

URANIUM IN THE CHATTANOOGA SHALE OF EASTERN TENNESSEE

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ABSTRACT

The Chattanooga shale contains in places sufficient uranium to make it a potential low-grade ore. The most promising areas are the Eastern Highland Rim in Tennessee, between the Alabama State line and approximately the latitude of Smithville, and the Walden Ridge area east of the Sequatchie Valley, Tenn.

The Chattanooga shale in this area is of late Devonian age and is divided into the Dowelltown and Gassaway members. The Dowelltown, or lower, member is of no present interest as a source of uranium, only the Gassaway member being considered a potential source. The Gassaway member includes three units: a lower black shale 3.5 to 10.5 feet thick and averaging 7 feet; a middle unit composed predominantly of black shale, with minor thin beds of gray shale, averaging about 2.5 feet thick and thinning eastward; and an upper black shale from 2 to 8 feet thick and averaging 6 feet. In the Eastern Highland Rim the total thickness of the Gassaway ranges from 13.5 to 18.5 feet; the average is 16 feet in the Eastern Highland Rim. In Walden Ridge the range is 10 to 17 feet; the average is 14 feet.

The black shale units of the Chattanooga are nearly massive in appearance and the rock breaks with a conchoidal fracture, but weathered outcrops show a marked fissility and a thin coating of iron oxide. Data from many outcrops and drill holes show that the Gassaway as a whole contains from 0.005 to 0.008 percent uranium. The highest average uranium content is in the upper unit; the lowest content is in the middle unit. The lower unit is of intermediate grade.

The lateral distribution of uranium in each unit of the Gassaway in eastern Tennessee is remarkably uniform, though it is somewhat higher than average in an area southeast of Smithville, and in Walden Ridge.

No uranium minerals have been identified in the shale, and the form in which the element occurs is not now known. It is considered to be of syngenetic origin.

INTRODUCTION

The uraniferous Chattanooga shale is one of the bituminous shales of Late Devonian and early Mississippian age which were deposited over much of the central United States from New York to Texas. Over this wide region the shale sequence varies widely in lithology and thickness and is known by several formational names. The name Chattanooga is used for this bituminous shale sequence in a large area including Tennessee, Arkansas, and adjoining States.

Reconnaissance in 1942 around the Nashville dome, now a topographic basin, showed that the Chattanooga shale is much more radioactive than other rocks in the area. Investigations in 1947 and later showed that the most uraniferous shale is in the Eastern Highland Rim of Tennessee and in Walden Ridge north and west of the city of Chattanooga; the favorable area also may extend southward into Alabama. This report is therefore concerned with the roughly triangular region bounded on the southeast by the folded Appalachians of Tennessee and Alabama, and on the west by the axis of the Nashville dome. The northern boundary is somewhat indefinite but follows in a general way the route of Tennessee Highway 26 and U. S. Highway 70 from Smithville, through Crossville to the Cumberland escarpment south of Rockwood (fig. 159). South of that line, the Chattanooga shale is generally less than 35 feet thick; to the north it thickens rapidly.

The geologic investigation of the Chattanooga shale was in charge of L. C. Conant. His contributions to this report, and those of W. H. Hass, R. C. Robeck, and R. E. Smith, who assisted in the field work, are gratefully acknowledged.

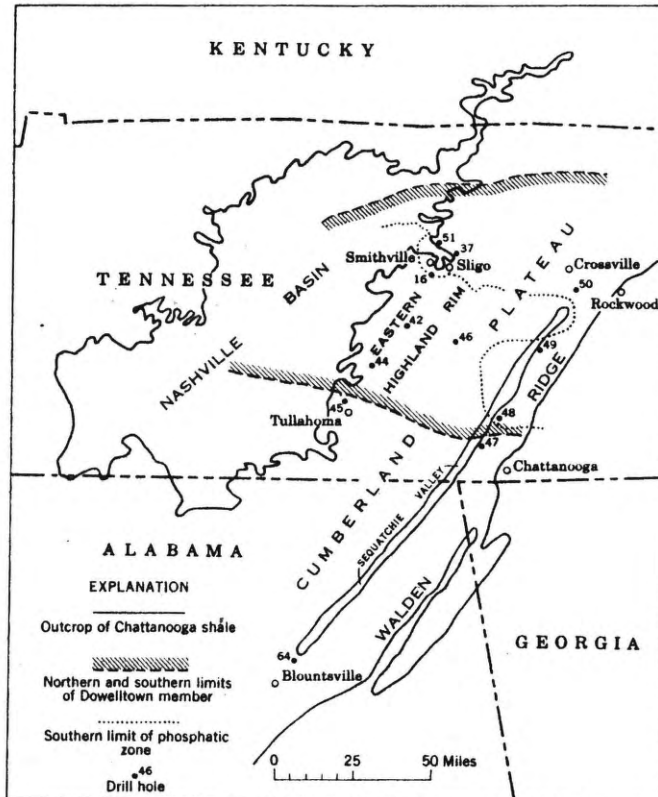


FIGURE 159.—Sketch map showing distribution of the most uraniferous part of the Chattanooga shale.

