. 32)	Rock unit	Location	Sample	Percent equivalent uranium	Percent uranium	Description
			Arkansas—Continued			
			GARLAND COUNTY—continued			
46	Upper division of the Arkansas novaculite.	S½ sec. 8, T. 3 S., R. 18 W.	147427	0.001	<0.001	Same material as sample 147426, but very little iron oxide; mainly light-gray granular quartz.
	Polk Creek shale	S½ sec. 8, T. 3 S., R. 18 W.	147188	.003	.004	Grab sample, badly weathered gray shale; probably black before weathering.
			147189	.004	.003	Grab sample, hard black graptolitic shale.
	Big Fork chert	do	147190	.003	.002	Grab sample, black shale.
47	Arkansas novaculite(?) (see pl. 5).	North line sec. 30, T. 1 N., R. 19 W.	148180	.002	.001	Grab sample, slaty black shale.
			MONTGOMERY COUNTY			
48	Upper division of the Arkansas (?) novaculite (see pl. 5).	NE¼ sec. 19, T. 4 S., R. 24 W.	147363	0.003	0.0012	Grab sample, badly weathered gray shale.
			147184	.004	.003	Channel sample, 0.2-ft black fissile shale; not as fissile as sample 147182.
			147183	.001	.002	Channel sample, 0.25-ft black siliceous shale.
			147182	.003	.004	Channel sample, 0.4-ft dark-gray to black fissile shale.
			147376	.002	.001	Grab sample, dark-gray fissile shale.
			147181	.003	.002	Do.
	Middle division of the Arkansas novaculite.	do	147377	.002	.002	Grab sample, weathered dark-gray shale.
			147187	.001	.001	Grab sample, badly weathered light-gray clayey shale.
49	Middle division of the Arkansas novaculite (see pl. 5).	NW ¼ sec. 10, T. 2 S., R. 25 W.	147203	.002	.001	Channel sample, 0.5-ft light-gray shale.
			SCOTT COUNTY			
50	Caney shale	Ctr. sec. 6, T. 1, N., R. 28 W.	[1] 140057	0.003	0.001	Channel sample, 5-ft black shale.
			[1] 140058	.002	.004	Do.
			[1] 140059	.004	.004	Channel sample, 0.3-ft black shale.

See footnotes at end of table.

TABLE 1.—*Description, radioactivity, and uranium content of samples*—Continued

Locality (fig. 32)	Rock unit	Location	Sample	Percent equivalent uranium	Percent uranium	Description
		Arkansas—Continued				
		POLK COUNTY				
51	Big Fork chert(?)	SE¼ sec. 36, T. 2 S., R. 29 W.	148185	0.001	0.001	Chip sample, 10-ft black shale interbedded with a few thin chert beds.
			148182	.002	.002	Channel sample, 1.5-ft black fissile shale.
52	Missouri Mountain shale.	S½ sec. 25, T. 2 S., R. 29 W.	148184	.002	.001	Grab sample, dark-gray shale, weathering red, tan, and light gray.
	Stanley(?) shale	do	148183	.002	.001	Chip sample, 10-ft black shale, with a few thin chert beds and silty shale beds.
53	Middle division of the Arkansas novaculite (see pl. 5).	N½ sec. 4, T. 3 S., R. 30 W.	148186	.002	.001	Chip sample, 6-ft greenish-black nonfissile shale.
	Lower division of the Arkansas novaculite.	do	148187	.002	.001	Channel sample, 0.5-ft black, fissile shale.
54	Stanley shale (see pl. 5).	Ctr. sec. 1, T. 5 S., R. 32 W.	147369	.002	.0008	Channel sample, 0.25-ft dark-gray shale about 10 ft above a tuff lentil.
			147428	.001	<.001	Grab sample, from uppermost part of 90-ft thick tuff lentil (Hatton tuff lentil).
			147429	.001	<.001	Grab sample, from 30 ft above base of tuff lentil.
			147430	.001	<.001	Grab sample, from 15 ft above base of tuff lentil.
			147370	.003	.0008	Channel sample, 0.75-ft dark-gray shale, immediately underlies the tuff lentil.
	Middle division(?) of the Arkansas novaculite.	do	147202	.002	.001	Chip sample, 2 ft light- to medium-gray shale.

[1] Sample collected by V. E. Swanson.
[2] Sample collected by W. H. Hass.
*Shown incorrectly on plate 5.
†Location is incorrect on plate 5.

WOODFORD SHALE

The marine shales and cherts of Devonian and Early Mississippian age that crop out around the margins of the Arbuckle Mountains and the western end of the Ouachita Mountains in south-central Oklahoma were named the Woodford chert by Taff (1902). The name was subsequently modified (Miser, 1954) to Woodford shale for most of the area, but the name Woodford chert is still retained for the small area along the northwest flank of the Ouachita Mountains of Oklahoma. Inasmuch as only one (loc. 12, pl. 3) of the outcrops that were measured and sampled for this report is in the area where the name Woodford chert is applicable, the name Woodford shale is used hereinafter.

The Geological Survey regards the Woodford as Mississippian and Devonian in age. Hass (1956a, p. 27–29) states that conodont collections indicate that the oldest beds of the Woodford are of early Late Devonian (or possibly late Middle Devonian) age and the youngest are Kinderhook (early Early Mississippian) in age.

In southern Oklahoma the Woodford is overlain at different places by the Sycamore limestone, Welden limestone, Caney shale, and the Stanley shale. The Sycamore probably grades laterally into the lower part of the Caney (Hamm, 1955, p. 31). The lower parts of both the Caney and the Stanley are considered to be of Mississippian, probably Meramec (early Late Mississippian), age by Hass (1956a, p. 29–32). The Welden limestone is considered by Hass (1959, p. 371) to be of late Kinderhook age. The Woodford unconformably overlies rocks of Devonian, Silurian, and Ordovician age, but at the two localities (1 and 12) shown on plate 3, where the rocks underlying the Woodford are exposed, they are of Devonian age.

The Woodford is comprised largely of thinly laminated to thin-bedded, black to dark-gray shale with subordinate amounts of very thin to thin-bedded, light-gray to black chert. The thinly laminated (less than 1/16 in. thick) to laminated (1/16 to 1/2 in. thick) shale generally weathers to small flakes and tends to retain its original color. The very thinly bedded (1/2 to 2 in. thick) and thin-bedded (2 in. to 2 ft thick) shale generally weathers to flaggy and slabby pieces with a buff to almost white color.

Most of the chert in the formation is bedded and cryptocrystalline, but at locality 5 (pl. 3) there are a few nodular or concretionary masses of chert. In general the outcrops in the southern part of the Arbuckle Mountains (locs. 1 and 3) and the northern part of the Ouachita Mountains (loc. 12) contain more chert than the outcrops northeast of the Arbuckle Mountains.

Light-gray to light-brownish-gray subspherical to flattened and elongate phosphatic nodules are present in the Woodford and are especially common in the upper part of the formation. However, nowhere do the nodules make up more than 2 or 3 percent of the formation. Most of the nodules are subspherical in shape, as much as 2 inches in diameter, and are composed of apatite and quartz in silt- to clay-sized grains.

Pyrite is a persistent minor constituent of the Woodford. It occurs as masses of minute imperfectly formed crystals, as disseminated very fine grained crystals, and as well-developed pyritohedrons as much as 5 mm in size. Limestone is rare in the Woodford and was only observed at one outcrop (loc. 7, pl. 3) where it seems to be concretionary. A few thin quartz sandstone or coarse siltstone laminae are present in the formation (locs. 3 and 6, pl. 3).

At three localities (locs. 5, 6, and 12, pl. 3) the contact of the Woodford with superjacent rocks is exposed. The Sycamore limestone, which is as much as 390 feet thick in the southwestern part of the Arbuckle Mountains (Hamm, 1955, p. 28), is only 2.5 feet thick at locality 5 on the north side of the Arbuckles. It is underlain by 3 feet of light-gray glauconitic very slightly calcareous shale containing light-gray phosphatic nodules and a few laminae less than 1 mm thick composed of rounded quartz grains. In plate 3 this shale unit is included with the Woodford but other workers might prefer to consider it is a part of the overlying Sycamore. At locality 6 the Woodford is overlain by the Welden limestone of late Kinderhook age. At the same locality, a 1-foot-thick unit of light-greenish-gray glauconitic shale containing phosphatic nodules is shown as the uppermost part of the Woodford. This shale was called the pre-Welden shale by Cooper (1939) to differentiate it from both the Woodford and the Welden. Hass (1959, p. 371) believes the pre-Welden shale to be late Kinderhook in age.

On the northwest side of the Ouachita Mountains the Woodford chert is overlain by the Caney shale. The Woodford-Caney contact shown on plate 3 (loc. 12) is at the contact of a light-greenish-gray glauconitic shale with a black fissile shale. This greenish-gray shale occupies the same stratigraphic position as the pre-Welden shale of Cooper (1939), but no lithologic equivalent of the Welden limestone is present.

On the northeast flank of the Arbuckle Mountains of south-central Oklahoma the Woodford is about 560 feet thick (Hamm, 1955, p. 31). In general, the Woodford in the area of this report is less than 300 feet thick.

CHATTANOOGA SHALE

The Chattanooga shale was named by C. W. Hayes (1891, p. 142, 143). In central Tennessee, it consists of two members totaling as much as 35 feet of black and gray shale and is of Devonian age (Hass, 1956b). Adams and Ulrich (1905) first applied the name Chattanooga to the marine black shale occupying about the same stratigraphic position in the central midcontinent region. Though several other names, both formal and informal, had precedence, the name Chattanooga shale has superseded them almost completely in Kansas, Arkansas, and adjacent parts of Missouri and Oklahoma.

The age of the Chattanooga has been the subject of much controversy. Some geologists have preferred to regard it as the oldest rock unit of Mississippian age in the area, mainly because it is much more consistent in stratigraphic relation to the overlying rocks of Mississippian age than it is to the rocks of Devonian, Silurian, and Ordovician age that underlie it. Other geologists prefer to place it in the Upper Devonian system, largely on the basis of paleontological evidence and because the Chattanooga in the type area in Tennessee is Devonian in age. Hass (1956a, p. 28–29) states that the Chattanooga in northeastern Oklahoma contains conodonts of both Late Devonian and Early Mississippian (Kinderhook) age.

The Chattanooga shale in the report area (pl. 4) is underlain by rocks ranging in age from Devonian to Precambrian and overlain by rocks ranging in age from Mississippian to Pennsylvanian. The unconformity at the base of the Chattanooga is of regional importance because many of the rock units that are overlain unconformably by the Chattanooga are important petroleum reservoirs. The unconformity at the top of the Chattanooga is as pronounced as that at the base in a few areas where, owing to post-Mississippian erosion, rocks of Pennsylvanian age overlie the Chattanooga. However, in most of the report area the Chattanooga is overlain by carbonate rocks of Early Mississippian age, and the contact seen in outcrops is apparently conformable and in some exposures seems to be transitional.

The Chattanooga shale consists primarily of black, grayish-black, or dark-gray, pyritiferous nonphosphatic noncalcareous marine shale. Most of the Chattanooga is thinly laminated and in general the formation is thinner bedded than its lateral correlative, the Woodford shale. Under weathering conditions the Chattanooga breaks down into iron-stained angular chunks and flakes and tends to retain its dark color. At locality 40 (pl. 4) the lower part of the section is more silty, lighter in color, and less fissile than the upper part of the exposed rocks. This lower part is here tentatively included in the Chattanooga. Minor constituents of the Chattanooga are phosphatic nodules and laminae, pyrite, cone-in-cone limestone nodules and lentils, calcareous cone-in-cone shale nodules, and sandstone.