GEOGRAPHY AND TOPOGRAPHY

The Nashville Basin extends across the State of Tennessee in a northeasterly direction and is about 125 miles long and 60 miles wide. Structurally it is a domal part of the Cincinnati arch (Wilson, 1949, p. 407). The present lowland surface is about 500 feet above sea level and is underlain by bevelled limestones of Ordovician age. The Highland Rim is a topographic terrace, averaging about 25 miles in width, and surrounds the basin. The part east of the basin, known as the Eastern Highland Rim, rises 500 to 600 feet above the basin floor. The edge of the Highland Rim is highly dissected and many outcrops of the Chattanooga shale are well exposed. To the east of the rim the topography rises 900 to 1,000 feet to the Cumberland Plateau, which extends eastward to the folded rocks of the Tennessee River valley. The plateau is cut by the anticlinal Sequatchie River valley, parallel to and about 25 miles west of the edge of the Cumberland Plateau (fig. 159). East of the valley is Walden Ridge, a

shallow syncline of about the same height as the plateau in the western side of which the Chattanooga shale is exposed.

The Chattanooga shale underlies the Eastern Highland Rim, the Cumberland Plateau proper, and Walden Ridge and apparently has much the same composition and thickness throughout the entire region.

STRATIGRAPHY

In the Eastern Highland Rim the Chattanooga shale rests on the Leipers limestone of Late Ordovician age and in Walden Ridge on Silurian rocks. The shale was deposited on a very flat surface; the relief at the time was a few tens of feet (Wilson, 1949).

The Chattanooga shale is of Late Devonian age and consists of two members, the Dowelltown and Gassaway, each containing several units (Camp, 1946, p. 829-908.)

The Dowelltown member consists from oldest to youngest, of three units: basal sandstone, lower black unit, and middle gray unit.

The basal sandstone is a fine-grained conglomerate commonly 2 inches or less in thickness. The lower black unit is a tough, black, relatively thin-bedded bituminous shale that underlies part of the Eastern Highland Rim. It is absent south of Tullahoma north of a line about 20 miles south of the Kentucky-Tennessee State line (fig. 159). It was thus deposited in a trough about 75 miles wide, the eastern and western limits of which cannot now be determined. In the central part of this trough the lower black unit is only 6 to 7 feet thick, though thicknesses of 4 to 12 feet are known.

The middle gray unit is a series of interbedded gray and black shales forming the top of the Dowelltown member. Gray beds comprise about three-fourths of the unit; black beds, generally 2 inches thick or less, are abundant in the lower and upper thirds. A consistent 0.1-foot of bentonite near the top of the unit is a useful stratigraphic marker (Hass, 1948, p. 816-817). The thickest measured sections of the middle gray unit in the Eastern Highland Rim are about 12 feet thick and in Walden Ridge about 5 to 6 feet thick. Above the lower black unit, the middle gray unit thins to the north and south and is absent not far beyond the limits of the lower black unit.

The Gassaway member comprises, from oldest to youngest, four units: the middle black unit, upper sandstone, top black unit, and phosphatic zone. The middle black unit is a black, bituminous shale similar to the lower black unit of the Dowelltown member but somewhat thicker bedded. It is 7 to 8 feet thick near Sligo, but thins to the north, south, and possibly east

Overlying the middle black unit is the upper siltstone, a black shale sequence that contains a few thin beds of gray shale or siltstone. It is 2 to 3 feet thick in the vicinity of Smithville but thins to the west, south, and north. It has not been recognized south of Tullahoma. In Walden Ridge the gray beds, though recognizable in some drill cores, are hard to detect at the outcrops.

The top black unit of the Gassaway member is the most widespread and most uraniferous unit of the Chattanooga shale. It is darker than the other "black" units, and its outcrops are commonly massive. It is 4 to 10 feet thick. Local differences in thickness are interpreted as being due to local erosion of the top of the unit. This variation in thickness, together with paleontologic data (Hass, 1953), indicates a minor unconformity at the top of the Gassaway member south of Smithville and in Walden Ridge.

North of the Smithville-Rockwood line, at a few localities to the south, and in parts of Walden Ridge, the massive top black unit is overlain by somewhat lighter colored shales that contain scattered phosphatic nodules. The nodules are commonly about 1 inch in diameter but some are larger. The contact between the top black unit and the phosphatic zone is not sharp but can be detected in the field by the difference in color of the rocks and the presence or absence of the nodules.