The phosphatic nodules are largely confined to the uppermost part of the Chattanooga and to its basal unit, the Sylamore sandstone member. The nodules in the Sylamore are black to dark gray, well rounded, smooth surfaced, irregular to spherical shaped, and as much as 12 inches in largest dimension. The nodules in the uppermost part of the Chattanooga are in general irregularly shaped, light gray to dark gray, and seldom more than 2 inches in largest dimension. Phosphatic material also occurs in thin laminae associated with pyrite (loc. 20. pl. 4) and in phosphatic sandstone and shale.

The uppermost part of the Chattanooga is generally a medium-gray to light-greenish-gray nonfissile shale, which in places is calcareous, glauconitic, silty, or sandy. This part contains phosphatic nodules at some of the exposures examined (locs. 22 and 30, pl. 4). It is typically softer than the underlying shale and on weathered outcrops forms a groove immediately beneath the overlying rock unit which at all examined exposures (pl. 4) is limestone or chert of the Boone formation. The nonfissile shale was not exposed at the outcrops in northeastern Arkansas (locs. 36, 38, 39, and 40), but a similar shale is reported in Independence County, near localities 39 and 40, by Gordon and Kinney (1944). They included the shale in the Boone formation but indicated that it was not present everywhere. They further suggested that this nonfissile shale might be equivalent to the Hannibal shale of Missouri, which is of late Kinderhook age. The Mississippian Subcommittee of the Geological Society of America (1948) suggested that this nonfissile shale in Independence County might be an attenuated representation of the Northview shale of southwestern Missouri, which they show as slightly younger than the Hannibal shale. This shale unit is also similar in stratigraphic position and lithology to the Maury formation of Tennessee, which Hass (1956b, p. 23) states is chiefly of Kinderhook age.

Where seen in outcrops (locs. 20–22, 24, 27, 28, 30–33, pl. 4), this nonfissile shale unit seems to be transitional between the Chattanooga and the overlying St. Joe limestone member of the Boone formation. It is similar in stratigraphic position to the pre-Welden shale of Cooper (see p. 305) and may have had a similar depositional history; it represents the sediments deposited during part or all of a time of transition when conditions ranged from those favoring the deposition of dark-colored, fine-grained clastics to those favoring deposition of calcareous shale, limestone, and chert. Its absence in some places could be caused by nondeposition or by erosion prior to the deposition of the overlying Boone formation.

The basal unit of the Chattanooga is a light- to brownish-gray sandstone that contains well-rounded black to dark-gray phosphatic nodules. This sandstone is called the Sylamore sandstone member of the Chattanooga shale and is the correlative of the Misener sand of drillers in northern Oklahoma and eastern Kansas. The Sylamore is probably a transgressive deposit of the advancing Late Devonian and Early Mississippian sea. At a locality in northeastern Oklahoma, Hass (1956a, p. 28) collected conodonts from the Sylamore which not only included representatives of the faunal zone of the shale directly overlying the sandstone but also included representatives of two older faunal zones.

In some areas in northern Arkansas the Sylamore is the only member of the Chattanooga shale (locs. 33, 34, and 36, pl. 4). In these areas the relation of this sandstone to the overlying rocks is still not completely understood. On the basis of stratigraphy, McKnight (1935) and Maher and Lantz (1953) mapped this sandstone as the basal member of the Boone formation and regarded it as Osage (late Early Mississippian) in age. However, conodont determinations by W. H. Hass (*in* Maher and Lantz, 1953) indicate that the sandstone in north-central Searcy County, Ark., is largely of Late Devonian age. The Sylamore in north-central Arkansas contains thin black-shale lentils at some places (locs. 33 and 34, pl. 4) and is overlain by thin black-shale beds at some other localities (Maher and Lantz, 1953). Locality 36 is in the type area of the Sylamore sandstone member. As shown on plate 4, the Sylamore here consists of two sandstones separated by a unit composed of shale, shaly sandstone, and sandstone. Exact relations of the various parts of this exposed section with rocks in areas both to the east and to the west are unknown.

The Chattanooga is absent in some parts of the report area due to nondeposition or postdepositional erosion, but it is 250 feet thick in the subsurface of central Kansas. In general, the Chattanooga is 50 feet or less thick throughout the area in which it crops out. The Sylamore sandstone member ranges in thickness from 0 to at least 18 feet (Huffman, 1958, p. 38) but is generally a few feet or less thick.

ARKANSAS NOVACULITE

Griswold (1892) informally applied the name Arkansas novaculite to the sequence of rocks from which whetstones were quarried in the Ouachita Mountains of Arkansas and Oklahoma, but the rock name "novaculite" had been applied in the area by earlier authors (Griswold, 1892, p. 83–88). Purdue (1909, p. 37) defined the formation and formally proposed the name. Throughout most of the Ouachita Mountains three divisions can be recognized, the upper, middle, and lower. However, the stratigraphy and distribution of the three divisions is little known in parts of the report area, particularly in the northern part of the Ouachita Mountains of Arkansas, and some of the stratigraphic assignments made in this report may subsequently prove to be erroneous (pl. 5). The upper and lower divisions are comprised predominantly of dark- to light-gray massive thick-bedded novaculite with a subordinate amount of black to gray shale. The middle division is made up largely of medium-gray to black shale, with some thin-bedded novaculite usually present. The Arkansas novaculite is considered to be Devonian and Mississippian in age by the U.S. Geological Survey. The lower division has been correlated with Lower or Middle Devonian formations (Hass, 1951, p. 2533), and on the basis of conodont collections, Hass considers the middle division to be chiefly of Late Devonian but partly of Early Mississippian (Kinderhook) age (1951, p. 2535) and the upper division to be of Early Mississippian (very late Kinderhook or Osage) age (1951, p. 2540).

The Stanley shale of Mississippian age overlies the novaculite, and the Missouri Mountain shale of Silurian age underlies it. The lowermost part of the Stanley is considered by Hass (1950, p. 1578) to be early Late Mississippian (Meramec) in age. The Missouri Mountain shale was assigned to the Silurian by Miser (1917, p. 66) on the basis of lithologic character and stratigraphic relations.

The upper and lower divisions of the Arkansas novaculite are comprised primarily of white to dark-gray, thin-bedded to massive, in some places slightly calcareous, cryptocrystalline rock called novaculite. Tarr (1938, p. 27) defined novaculite as "a very dense, even-textured, light-colored, cryptocrystalline siliceous rock; similar to chert but characterized by a dominance of quartz rather than chalcedony." Interbedded with the novaculite are various amounts of black, gray, dark greenish-gray, and reddish-gray shale. The black-shale beds are generally thin, a few inches or less thick, and very fissile and papery. The gray, greenish-gray, and reddish-gray shales are usually not as fissile nor as hard as the black shales.

The middle division of the Arkansas novaculite is generally comprised of black to medium-dark-gray shale with a subordinate amount of thin-bedded gray to black novaculite. Most of the shale is thinly laminated to laminated, noncalcareous, and slightly pyritiferous. In some places as at locality 14 (pl. 5 and table 1), the middle division is almost wholly comprised of dark greenish-gray, sometimes silty, nonfissile shale, some of which breaks with a hackly fracture. The middle division ranges in thickness from 0 to about 525 feet (Miser, 1944, p. 135).

The Arkansas novaculite ranges from 950 to about 250 feet in thickness in western Arkansas (Miser and Purdue, 1929, p. 50). Honess (1923, p. 114 and 116) states that the formation does not exceed 600 feet in thickness in Oklahoma; at the westernmost outcrops the novaculite ranges from 234 to 340 feet in thickness (Hendricks and others, 1947).

OTHER SAMPLED UNITS

The main emphasis of this study was on the Chattanooga shale, Woodford shale, and Arkansas novaculite, but during the course of fieldwork some samples were collected from other rock units in the area.

The Stanley shale of Mississippian age was sampled at six outcrop localities (locs. 14, 16, 43, 45, 52, and 54, fig. 32 and table 1).

The Caney shale of Mississippian age was sampled at localities 4, 12, 13, and 50 (fig. 32 and table 1). The Fayetteville shale of Late Mississippian (Chester) age, was sampled at localities 29 and 35 (fig. 32 and table 1). The Missouri Mountain shale of Silurian age was examined at several outcrops in western Arkansas and sampled at locality 52 (fig. 32; table 1). The Polk Creek shale and Big Fork chert of Ordovician age were examined at several outcrops in western Arkansas. The Polk Creek was sampled at locality 46 and the Big Fork at localities 46 and 51 (fig. 32 and table 1).

The Cason shale of Ordovician age was examined and sampled at locality 37 (fig. 32 and table 1) where the Chattanooga is absent, and the Cason is overlain by the Boone formation of Mississippian age.

Any evaluation of the uranium content of these rock units is beyond the scope of this report, but the rocks were examined and a few samples were collected in areas where these rock units are closely associated with the Chattanooga shale, Woodford shale, and Arkansas novaculite.

RADIOACTIVITY AND URANIUM CONTENT

All samples collected for this report were analyzed for radioactivity and uranium content. Sample descriptions and analyses are listed by locality (fig. 32) in table 1 and are shown on the columnar sections in plates 3–5. Most of the samples were collected by the author but some were collected by V. E. Swanson in the initial stages of the investigation and some were collected by W. H. Hass in connection with his paleontological studies.

WOODFORD SHALE

The Woodford shale was examined and sampled at 10 localities in Oklahoma. Distribution of equivalent uranium and uranium values in shale, phosphatic nodules, and laminae, and in the Woodford as a whole, are shown on the histograms of figure 33. Modal median, and arithmetic mean values are also shown on figure 33. Samples of the shale, and samples of the Woodford as a whole, have a modal value of 0.002 percent equivalent uranium and 0.001 percent uranium. However, as shown on plate 3, the Woodford at some localities contains as much as 0.005 percent uranium in intervals as much as 20 feet thick (loc. 5, pl. 3). The phosphatic nodules and laminae from the Woodford have a considerable range of equivalent uranium and uranium content for the number of samples, and the fact that the mode, median, and arithmetic mean are all 0.007 percent equivalent uranium and 0.006 percent uranium may be fortuitous.

The largest uranium content yet reported for samples from the Woodford is from a locality in sec. 35, T. 1 S., R. 2 W., Carter County,

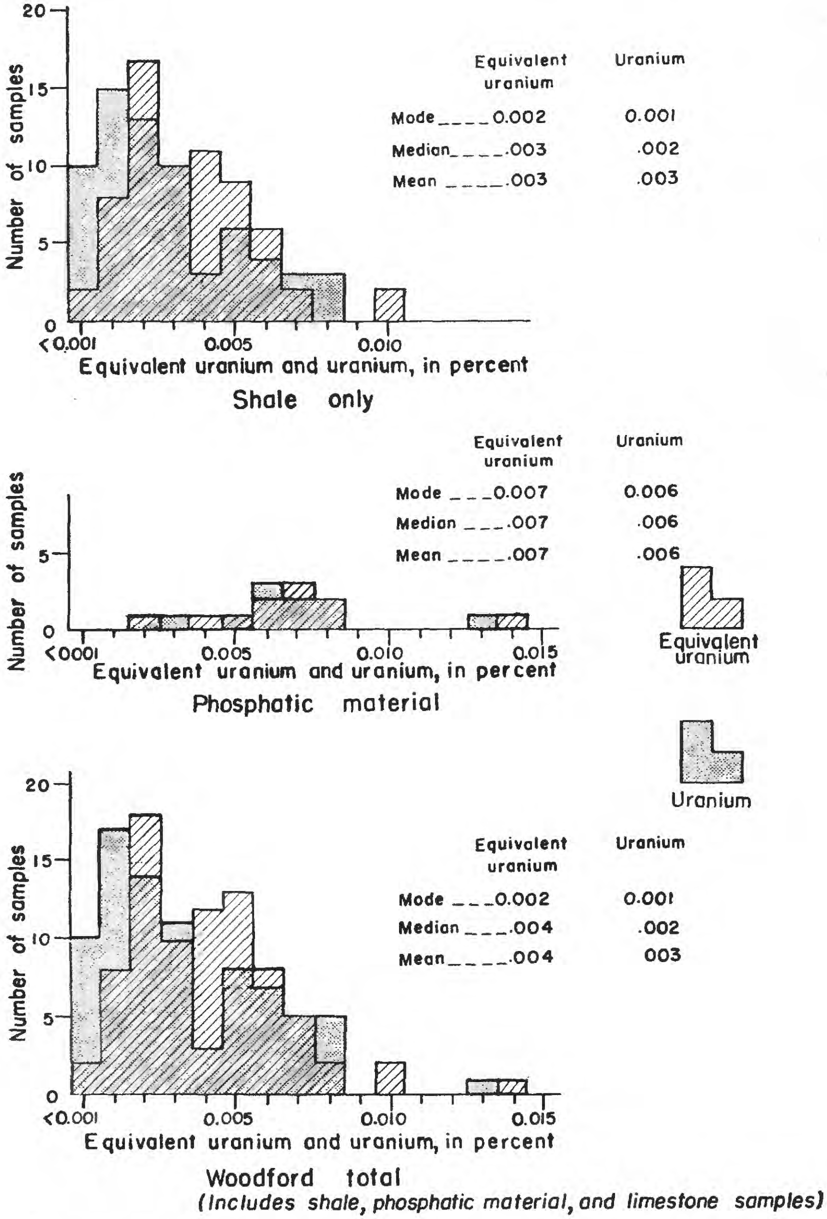

FIGURE 33.—Distribution of equivalent uranium and uranium values in samples of the Woodford shale.

Okla. E. P. Beroni (written communication, 1957) reports the presence of "* * * uraniferous asphaltic(?) material, associated with highly folded Woodford shale * * *. The asphaltic(?) material occurs as small lenses and pods confined to the shale laminae. One sample * * * assayed 0.11 percent U_3O_8." The author has examined samples of this material and it seems to be a concentration of uranium in carbonaceous fossil bone. No estimate is available as to the amount of ore-grade rock present, but it is probably small.

CHATTANOOGA SHALE

The Chattanooga shale, including the Sylamore sandstone member, was examined and sampled at 7 localities in Oklahoma, 2 in Kansas, 1 in Missouri, and 10 in Arkansas. A histogram showing the distribution of equivalent uranium and uranium values in all samples from the Chattanooga except the well-core samples from Kansas (fig. 34) shows that both the modal and median values of the samples are 0.004 percent equivalent uranium and 0.002 percent uranium. The

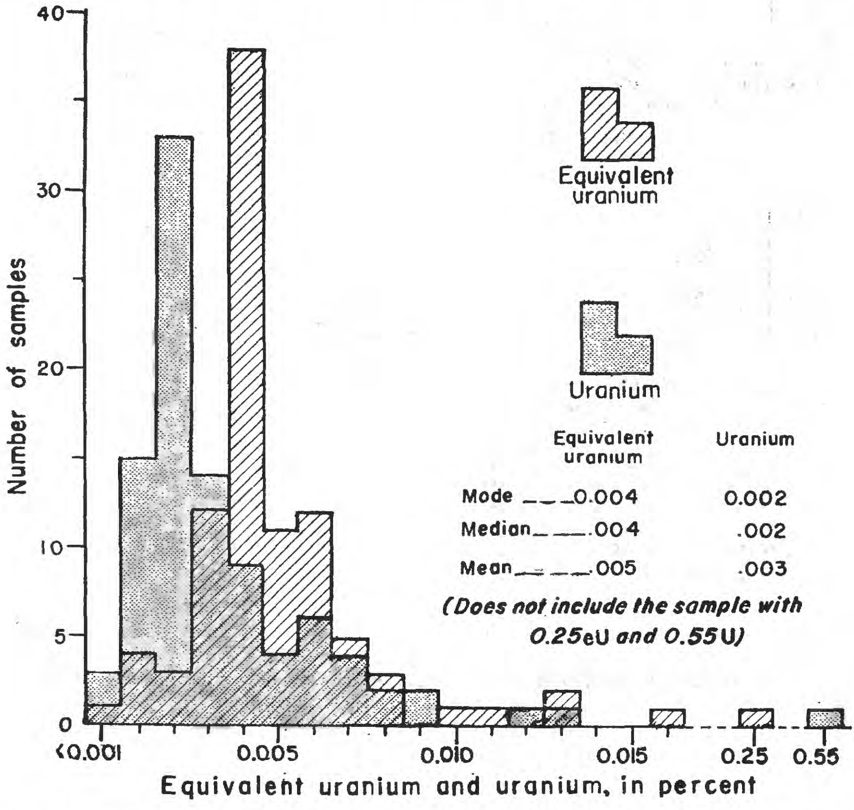

FIGURE 34.—Distribution of equivalent uranium and uranium values in samples of the Chattanooga shale.

arithmetic mean is 0.005 percent equivalent uranium and 0.003 percent uranium if the sample from locality 33 (sample 228906, table 1) is excluded from the calculation. These averages are probably representative of the Chattanooga in the report area. However, at locality 19 (pl. 4), a unit 6 feet thick contains 0.004 percent uranium and at locality 20 (pl. 4) the lower 10.1 feet of the Chattanooga contains a weighted average of 0.005 percent uranium.

At locality 33, selected samples of the shale lens in the Sylamore sandstone member, which is the only part of the Chattanooga there present (pl. 4), contain as much as 0.55 percent uranium, and Swanson (1955, p. 169) reports that samples he collected contain as much as 0.71 percent uranium. The uranium is concentrated in the organic-rich parts of layers within the shale lens. These layers have oolitic textures because of uncompressed specimens of the sporelike microfossil *Tasmanites*. The *Tasmanites*-bearing layers are as thick as 0.1 foot and have a lateral extent of as much as 1 foot, though most are not that large. The organic-rich parts of the *Tasmanites*-bearing layers are generally about 0.1 inch thick. In the most uraniferous specimens found, the organic-rich part is podlike or nodular in gross shape. The largest pod found was about 0.1 foot thick and less than 0.2 foot in longest dimension.

J. M. Schopf of the U.S. Geological Survey examined samples from locality 33 and reported that the organic-rich parts of the samples consist of dense, black, opaque organic material that resembles opaque attritus of coal and that it probably "consists of flocculated colloidal humic materials that were diagenetically altered in the same way that fusain is formed" (written communication, 1956). He also reported that the *Tasmanites* coats that are generally present in the organic-rich parts seem to be equally fusinized.

Though this occurrence is interesting because it has the highest uranium content yet reported from black shales in the United States, the amount of ore-grade rock present is too small to be of economic interest.

ARKANSAS NOVACULITE

The distribution of equivalent uranium and uranium values and modal, median, and mean values in samples from 15 localities at which the Arkansas novaculite was examined and sampled is shown on figure 35. Samples were collected from the upper division at 4 localities and from the lower division at 1 locality (pl. 5). As the unit of major interest, the middle division was sampled at 13 localities. The Arkansas novaculite samples range in uranium content less than samples from either the Woodford or Chattanooga. Only one shale sample contained as much as 0.004 percent uranium, and the average values of 0.002 percent equivalent uranium and 0.001 percent uranium are

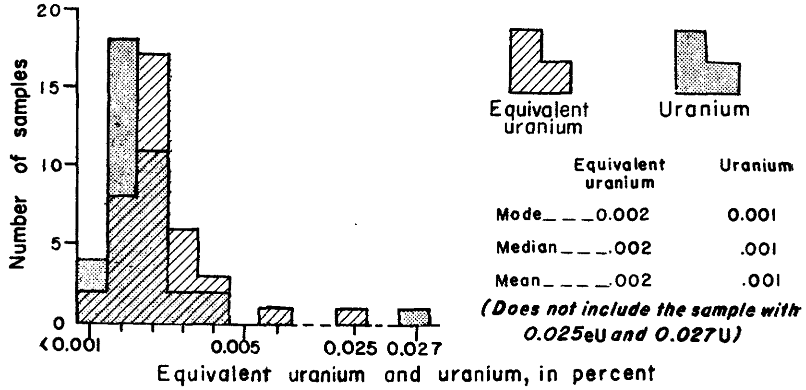

FIGURE 35.—Distribution of equivalent uranium and uranium values in samples of the Arkansas novaculite.

believed to be representative for the formation in the report area. The only samples containing more than 0.004 percent equivalent uranium or uranium are from locality 47, where the upper division has undergone contact metamorphism, with the resultant addition of a large suite of elements including uranium.

OTHER SAMPLED UNITS

Other rock units that were sampled during the investigation are shown on the columnar sections (pls. 3 and 5) at localities where they were examined in conjunction with the Woodford shale and Arkansas novaculite. All analytical results are listed in table 1.

None of the samples of the Stanley, Fayetteville, or Missouri Mountain shale contained more than 0.001 percent uranium. Two of the nine samples collected from the Caney shale contained 0.004 percent uranium (loc. 50, table 1), but the other seven contained no more than 0.002 percent uranium. Only two samples were collected from the Polk Creek shale (loc. 46, table 1), and they contained 0.004 and 0.003 percent uranium. Three samples of black shale from the Big Fork chert (locs. 46 and 51, table 1) contained no more than 0.002 percent uranium. The analytical results, and general observations at other outcrops from which no samples were collected, indicate that the only one of these units that might be worth further investigation is the Polk Creek shale.

The Cason shale of Ordovician age was examined and sampled at locality 37 (table 1), where it was at first mistaken for the Chattanooga shale, which is absent at this locality. The only samples of the Cason that contain more than 0.002 percent uranium are selected samples from a black phosphatic concretionary unit at the top of the formation.

OTHER MAJOR AND MINOR CONSTITUENTS

SHALE

TRACE-ELEMENT CONTENT

The trace-element content of 21 samples of shale from the Woodford and Chattanooga shale and Arkansas novaculite as determined by semiquantitative spectrographic analysis is shown in table 2. The samples are arranged in the table by rock unit in order of decreasing uranium content and are described in table 1. The minimum concentration of the elements that are detectable by semiquantitative spectrographic analysis is listed in table 3.

The analyses of samples from the Woodford shale do not indicate any relation, positive or negative, between uranium and any other elements. The two samples of Chattanooga shale from locality 33

TABLE 2.—*Trace-elements composition of shale samples from the Woodford and Chattanooga shales and Arkansas novaculite*

See table 1 for description of samples. Semiquantitative spectrographic analyses by Mona Frank, U.S. Geological Survey. Percentages are coded as follows:

Percent	*Code*	*Percent*	*Code*	*Percent*	*Code*	*Percent*	*Code*	*Percent*	*Code*
>10	17	1 -2	14	0.1 -0.2	11	0.01 -0.02	8	0.0005 -0.001	4
5-10	16	.5-1	13	.05- .1	10	.005- .01	7	.0002 - .0005	3
2- 5	15	.2-0.5	12	.02- .05	9	.002- .005	6	.0001 - .0002	2
						.001- .002	5	.00005- .0001	1

About 50 percent of these results may be expected to be accurately bracketed in these subdivisions of the orders of magnitude. 0 indicates element looked for but not found. Other elements listed in table 3 were also looked for but not found in concentrations equal to or larger than the concentrations listed in the table.