In summary, the Chattanooga shale in the Eastern Highland Rim and Walden Ridge areas has a maximum thickness of about 35 feet. The Dowelltown member reaches a maximum thickness of about 18 feet; the Gassaway member ranges from 7 feet near Tullahoma to 18 feet near Smithville and from 11 to 21 feet in Walden Ridge.

The Chattanooga shale is immediately overlain by the soft, light-green shale of the Maury formation which weathers to yellow or brown. Locally, the base of the Maury in the northern part of the area is a 4-inch to 2-foot bed of large, flattened phosphatic nodules in black shale. Hass (1953), on the basis of its conodont fauna, considers this bed to be of latest Devonian age. He assigned the green shale, also from fossil evidence, to early Mississippian.

In the Eastern Highland Rim and Walden Ridge the Maury formation is from 1 to 3 feet thick. It is overlain by the Fort Payne chert, which forms cliffs along the Eastern Highland Rim and Walden Ridge.

STRUCTURE

The Chattanooga shale dips eastward from the axis of the Nashville dome to the Sequatchie Valley at the rate of about 30 feet to the mile. Folds in the monocline trend northeast and are of minor importance.

The highest observed local dips are about 5°. The one fault observed, though others are doubtless present, has cut out all but 3 feet of the Chattanooga shale by horizontal thrusting.

The monoclinical structure is broken along the west side of the Sequatchie Valley by the Sequatchie fault, overthrust from the southeast. The fault brings the Chattanooga shale, which is under about 2,000 feet of cover west of the valley, to the surface in its eastern escarpment, Walden Ridge. In the ridge the Chattanooga shale dips southeast at an average rate of about 8°, the maximum observed dip being 15°. All outcrops in Walden Ridge are fractured but cores from drill holes not far behind the outcrops show less disturbance of the rocks than the exposures would indicate.

COMPOSITION OF THE SHALE

The predominant components of all units of the Chattanooga shale are fine silt and clay particles, most of which could have been transported by either wind or water. The black units contain abundant pyrite and organic material (Rich, 1951, p. 2017-2040; Strahl, Silverman, O'Neill, and others, 1955), some in the form of plant debris but most as a translucent, yellow or brown material known as kerogen. The gray units contain much smaller quantities of carbonaceous matter and pyrite than do the black beds.

Analyses of two cores from drill holes about 5 miles apart between Smithville and Sligo (fig. 159) show that silicates make up the bulk of all units of the Chattanooga shale, and that pyrite and carbon are next in importance. The amounts of these constituents are shown below (Strahl, Silverman, O'Neill, and others, 1955):

Silicate, pyrite, and carbon content of the units of the Chattanooga shale, in percent

Unit	Silicates	Pyrite	Carbon	Total
Gassaway member:				
Top black unit.....	62	15	13	90
Upper siltstone.....	78	6	6	92
Middle black unit.....	69	8	13	90
Dowelltown member:				
Middle gray unit.....	80	4	4	88
Lower black unit.....	70	6	9	85

The amount of silica varies in indirect proportion to the amount of pyrite and carbon in all units, but particularly in those of the Gassaway member. The pyrite and carbon content of the upper siltstone in these cores probably is lower than it is in the Eastern Highland Rim as a whole, as the gray beds of the unit are best developed in the Smithville area.

Kerogen, which makes up much of the organic material in the shale, is derived largely from spores. In the lower part of the shale *Foerstia*, a planktonic marine algae, is common, and rarely a large algal plant,

Prototaxites, has been found. The most common woody material, both silicified and as bituminous coaly streaks, is drift wood of *Callixylon*. Most of the uranium-rich stringers formerly identified as asphaltite are now known to be *Callixylon* fragments (Schopf, 1953, p. 146-152).

Semiquantitative spectrographic analyses of three cores of the total thickness of the Chattanooga shale and 15 cores across the Gassaway member show that the chemical composition of the shale is fairly constant, both vertically and laterally, from northeast of Smithville (holes 37 and 51, fig. 159) to the vicinity of Blountsville, Ala. (hole 64, fig. 159) and in Walden Ridge (holes 48 to 50, fig. 159). The amount of the following elements is in percent:

ONE-MAGNITUDE RANGE					
0.0001-0.001	0.001-0.01	0.01-0.1	0.1-1.0	1.0-10.0	10+
Be, Yb	Zr, Ga, Y	Cu, B	Tl	Fe	Si
TWO-MAGNITUDE RANGE					
0.0001-0.01	0.001-0.1	0.01-1.0	0.1-10	1.0-10	
Sc, Ag	Pb, Cr, Co, V, Sr, Mn, Ni, La, Sn	Ba	Mg, Na, Ca, K	Al	

The abundance of cobalt, molybdenum, and nickel in the middle gray shale is one order of magnitude below the average—0.01 percent—of the other units. The vertical distribution of elements in the Gassaway is uniform except that aluminum is less than 10 percent in most samples of the top black unit, and is more than 10 percent in the other units. The barium content is more than 0.1 percent in the top black unit and less than 0.1 percent in the lower units. Strontium is most abundant—0.001 percent—in the top black unit. The amount of calcium in about half of the samples is more than 1.0 percent and apparently is never as much as 2 percent.