Sample	Locality	Si	Al	Fe	Mg	Ca	Na	K	Ti	P	Mn	Ag	B	Ba	Be	Ce	Co
								Woodford shale									
147391	9	17	14	14	11	8	9	12	10	0	7	3	8	10	1	0	5
147371	5	17	14	13	11	12	10	12	10	0	5	0	8	11	1	0	0
147392	10	17	15	14	12	11	10	13	11	0	7	3	8	10	2	0	5
147372	5	17	16	13	13	12	11	15	12	0	5	0	8	11	2	0	5
147383	2	17	15	14	12	15	9	13	11	14	6	4	9	11	2	0	5
147388	2	17	14	13	11	8	9	13	10	0	5	3	9	11	1	0	0
147384	5	17	16	16	13	15	12	15	11	14	8	1	9	11	2	0	6
147373	8	17	16	13	13	12	12	15	12	0	5	0	8	10	1	0	5
147389	12	17	17	15	13	10	11	15	12	13	6	1	10	12	3	0	0
147385	12	17	16	15	12	13	10	15	13	13	7	1	9	11	2	10	5
147386	12	17	14	12	11	14	9	13	10	14	5	1	8	10	1	0	5
147387	12	17	14	13	11	12	10	13	10	12	5	3	8	10	1	0	5
								Chattanooga shale									
147380	33	17	16	14	13	13	11	16	12	0	6	2	9	10	2	0	8
147381	33	17	16	14	13	13	11	16	12	0	6	2	9	10	2	0	8
147375	20	17	16	14	13	13	12	16	12	0	7	0	9	10	2	0	5
147382	36	17	16	14	13	13	11	16	12	0	6	0	9	10	2	0	5
147374	20	17	16	14	14	13	12	16	12	0	7	0	9	10	2	0	6
								Arkansas novaculite									
147377	48	17	16	16	13	12	10	15	12	0	6	0	9	12	2	0	5
147379	42	17	16	15	11	12	15	15	12	0	6	0	8	11	2	0	5
147376	48	17	15	13	13	8	10	15	12	0	6	0	9	10	1	0	5
147378	41	17	16	14	13	11	10	15	12	0	6	0	9	12	2	0	5

TABLE 2. *Trace-elements composition of shale samples from the Woodford and Chattanooga shales and Arkansas novaculite*—Continued

Sample	Locality	Cr	Cu	Ga	La	Mo	Nd	Ni	Pb	Sc	Sn	Sr	V	Y	Yb	Zn	Zr	U [1]
Woodford shale—Continued																		
147391	9	5	9	6	0	6	0	8	5	5	5	8	9	6	3	7	5	0.005
147371	5	6	9	6	0	8	0	8	5	5	5	7	10	6	3	0	5	.004
147392	10	7	9	7	0	7	0	8	5	5	5	8	11	7	4	9	6	.003
147372	5	7	9	6	6	0	0	8	5	5	5	9	9	6	3	0	7	.003
147383	2	9	9	6	6	7	6	9	5	5	0	9	10	7	4	8	5	.002
147388	2	8	9	6	0	5	0	8	0	5	0	7	9	6	3	7	5	.001
147384	5	10	8	7	6	5	6	8	5	5	0	9	9	7	4	0	7	.001
147373	8	7	8	6	6	4	0	8	5	5	0	8	8	6	3	0	6	.001
147389	12	8	10	7	6	5	0	8	7	5	0	9	12	7	4	0	7	.001
147385	12	8	8	7	6	5	7	8	8	5	0	9	10	7	4	0	7	.001
147386	12	8	8	6	0	7	0	7	5	5	0	7	9	6	3	0	5	.001
147387	12	8	8	6	0	5	0	8	5	5	0	7	9	6	3	0	5	.001
Chattanooga shale—Continued																		
147380	33	7	7	7	7	8	0	9	7	5	0	9	9	6	3	8	7	0.008
147381	33	7	8	7	6	8	0	9	8	5	0	9	9	6	3	8	7	.007
147375	20	7	7	7	0	7	0	8	5	5	0	8	8	6	3	0	7	.003
147382	36	7	7	7	6	5	0	8	5	5	0	8	9	6	3	0	7	.002
147374	20	7	7	7	7	8	0	8	5	5	0	8	8	6	3	0	7	.001
Arkansas novaculite—Continued																		
147377	48	8	7	7	7	6	0	8	5	5	0	10	9	7	4	0	7	0.002
147379	42	7	9	7	6	5	0	8	5	5	0	9	8	6	3	0	7	.002
147376	48	7	7	6	0	0	0	8	5	5	0	8	8	6	3	0	7	.001
147378	41	8	7	7	6	4	0	8	5	5	0	7	8	6	3	0	7	.001

[1] Uranium content determined chemically and shown in percent (see table 1).

contain considerably more uranium than do the other three samples of the Chattanooga; the two also contain more silver, cobalt, and lead, and may contain slightly more nickel, zinc, and strontium. Selected samples from locality 33 contain as much as 0.55 percent uranium, and it is probable that some, or all, of the above-cited metallic elements that have an apparent positive relation to the uranium content of the samples were deposited contemporaneously with the uranium.

The relative abundance and distribution of elements in the suite of samples determined by semiquantitative spectrographic analyses are shown on figure 36. The percentages and distribution of the reported elements are seen for the samples as a whole and for each of the rock units under discussion. Also shown in figure 36 are mean contents of some elements in pelitic rock as determined by Shaw (1954, tables 11 and 14). Several generalizations are indicated by figure 36. It is apparent that most of the samples from the Woodford shale and the lowermost part of the Caney shale contain less aluminum, magnesium, potassium, titanium, and zirconium, and more copper and silver, than do the samples from the Chattanooga shale and Arkansas novaculite.

The mean contents for pelitic rocks derived by Shaw (1954, tables 11 and 14) agree with the data for cobalt, chromium, lead, scandium,

TABLE 3.—*Minimum concentrations of the elements detectable by the semiquantitative spectrographic method*

[Revised Mar. 20, 1956. U.S. Geological Survey, Washington laboratory]

Element	Percent	Element	Percent	Element	Percent
SI	0.005	Dy	0.006	Rb	7.0
Al	.0001	Er	.003	Re	.04
Fe	.0008	Eu	.003	Rh	.004
Mg	.00003	Ga	.001	Ru	.008
Ca	.01	Gd	.006	Sb	.01
Na	.01	Ge	.001	Sc	.0005
K	.1	Hf	.007	Sn	.001
Ti	.0005	Hg	.08	Sr	.001
P	.07	Ho	.001	Sm	.008
Mn	.0007	In	.0004	Ta	.1
Ag	.00001	Ir	.03	Tb	.01
As	.01	La	.003	Te	.08
Au	.001	Li	.01	Th	.05
B	.005	Lu	.005	Tl	.04
Ba	.0005	Mo	.0005	Tm	.001
Be	.00005	Nb	.001	U	.08
Bi	.005	Nd	.006	V	.001
Cd	.005	Ni	.001	W	.05
Ce	.03	Os	.1	Y	.001
Co	.001	Pb	.001	Yb	.0001
Cr	.0006	Pd	.003	Zn	.008
Cs	.8	Pr	.01	Zr	.0008
Cu	.00005	Pt	.003		

NOTE.—These sensitivities are realized under ideal conditions, that is, no interferences. Some combinations of elements affect the sensitivity, changing the threshold values. (Note Nd content of samples 147383 and 147384, table 2.)

and yttrium. Shaw (1954, p. 1172–1173) did not apply the mean content of yttrium that he derived for the samples he analyzed to the mean content of pelitic rocks as a whole because of some analytical uncertainty, but the data in this report tend to confirm his findings. The samples contain considerably more copper and more gallium, nickel, and vanadium than Shaw's pelitic rock mean, and contain considerably less zirconium and less strontium.

ORGANIC-CARBON CONTENT

Samples of the Woodford and Chattanooga shale and the Arkansas novaculite were selected for organic-carbon determinations in order to obtain data on the range of organic-carbon content in representative samples and to determine, insofar as the small number of samples would allow, whether any discernible relation existed between the uranium and organic carbon. Analytical methods used were modifications of the techniques described by Hillebrand and others (1953, p. 768–775; Irving May, written communication, 1959). Results of the analyses are listed in table 4 and a graphical representation of the organic-carbon analyses versus the uranium content is shown in figure 37. The Woodford shale samples have a much larger range of organic-

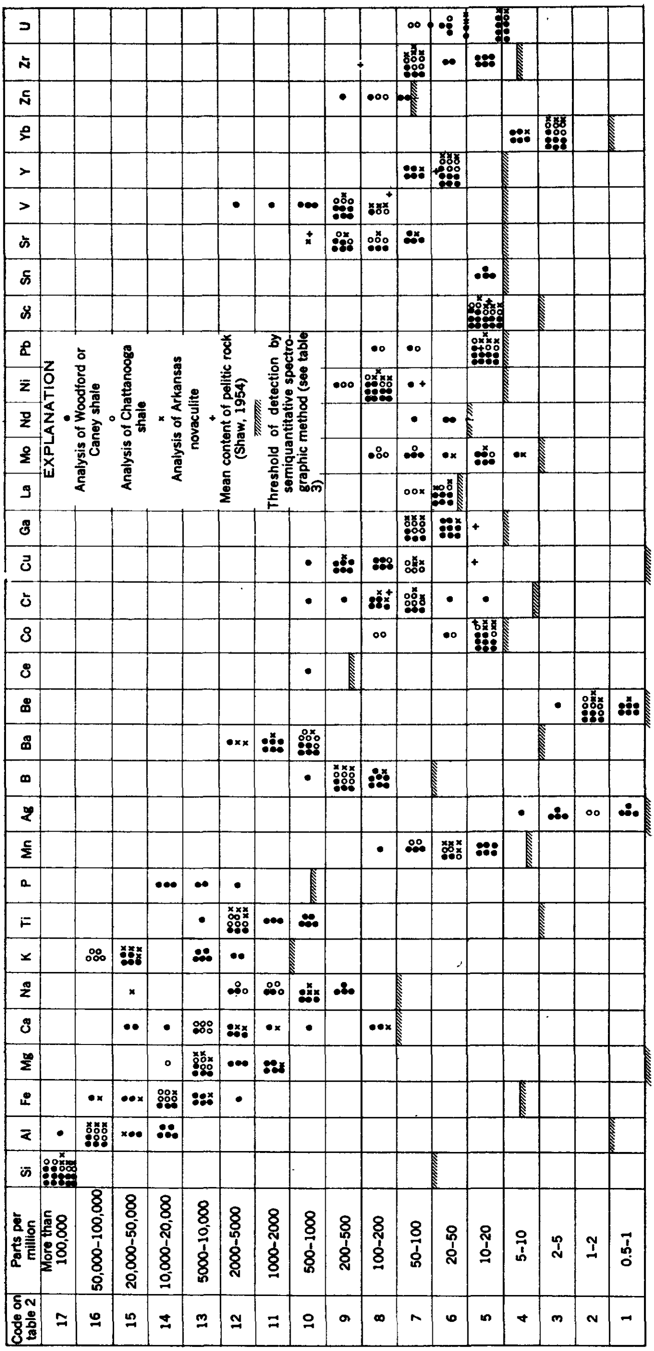

FIGURE 36.—Distribution of elements in shale samples from the Woodford and Chattanooga shales and Arkansas novaculite.

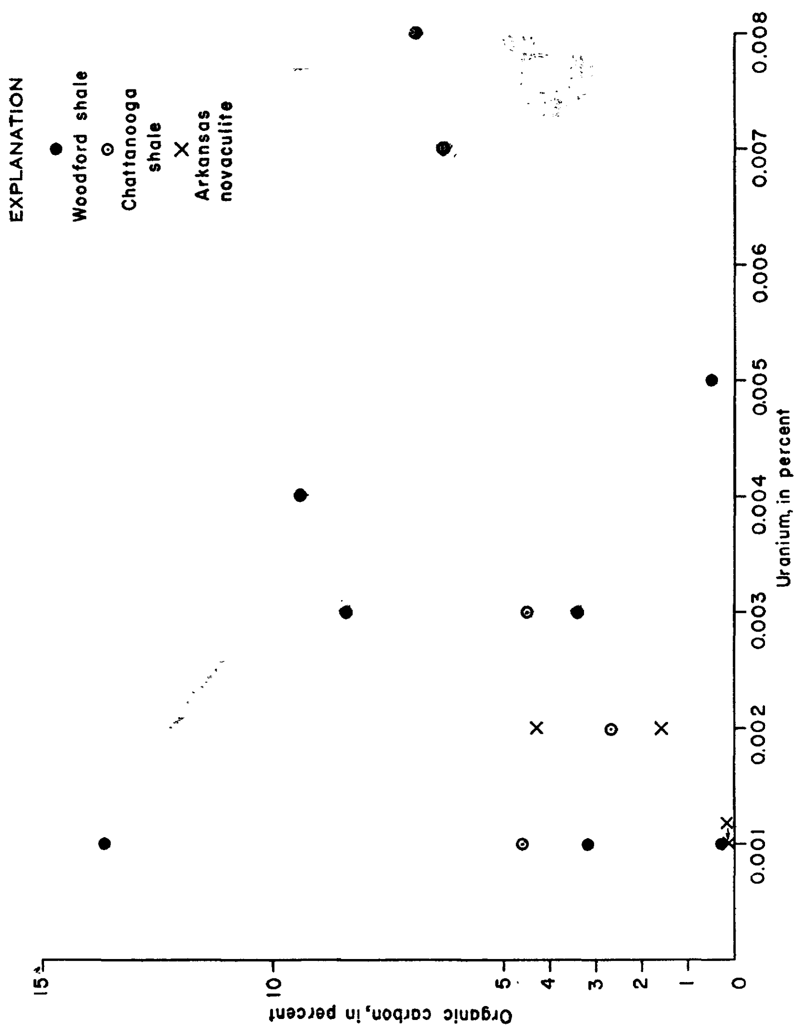

FIGURE 37.—Organic-carbon content versus uranium content.

carbon content than do the samples of the Arkansas novaculite and Chattanooga shale. There is no relation between organic carbon and uranium in the samples as a whole; the apparent relation between them in the samples of the Chattanooga shale and Arkansas novaculite cannot be evaluated because of the small number of samples.

OIL YIELD

The oil yield of 18 samples from the Chattanooga and Woodford shales was determined by the modified Fischer Retort method (Stanfield and Frost, 1949; Irving May, written communication, 1959). The results of the analyses are listed in table 5, and a graphical representation of the oil yield versus the uranium content of the samples is shown on figure 38.

The samples from the Chattanooga have a small range of oil yield and do not seem to indicate any relation between oil and uranium. The Woodford samples have a large range of oil yield, but any relation between oil yield and uranium content is obscure.

Six samples from the Woodford shale contained enough oil for determination of the specific gravity of the oil. Figure 39 is a plot of the specific gravity of the oil versus the uranium content of the sample from which the oil was obtained. Plotted on the same graph are the oil yields of the samples. In the six samples whose analyses are plotted on figure 39 the oil yield and uranium contents of the samples seem to have no relation, but the specific gravity of the oil and the

TABLE 4.—*Organic-carbon analyses*

[Analysts: C. Johnson, Wendell Tucker, Grafton Daniels, Joseph Budinsky, and R. Moore, U.S. Geological Survey]

Stratigraphic unit	Sample	Locality (fig. 32)	Percent organic carbon	Percent carbonate (CO_2)	Percent uranium	Remarks
Woodford shale	147391	9	0.50	0.01	0.005	
Do	147371	5	9.4	.07	.004	
Do	147372	5	3.4	.03	.003	
Do	147392	10	8.37	.04	.003	
Do	147373	8	3.2	.02	.001	
Do	147388	2	13.7	.03	.001	
Woodford chert	147389	12	.27	.03	.001	
Chattanooga shale	147380	33	6.9	.03	.008	Sylamore sandstone member.
Do	147381	33	6.3	.08	.007	Do.
Do	147375	20	4.5	.14	.003	
Do	147382	36	2.7	<.01	.002	
Do	147374	20	4.6	.53	.001	
Arkansas novaculite	147377	48	1.6	.02	.002	Middle division.
Do	147379	42	4.3	.05	.002	Do.
Do	147376	48	.3	.02	.001	Upper division.
Do	147378	41	.3	<.01	.001	Do.

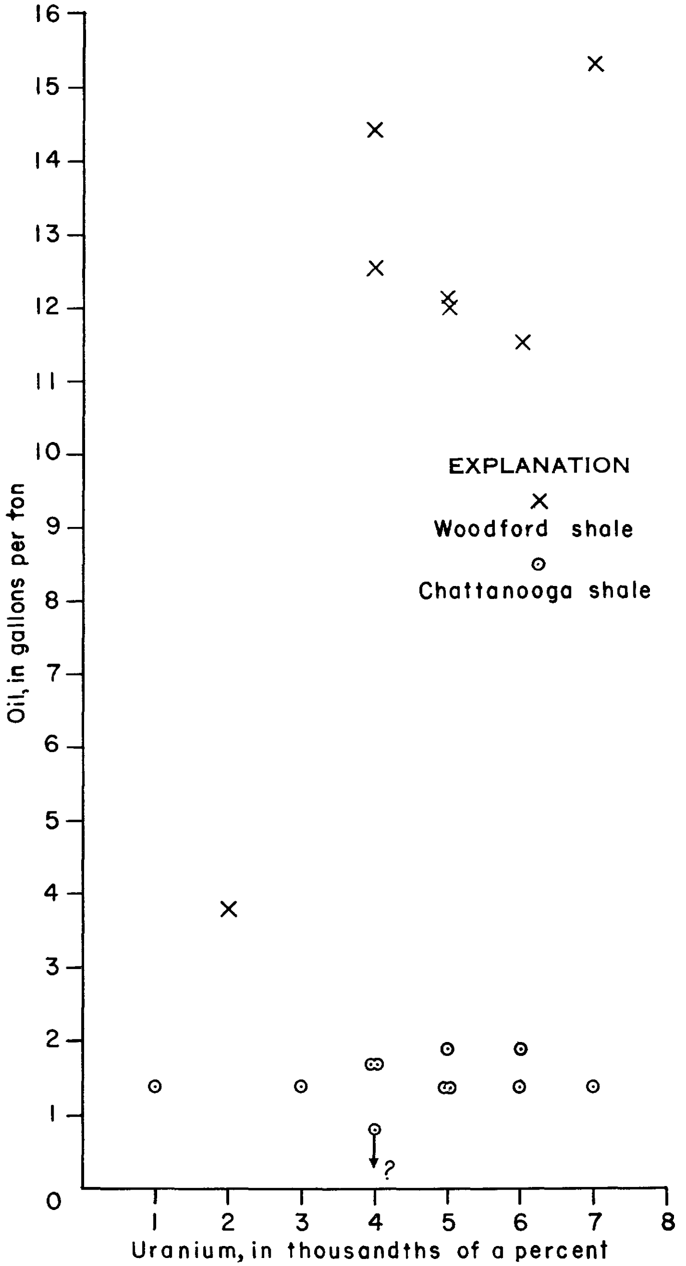

FIGURE 38.—Oil yield versus uranium content of Woodford and Chattanooga shales.

TABLE 5.—*Oil yield of samples from the Chattanooga and Woodford shales*

[Analyst: Wendell Tucker, U.S. Geological Survey. ND, not determined, insufficient oil]

Sample	Oil (gallons per ton)	Specific gravity of oil	Water (gallons per ton)	Percent gas and loss	Percent uranium
Chattanooga shale (loc. 20)					
147172	1.7	ND	4.3	4.0	0.004
147173	1.9	ND	4.3	2.0	.005
147174	1.4	ND	5.3	1.5	.005
147175	1.9	ND	5.3	.5	.006
147176	1.4	ND	5.3	3.5	.007
147177	1.4	ND	5.8	2.5	.006
147178	1.7	ND	6.2	1.5	.004
147179	1.4	ND	5.3	1.0	.005
147180	<1.0	ND	6.0	1.0	.004
147374	1.4	ND	4.3	.5	.001
147375	1.4	ND	4.8	2.5	.003
Woodford shale (loc. 5)					
147205	15.3	1.014	7.2	2.5	0.007
147206	11.5	1.033	8.6	1.0	.006
147207	12.0	.996	7.2	3.0	.005
147208	14.4	.988	4.8	1.0	.004
147209	12.0	.991	7.2	1.5	.005
147210	3.8	ND	10.5	2.0	.002
147211	12.5	.984	5.3	2.0	.004

uranium content seem to indicate a positive relation. The specific gravity of the oil is generally higher in the samples that have larger uranium contents. Many more data would be necessary to confirm this relation.

PHOSPHATIC MATERIAL

Twenty-seven samples (table 6) were analyzed to determine the P_2O_5 content of various parts of the rock units that were sampled; 8 of the samples are shale that was selected to obtain data on the range of P_2O_5 content and for comparison with the P_2O_5 content of phosphatic nodules or other phosphatic material; 12 samples of phosphatic nodules and 7 samples of other phosphate-bearing rock, mainly sandstone, were analyzed for comparison of the phosphate and uranium content. Also shown for comparison on table 6 are analyses supplied by V. E. Swanson of six samples of phosphatic nodules from the Chattanooga shale of Tennessee.

A graphic representation of the P_2O_5 content versus the uranium content of the samples listed in table 6, by rock type, is shown on figure 40. In general, within each of the four groups of samples, the samples with larger phosphate content also have a larger uranium content and the same relation holds for all the samples when considered in total.

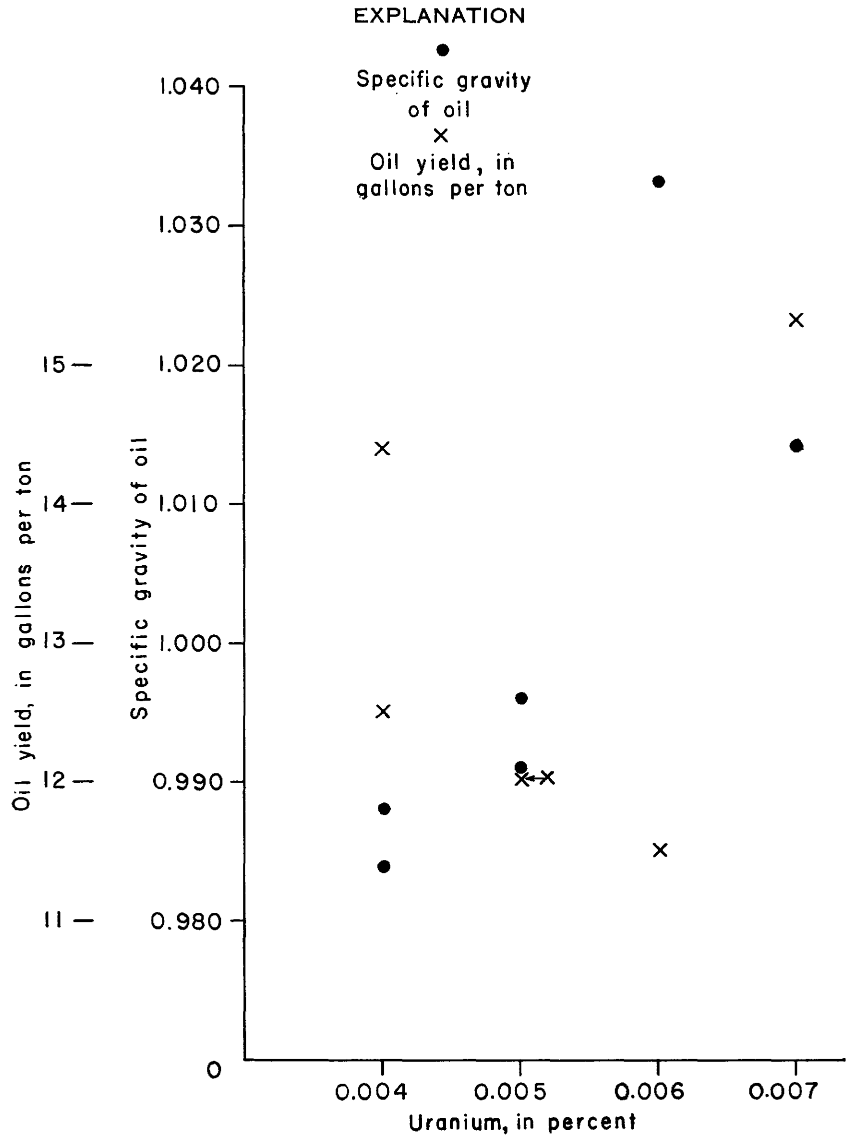

FIGURE 39.—Specific gravity of oil and oil yield versus uranium content of samples of the Woodford shale.

Ten of the samples listed on table 6 were submitted for identification (by X-ray methods) of the minerals comprising the rocks (table 7). All samples contained apatite plus quartz except sample 147334, in which pyrite and "possibly dolomite" were also identified.

Semiquantitative spectrographic analyses (table 8) of the same 10 samples of phosphate-bearing rock indicate a rather uniform minor-

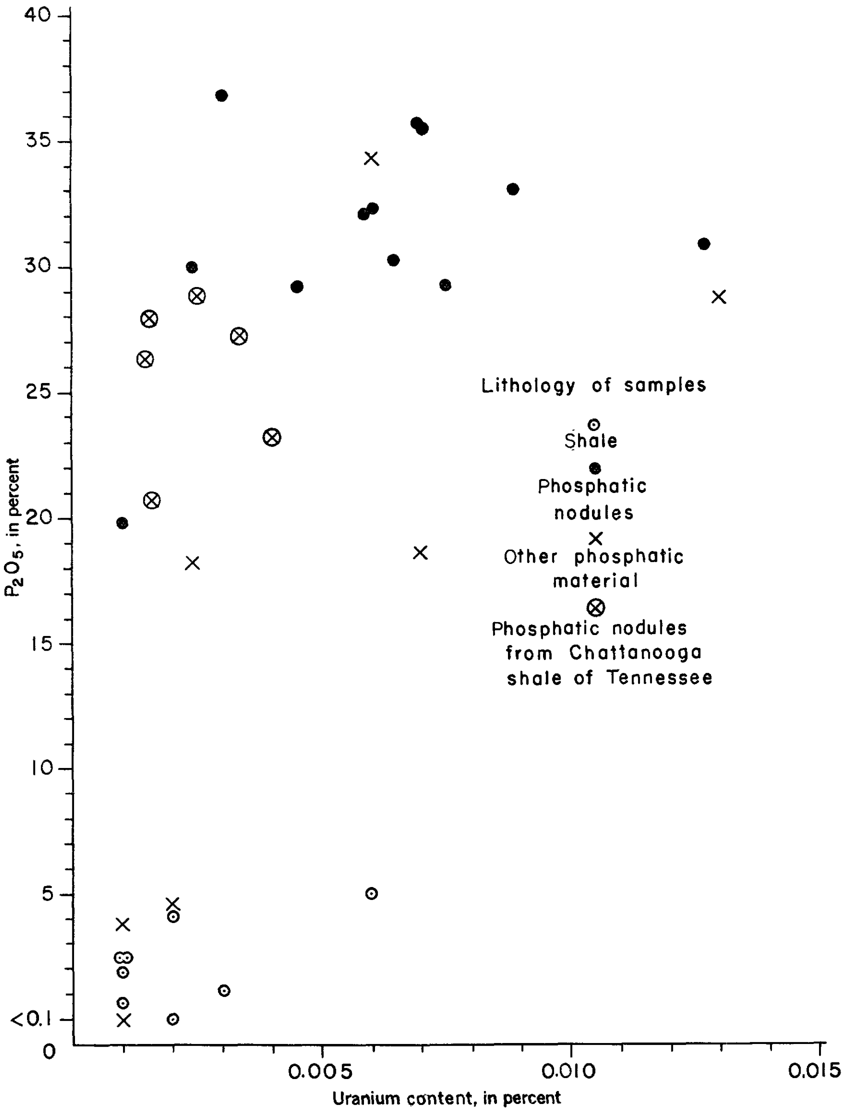

FIGURE 40.—Phosphate content versus uranium content

element composition with the exception of the rare-earth content of four of the samples. These samples, Nos. 147339, 147335, 147333, and 147336, contain relatively large amounts of both cerium-earth elements (cerium, neodymium, lanthanum, samarium, and praseodymium) and the yttrium-earth elements (yttrium, gadolinium, dysprosium, ytterbium, erbium, holmium, terbium, lutecium, and thulium) as compared to the other six samples. A plot of the total

TABLE 6.—*Phosphate content of selected samples*

[Analysts: Joseph Budinsky and Grafton Daniels, U.S. Geological Survey]

Sample (field)	Locality	Percent P_2O_5	Percent equivalent uranium	Percent uranium	Remarks	
					Formation	Rock type
147383	2	4.1	0.003	0.002	Woodford shale	Black shale.
147384	5	2.5	.002	.001	do	Gray shale.
147385	12	1.9	.002	.001	Caney shale	Greenish-gray shale.
147386	12	2.5	.001	.001	Woodford chert	Black shale.
147387	12	.7	.001	.001	do	Do.
147345	20	<.1	.003	.002	Chattanooga shale	Do.
147346	36	5.1	.006	.006	Sylamore sandstone member of Chattanooga shale.	Greenish-gray shale from same unit as 147422.
147347	36	1.2	.004	.003	do	Greenish-gray shale.
147515	2	36.8	.002	.003	Woodford shale	Phosphatic nodules from same unit as 147388 (table 1).
147332	2	35.8	.007	.0069	do	Phosphatic nodules from unit sampled as 147383.
147333	5	32.1	.008	.0058	do	Phosphatic nudules from unit sampled as 147384.
147341	9	29.3	.007	.0075	do	Phosphatic nodules.
147342	9	30.9	.014	.0127	do	Do.
147517	8	19.9	.002	.001	do	Phosphatic nodules from unit sampled as 147354 (table 1).
147335	12	30.3	.006	.0064	Woodford chert	Phosphatic nodules from same unit as 147389 (table 1).
147336	12	30.0	.003	.0024	Caney shale	Phosphatic nodules from unit sampled as 147385.
147337	12	29.2	.005	.0045	Woodford chert	Phosphatic nodules from unit sampled as 147386.
147338	12	32.3	.008	.0060	do	Phosphatic nodules from unit sampled as 147387.
147421	12	35.6	.006	.007	do	Phosphatic nodules from same unit as 147215 (table 1).
147339	20	33.1	.007	.0088	Chattanooga shale	Phosphatic nodules from unit sampled as 147524.
147334	5	18.4	.004	.0024	Woodford shale	Phosphatic pyritiferous bed about 1 in. thick.
147519	20	<.1	.001	.001	Chattanooga shale	Cone-in-cone limestone lens.
147393	20	28.8	.013	.013	Sylamore sandstone member of Chattanooga shale.	Phosphatic shaly sandstone.
147524	20	3.8	.001	.001	do	Do.
147523	20	34.4	.006	.006	do	Phosphatic material from 147524.
147422	36	18.7	.007	.007	do	Sandstone from same unit as 147346.
147423	36	4.7	.002	.002	do	Sandstone.
101946		28.0		.0016	Upper unit of the Gassaway member of the Chattanooga shale in southwestern Putnam County, Tenn.	Phosphatic nodules.
101947		26.3		.0014	Upper unit of the Gassaway member of the Chattanooga shale in east-central Smith County, Tenn.	Do.
101948		28.9		.0025	do	Do.
103637		20.8		.0017	Upper unit of the Gassaway member of the Chattanooga shale in western Putnam County, Tenn.	Do.
103638		23.2		.0040	do	Do.
103639		27.3		.0033	do	Do.

TABLE 7.—*Mineral composition of selected samples of phosphate-bearing rock*

[X-ray diffraction analyses by S. Rubenstein, U.S. Geological Survey]

Sample	Locality	Mineral identification	Sample	Locality	Mineral identification
147342	9	Apatite plus quartz.	147333	5	Apatite plus quartz.
147339	20	Do.	147337	12	Do.
147341	9	Do.	147336	12	Do.
147332	2	Do.	147334	5	Apatite, quartz, pyrite, and possibly dolomite.
147335	12	Do.			
147338	12	Do.			

rare-earth-element content (as approximated by summation of the series figures of the semiquantitative spectrographic analyses) versus the uranium content (fig. 41) indicates a positive relation of the rare-earth content with the uranium in all of the samples except the four with the relatively large rare-earth contents.

The rare-earth elements are known to substitute for calcium in minerals of the apatite group (Goldschmidt, 1954, p. 314) and uranium has been shown to replace calcium in the apatite structure (McKelvey and others, 1955, p. 523). Evidently the positive relation of uranium and rare-earth elements in the phosphate-bearing rocks analyzed for this report is not a direct relation per se, but is probably a reflection of a negative direct relation of both uranium and rare-earth elements with calcium.

The four samples with the relatively large rare-earth content that do not imply a uranium-rare-earth correlation may indicate that some other environmental factors, such as pH or carbonate-ion concentration (Neuman and others, 1949, p. 347), favored the absorption of rare-earth elements by the phosphatic material rather than absorption of uranium.

LIMESTONE

Four samples of limestones, 3 from the Woodford shale and 1 from the Chattanooga shale, were submitted for semiquantitative spectrographic analyses (table 9). The Woodford samples are from 2 limestone lenses or concretions at locality 7 (fig. 32 and table 1). All 3 have a radioactivity of 0.005 percent equivalent uranium but only 1 sample is in equilibrium; the other 2 contain only 0.001 percent uranium. It is possible that uranium has been removed during weathering of these rocks, though at the time of collection sample 147528 appeared to be less weathered than sample 147527. The limestone concretions contain relict carbonaceous matter similar to that in the black shale of the Woodford. The uranium is probably confined to the carbonaceous matter, and is not in the calcite which is the main constituent of the concretionary limestone. The analyses suggest that the sample with the larger uranium content also contains more cobalt, copper, molybdenum, and nickel, but the number of samples and small element range involved do not allow even tentative conclusions to be made. The Chattanooga sample, 147529, was collected from a dark-gray to black limestone lens with cone-in-cone structure.

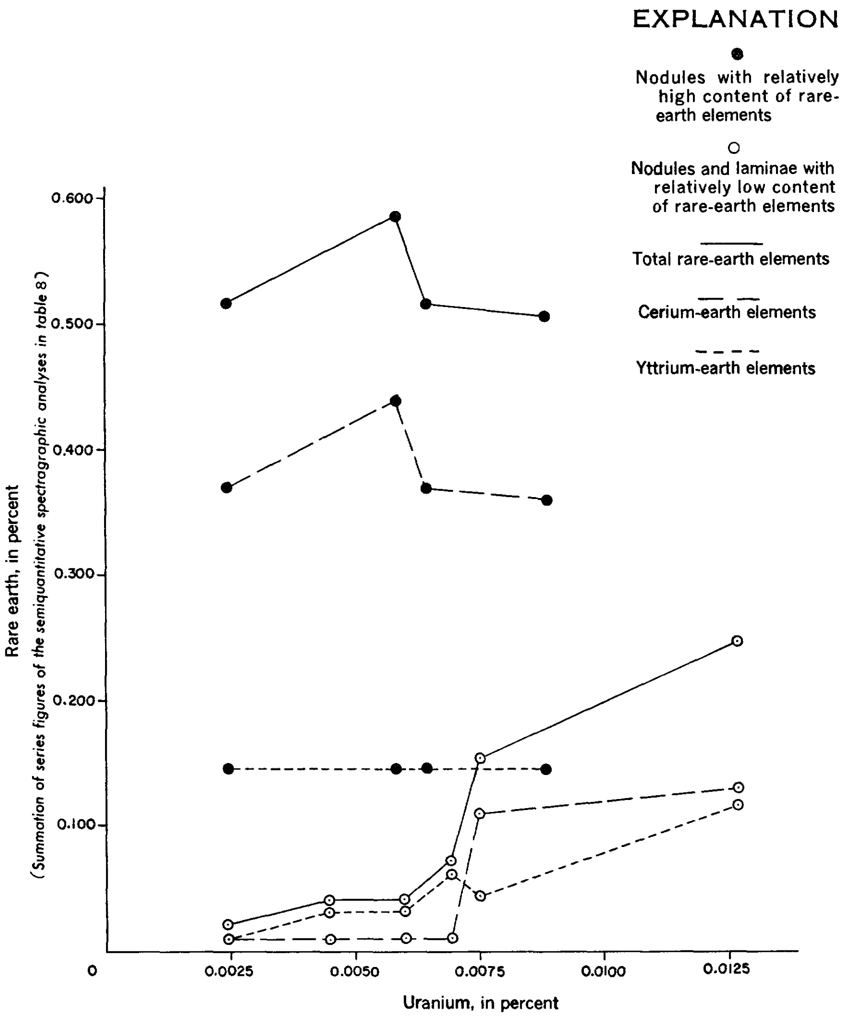

FIGURE 41.—Rare-earth-element content versus uranium content in phosphatic material.

TABLE 8.—*Trace-elements composition of phosphatic nodules and lenses*

[See table 1 for description of samples. Semiquantitative spectrographic analyses by Charles Annell, U.S. Geological Survey; uranium and P_2O_5 contents determined chemically (see table 6). Figures are reported to the nearest number in the series 10, 3, 1, 0.3, in percent; 80 percent of the reported results may be expected to agree with the results of quantitative methods. M indicates element is a major constituent, greater than 10 percent; 0 indicates element looked for but not found. Other elements listed in table 3 were also looked for but not found in concentrations equal to or larger than the concentrations listed in the table]

Sample	Locality	Si	Al	Fe	Mg	Ca	Na	Ti	P	Mn	Ag	B	Ba	Be	Cd	Ce	Cr	Cu	Dy
147342	9	3.0	1.0	1.0	0.03	M	0.1	0.01	M	0.003	0.001	0	0.03	0.0003	0	0.1	0.003	0.01	0.01
147339	20	1.0	1.0	1.0	.3	M	.1	.1	M	.001	.0001	0	.01	0	0	.3	.01	.03	.01
147341	9	3.0	1.0	1.0	.03	M	.1	.01	M	.003	.0003	0	.03	.0001	0	.1	.003	.01	.01
147332	2	3.0	1.0	.3	.03	M	.03	.03	M	.003	.0001	0	.03	.0001	0	0	.01	.003	0
147335	12	3.0	1.0	.3	.03	M	.1	.01	M	.001	0	0	1.0	.0001	0.01	.3	.01	.01	.01
147338	12	3.0	1.0	3.0	.01	M	.1	.01	M	.001	.0003	0	.1	.0001	0	0	.003	.003	0
147333	5	3.0	1.0	1.0	.1	M	.3	.03	M	.003	0	0.003	.03	0	0	.3	.01	.003	.01
147337	12	10.0	.3	1.0	.03	M	.1	.01	M	.001	.0003	0	.1	.0001	0	0	.003	.003	0
147336	12	10.0	1.0	1.0	.1	M	.1	.01	M	.001	0	.003	.3	.0001	.01	.3	.01	.01	.01
147334	5	3.0	1.0	3.0	1.0	M	.3	.03	M	.01	.0001	0	.03	0	0	0	.01	.01	0

Sample	Locality	Er	Gd	Ho	La	Mo	Nd	Ni	Pb	Sc	Sr	Sm	V	Y	Yb	Zn	Zr	U	P_2O_5
147342	9	0.003	0	0.001	0.01	0.01	0.01	0.01	0.001	0.01	0.3	0.01	0.01	0.1	0.003	0.01	0.01	0.0127	30.9
147339	20	.003	0.03	.001	.03	.003	.03	.01	.003	.003	.03	0	.003	.1	.001	.1	.003	.0088	33.1
147341	9	.003	0	0	.01	.003	0	.01	.001	.01	.3	0	.01	.03	.001	.01	.01	.0075	29.3
147332	2	0	.03	0	.01	.003	0	.01	.001	.003	.3	0	.01	.03	.001	.01	.001	.0069	35.8
147335	12	.003	.03	.001	.03	.003	.03	0	.001	.003	.1	.01	.01	.1	.003	0	.001	.0064	30.3
147338	12	0	0	0	.01	.003	0	0	.001	.003	.03	0	.003	.03	.001	0	.001	.0060	32.3
147333	5	.003	.03	.001	.1	0	.03	.003	.001	.003	.03	.01	.01	.1	.003	0	.003	.0058	32.1
147337	12	0	0	0	.01	.003	0	0	.001	.003	.1	0	.003	.03	.001	0	.001	.0045	29.2
147336	12	.003	.03	.001	.03	.01	.03	0	.001	.003	.1	.01	.01	.1	.003	0	.001	.0024	30.0
147334	5	0	0	0	.01	.003	0	.01	.001	0	.1	0	.01	.01	.0003	0	.001	.0024	18.4

TABLE 9.—*Trace-elements composition of limestone samples from the Woodford and Chattanooga shales*

[See table 1 for description of samples. Semiquantitative spectrographic analyses by Mona Frank, U.S. Geological Survey. Percentages are coded as follows:

Percent	*Code*	*Percent*	*Code*	*Percent*	*Code*	*Percent*	*Code*	*Percent*	*Code*
>10	17	1 -2	14	0.1 -0.2	11	0.01 -0.02	8	0.0005 -0.001	4
5-10	16	.5-1	13	.05- .1	10	.005- .01	7	.0002 - .0005	3
2- 5	15	.2- .5	12	.02- .05	9	.002- .005	6	.0001 - .0002	2
						.001- .002	5	.00005- .0001	1

About 50 percent of these results may be expected to be accurately bracketed in these subdivisions of the orders of magnitude. 0 indicates element looked for but not found. Other elements listed in table 3 were also looked for but not found in concentrations equal to or larger than the concentrations listed in the table]

Sample	Locality	Si	Al	Fe	Mg	Ca	Na	K	Ti	Mn	Ag	B	Ba	Co	Cr
147527	7	16	14	15	12	17	11	13	10	9	2	8	8	7	6
147528	7	16	14	14	13	17	11	13	10	9	1	8	8	6	6
147526	7	16	14	13	12	17	11	13	10	8	2	8	8	5	6
147529	20	16	14	13	12	17	10	13	10	11	2	8	8	5	6

Sample	Locality	Cu	Ga	La	Mo	Ni	Sc	Sn	Sr	V	Y	Yb	Zr	U [1]
147527	7	8	6	7	6	9	5	5	7	8	7	4	5	0.005
147528	7	6	6	7	5	8	5	5	8	8	7	4	5	.001
147526	7	7	6	8	5	8	5	5	7	9	6	3	5	.001
147529	20	5	6	6	5	7	5	5	9	8	6	3	5	<.001

[1] Uranium content determined chemically and shown in percent (see table 1).

METANOVACULITE

Semiquantitative spectrographic analyses of three samples of metamorphosed novaculite from the Arkansas novaculite near Potash Sulphur Springs, Garland County, Ark., are shown on table 10. All samples were collected near the western edge of the Potash Sulphur Springs intrusive body, which is composed of alkalic igneous rocks that have intruded the sedimentary rocks of the area (Fryklund and others, 1954, p. 51). Sample 147426 is a highly altered novaculite that consists largely of sinterlike red to black iron oxide minerals; sample 147425 is novaculite that contains a large quantity of red iron oxides in the interstices; and sample 147427 is novaculite that contains a very minor amount of visible iron minerals. The analyses indicate a relatively large tungsten and niobium (columbium) content for all three samples. Rankama and Sahama (1950, table 2.3) show the abundance of tungsten in igneous rocks to be 1.5 to 69 parts per million and niobium to be 24 parts per million. The abundance of these elements in sedimentary rocks is relatively unknown. The analyses also suggest that the sample (147426) containing 0.027 percent uranium contains more titanium, manganese, barium, cerium, cobalt, chromium, lanthanum, niobium, neodymium, nickel, lead, strontium, vanadium, yttrium, zinc, and zirconium, and contains less silica, magnesium, copper, and tin than the samples with less than 0.001 percent uranium. Some of these apparent relative differences are probably coincidental and might not be substantiated by quantitative analyses of a larger number of samples. Niobium and tungsten are characteristic of pneumatolytic metamorphism and many of the other elements are commonly deposited during the pneumatolytic and hydrothermal phases of pyrometasomatism. It is possible that during or following the emplacement of the Potash Sulphur Springs intrusive, liquids and (or) gases carrying an assemblage of elements, including niobium, uranium, and tungsten, were introduced into the sedimentary rocks.

TABLE 10.—*Trace-elements composition of metanovaculite from the Arkansas novaculite*

See table 1 for description of samples. Semiquantitative spectographic analyses by Mona Frank, U.S. Geological Survey. Percentages are coded as follows:

Percent	*Code*	*Percent*	*Code*	*Percent*	*Code*	*Percent*	*Code*	*Percent*	*Code*
>10	17	1 -2	14	0.1 -0.2	11	0.01 -0.02	8	0.0005 -0.001	4
5-10	16	.5-1	13	.05- .1	10	.005- .01	7	.0002 - .0005	3
2- 5	15	.2-0.5	12	.02- .05	9	.002- .005	6	.0001 - .0002	2
						.001- .002	5	.00005- .0001	1

About 50 percent of these results may be expected to be accurately bracketed in these subdivisions of the orders of magnitude. 0 indicates element looked for but not found. Other elements listed in table 3 were also looked for but not found in concentrations equal to or larger than the concentrations listed in the table.

Sample	Locality	Si	Al	Fe	Mg	Ca	Ti	Mn	Ag	B	Ba	Be	Ce	Co	Cr	Cu	La
147426	46	16	12	17	6	8	11	11	2	8	12	1	11	6	7	9	10
147425	46	17	11	17	6	0	9	8	2	8	9	1	9	5	6	9	6
147427	46	17	13	13	8	8	9	8	0	7	8	1	9	5	6	10	0

Sample	Locality	Mo	Nb	Nd	Ni	Pb	Sc	Sn	Sr	V	W	Y	Yb	Zn	Zr	U[1]
147426	46	6	11	7	8	9	5	6	10	11	10	7	4	8	8	0.027
147425	46	8	7	0	7	5	5	6	5	9	10	6	4	7	6	<.001
147427	46	5	6	0	7	5	5	7	5	8	10	6	3	0	4	<.001

[1] Uranium content determined chemically and shown in percent (see table 1).

ORIGIN OF THE URANIUM

The form in which uranium is included in marine black shales has been under investigation for a number of years. As yet no definite conclusion has been reached, but there is little doubt that most of the uranium found in marine black shales is of syngenetic or penecontemporaneous origin; that is, the uranium was deposited at about the same time as the other sediment that was subsequently lithified to shale, or was deposited in the sediment after deposition but prior to compaction and burial. It is probable that both of these processes were operative and it is difficult to assign a dominant role to either.

Laboratory investigations of the uranium in the Chattanooga shale of Tennessee indicate that: (a) the uranium exists largely as a colloidal phase dispersed through the organic matrix; (b) at present, most of the uranium is not combined with the organic matter nor with the mineral matter; (c) the uranium in the shale was probably derived from the Chattanooga sea by reduction of the uranyl ion to uranium dioxide (Deul, 1957, p. 218). Bates and others (1956, p.

100–101) found by statistical analysis of their analytical data on the Chattanooga shale of Tennessee that

> although the number of grams of uranium per ton of rock depends on the relative amounts of carbon, silicates, pyrite, and "free iron" (HCl soluble), it is only the carbon and free iron which are direct measures of the conditions which promote (reduction) or discourage (oxidation) the precipitation and preservation of the uranium. In the overall picture the silicates and pyrite act only as diluents.

The uranium contained in the highly uraniferous Chattanooga shale at locality 33 in Marion County, Ark., may be associated with the organic matter in the same manner as the uranium in the shales. The samples from this locality contain more lead, silver, and cobalt, and may contain slightly more zinc, nickel, and strontium than the other Chattanooga samples (table 2). A short distance from the uraniferous shale outcrop, zinc ore was formerly mined from the underlying Everton formation and the Powell dolomite of Ordovician age. The fact that uranium has not been reported to be a constituent of the zinc and lead deposits of north-central Arkansas plus the fact that lead, silver, cobalt, zinc, nickel, and strontium are known to be enriched in organic substances indicates that the uranium is probably of syngenetic or penecontemporaneous origin.

The uranium contained in the phosphatic material in the Chattanooga and Woodford shale is probably of syngenetic or penecontemporaneous origin and was absorbed by minerals of the apatite group from sea water during deposition of the shale and prior to burial and compaction.

CONCLUSIONS

The rocks of Late Devonian and Early Mississippian age that were examined in the report area have a range of uranium content from less than 0.001 to 0.55 percent uranium, but generally contain about 0.001 to 0.002 percent uranium. Radioactivity is generally on the order of 0.002 to 0.004 percent equivalent uranium. The black and dark-gray shales are more radioactive and uraniferous than the other rock types associated with them, with the exception of phosphatic nodules and other phosphate-bearing rocks, mostly sandstones, that are present in minor quantities in some of the rock units. At one locality, selected samples of small parts of the Chattanooga shale contain as much as 0.55 percent uranium, but the quantity of rock of such grade is too small to be of economic interest. Large quantities of shale, containing 0.004 to 0.005 percent uranium in intervals as much as 20 feet thick are present in the Woodford and Chattanooga shale. If low-grade shale should ever become of economic interest, the Woodford shale would be better suited for large-scale utilization than the Chattanooga because its thickness and nonresistant character generally result in a wide relatively flat outcrop area suitable for strip or open-pit mining. In contrast, the Chattanooga shale is generally overlain by thick cliff-forming rock units and usually crops out in a narrow band near the base of high bluffs.

Semiquantitative spectrographic analyses indicate that there are minor elemental composition differences between the shales of the Woodford and Chattanooga shale and the Arkansas novaculite. Relative-abundance diagrams show that most samples from the Woodford shale contain less aluminum, magnesium, potassium, titanium, and zirconium, and more copper and silver, than do the samples from the Chattanooga shale and Arkansas novaculite. The shale samples analyzed for this report contain considerably more copper, more gallium, nickel, and vanadium, considerably less zirconium, and less strontium than the pelitic-rock mean derived by Shaw (1954), but they agree with Shaw's figures for the elements cobalt, chromium, lead, scandium, and yttrium.

Selected shale samples were analyzed for organic-carbon content and oil yield. The specific gravity was determined for those samples with a large enough oil yield. There is a suggestion of a positive relation of the organic-carbon content with the uranium content of the samples but the relation is obscure because of a wide range of organic-carbon content compared to the uranium content. Six samples of the Woodford shale yielded enough oil for specific-gravity determination and there is a positive relation between the specific gravity of the oil and the uranium content of the samples. The number of samples is not enough to evaluate the relation, but in these particular samples the larger the uranium content, the higher the specific gravity of the oil.

The phosphatic nodules and other phosphate-bearing rocks that are present in the Woodford and Chattanooga shale contain as much as 0.013 percent uranium but generally contain 0.006 percent uranium or less. There is a suggestion of a general positive relation between the P_2O_5 and uranium contents of the samples but the range of P_2O_5 is so much larger than that of the uranium, it is concluded that there is not a simple direct relation. Other factors evidently enter into the system, the most important of which are probably differences in chemical and environmental conditions at, and subsequent to, the time of deposition. Semiquantitative spectrographic analyses of a small suite of samples of phosphatic material indicate that for most of the samples the rare-earth content increases with the uranium content. As both the rare-earth elements and uranium are known to substitute for calcium in the apatite structure, the indicated positive relation may be a reflection of a negative relation of both the rare earths and uranium with calcium. Some of the samples contain as much as 0.5 percent rare-earth elements, and these show no correlation between uranium and rare earths. If at a future date the phosphatic nodules or other phosphate-bearing rock in the Woodford and Chattanooga should become of economic interest for the phosphate content, the uranium and rare-earth elements might be valuable byproducts.

REFERENCES CITED

Adams, G. I., and Ulrich, E. O., 1905, Description of the Fayetteville quadrangle, Arkansas–Missouri: U.S. Geol. Survey Geol. Atlas, Folio 119, 6 p.

Bates, T. F., and others, 1956, An investigation of the mineralogy, petrography, and paleobotany of uranium-bearing shales and lignites, 5th Ann. Rept., April 1, 1955, to March 31, 1956: U.S. Atomic Energy Comm. NYO–7411, 106 p., issued by U.S. Atomic Energy Comm., Tech. Inf. Service Ext., Oak Ridge, Tenn.

Cooper, C. L., 1939, Conodonts from a Bushberg-Hannibal horizon in Oklahoma: Jour. Paleontology, v. 13, no. 4, p. 379–422.

Deul, Maurice, 1957, Geochemistry of uranium-bearing shales, *in* Geologic investigations of radioactive deposits—Semiannual progress report for June 1, 1957 to November 30, 1957: U.S. Geol. Survey TEI–700, p. 213–224, issued by U.S. Atomic Energy Comm., Tech. Inf. Service Ext., Oak Ridge, Tenn.

Fryklund, V. C., Jr., Harner, R. S., and Kaiser, E. P., 1954, Niobium (columbium) and titanium at Magnet Cove and Potash Sulphur Springs, Ark: U.S. Geol. Survey Bull. 1015–B, p. 23–57.

Goldschmidt, V. M., 1954, Geochemistry: London, Oxford Univ. Press, 730 p.

Gordon, Mackenzie, Jr., and Kinney, D. M., 1944, Geologic map and structure sections of the Batesville district, Independence County, Ark.: U.S. Geol. Survey Oil and Gas Inv. Prelim. Map 12.

Griswold, L. S., 1892, Whetstones and novaculites of Arkansas: Arkansas Geol. Survey Ann. Rept., 1890, v. 3, 443 p.

Hamm, W. E., 1955, Stratigraphy and structure of the Arbuckle Mountain region, *in* Oklahoma Geol. Survey Guidebook 3, Geology of the Arbuckle Mountain region: p. 28–35.

Hass, W. H., 1950, Age of lower part of Stanley shale: Am. Assoc. Petroleum Geologists Bull., v. 34, p. 1578–1584.

——— 1951, Age of Arkansas novaculite: Am. Assoc. Petroleum Geologists Bull., v. 35, p. 2526–2541.

——— 1956a, Conodonts from the Arkansas novaculite, Stanley shale, and Jackfork sandstone [Arkansas–Oklahoma], *in* Ardmore Geol. Soc. Guidebook, Ouachita Mountain Field Conf., 1956: p. 25–33.

——— 1956b, Age and correlation of the Chattanooga shale and the Maury formation: U.S. Geol. Survey Prof. Paper 286, 47 p.

——— 1959, Conodonts from the Chappel limestone of Texas: U.S. Geol. Survey Prof. Paper 294–J, p. 365–399.

Hayes, C. W., 1891, The overthrust faults of the southern Appalachians: Geol. Soc. America Bull., v. 2, p. 141–154.

Hendricks, T. A., Gardner, L. S., Knechtel, M. M., and Averitt, Paul, 1947, Geology of the western part of the Ouachita Mountains, Oklahoma: U.S. Geol. Survey Oil and Gas Inv. Prelim. Map 66.

Hillebrand, W. F., Lundell, G. E. F., Bright, H. A., and Hoffman, J. I., 1953, Applied inorganic analysis: New York, John Wiley & Sons, 1034 p.

Honess, C. W., 1923, Geology of the southern Ouachita Mountains of Oklahoma: Oklahoma Geol. Survey Bull. 32, pt. 1, 278 p.

Huffman, G. G., 1958, Geology of the flanks of the Ozark uplift: Oklahoma Geol. Survey Bull. 77, 281 p.

Landis, E.R., 1955, Midcontinent Devonian shale, *in* Geologic investigations of radioactive deposits—Semiannual progress report, June 1, 1955 to November 30, 1955: U.S. Geol. Survey TEI–590, p. 249–252, issued by U.S. Atomic Energy Comm., Tech. Inf. Service Ext., Oak Ridge, Tenn.

McKelvey, V. E., Everhart, D. L., and Garrels, R. M., 1955, Origin of uranium deposits: Econ. Geology, 50th Anniversary Volume, 1905–1955, pt. 1, p. 464–533.

McKnight, E. T., 1935, Zinc and lead deposits of northern Arkansas: U.S. Geol. Survey Bull. 853, 311 p.

Maher, J. C., and Lantz, R. J., 1953, Geology of the Gilbert area, Searcy County, Ark.: U.S. Geol. Survey Oil and Gas Inv. Map OM 132.

Miser, H. D., 1917, Manganese deposits of the Caddo Gap and De Queen quadrangles, Arkansas: U.S. Geol. Survey Bull. 660–C, p. 59–122 [1918].

——— 1944, Devonian system in Arkansas and Oklahoma: Illinois Geol. Survey Bull. 68, p. 132–138.

——— 1954, Geologic map of Oklahoma: U.S. Geol. Survey map.

Miser, H. D., and Purdue, A. H., 1929, Geology of the De Queen and Caddo Gap quadrangles, Arkansas: U.S. Geol. Survey Bull. 808, 195 p.

Mississippian Subcommittee, Geological Society of America, 1948, Correlation of Mississippian formations of North America: Geol. Soc. America Bull., v. 59, p. 91–196.

Neuman, W. F., Neuman, M. W., Main, E. R., and Mulryan, B. J., 1949, The deposition of uranium in bone; pt. 6, Ion competition studies: Jour. Biol. Chemistry, v. 179, p. 341–348.

Purdue, A. H., 1909, The slates of Arkansas: Arkansas Geol. Survey, 170 p.

Rankama, Kalervo, and Sahama, T. G., 1950, Geochemistry: Chicago, Ill., Chicago Univ. Press, 911 p.

Russell, W. L., 1944, The total gamma ray activity of sedimentary rocks as indicated by Geiger counter determinations: Geophysics, v. 9, p. 180–216.

——— 1945, Relation of radioactivity, organic content, and sedimentation: Am. Assoc. Petroleum Geologists Bull., v. 29, p. 1470–1493.

Shaw, D. M., 1954, Trace elements in pelitic rocks; Pt. I, Variation during metamorphism, Pt. II, Geochemical relations: Geol. Soc. America Bull., v. 65, no. 12, pt. 1, p. 1151–1182.

Stanfield, K. E., and Frost, I. C., 1949, Method of assaying oil shale by a modified Fischer retort: U.S. Bur. Mines Rept. Inv. 4477, 13 p.

Swanson, V. E., 1955, Midcontinent Devonian shales, *in* Geologic investigations of radioactive deposits—Semiannual progress report for December 1, 1954, to May 31, 1955: U.S. Geol. Survey TEI–540, p. 169–170, issued by U.S. Atomic Energy Comm., Tech. Inf. Service Ext., Oak Ridge, Tenn.

Taff, J. A., 1902, Geology of the Atoka quadrangle, Oklahoma: U.S. Geol. Survey Geol. Atlas, Folio 79, 8 p.

Tarr, W. A., 1938, Exhibit A, Terminology of the chemical siliceous sediments: Rept. of Committee on Sedimentation, Natl. Res. Council Ann. Rept. 1937–38, p. 8–27.

Tulsa Geological Society Guidebook, 1947, Field conference in western part of the Ouachita Mountains in Oklahoma: Tulsa, Okla., Tulsa Geol. Soc., 56 p.

INDEX