Variations in the content of minor constituents are greater laterally in the Chattanooga than the changes across its Gassaway member. The amounts of lead, cobalt, and sodium in samples from the Eastern Highland Rim vary in indirect proportion to the amount of vanadium. Magnesium, sodium, lead, manganese, and strontium are more abundant in rocks from hole 49 in Walden Ridge than in hole 48 to the south and hole 50 to the north.

Lanthanum was found only in holes 48 and 50 in Walden Ridge and in hole 42 in the Eastern Highland Rim; silver occurs only in holes 48, 49, and 50 in Walden Ridge and holes 44, 45, 64, and 51 in the southern part of the Eastern Highland Rim; and tin is found in all holes in the Eastern Highland Rim and in hole 49 in Walden Ridge. No correlations can be made between uranium and minor metal content.

URANIUM IN THE CHATTANOOGA SHALE

DISTRIBUTION

All units of the Chattanooga shale contain more uranium than most marine shales, but the content varies considerably from unit to unit as shown below.

	Range of uranium content, in percent
Gassaway member:	
Phosphatic zone.....	0.0016-0.0036
Top black unit.....	.0060- .0086
Upper siltstone.....	.0028- .0058
Middle black unit.....	.0039- .0066
Dowelltown member:	
Middle gray unit.....	.0011- .0020
Lower black unit.....	.0024- .0052

The wide range of uranium content in the upper siltstone unit reflects the relative abundance of interbedded gray, slightly uraniferous shale in that unit.

The presence of the thick, almost barren middle gray unit above the relatively thin lower black unit rules out the Dowelltown member as a source of uranium, and only the Gassaway member can be considered a potential producer under present conditions.

Throughout most of the Eastern Highland Rim area the highest uranium content of the Gassaway member is in the upper part of the top black unit. At the northernmost and southernmost holes in Walden Ridge (holes 47 and 50, fig. 159) the vertical distribution of uranium is the same as in the Eastern Highland Rim. In the central area (holes 48 and 49) the high uranium-content zone parallels the bottom of a tongue of the phosphatic zone. The upper siltstone is not conspicuous in Walden Ridge, and the Gassaway member beneath the phosphatic zone is about 20 percent higher in uranium content than is the same member in the Eastern Highland Rim.

No uranium minerals have been identified in the shale. The element is present as a separate colloidal phase disseminated through the organic matrix and is not chemically combined with the organic matter (Deul and Breger, 1955, p. 187-189). Autoradiographic studies by Bates, Strahl, Short, and others (1954) demonstrate that the alpha-particle source material is localized around concentrations of organic matter and pyrite.

RELATIONS OF URANIUM CONTENT TO OTHER CONSTITUENTS AND TO CHARACTERISTICS OF THE SHALE

Uraniferous black shales are generally characterized by the relative thinness of the formations, fairly high phosphate content or the presence of phosphatic nodules, high oil content and low calcium content (McKelvey, Everhart, and Garrels, this volume, p. 41). The Chattanooga shale is very thin and has a low cal-

cium content. The phosphate and oil contents of the rock, however, are relatively low and in these two ways the Chattanooga differs from the "typical" uraniferous black shale as described above and by other writers.

The relation between the thinness of the Chattanooga shale and its uranium content is obvious; the 35-foot thickness of the formation represents all of Late Devonian time and is equivalent to 10,000 or more feet of sediments in other areas (Rich, 1951). Thinness, however, is only one factor, as the distribution of uranium in the Chattanooga shale itself shows. The formation is of about the same thickness on all sides of the Nashville dome; yet the uranium content is much higher on the eastern side of the dome than elsewhere.

The most uraniferous part of the Chattanooga shale contains only 0.2 to 0.3 percent phosphate and does not contain visible phosphatic nodules. West of Nashville, where such nodules occur near the base of the formation, the uranium content is low. The phosphatic zone on the Highland Rim and in Walden Ridge also contains appreciably less uranium than do the other black units of the formation.

The oil content of the most uraniferous part of the Chattanooga shale, the top black unit of the Gassaway member, appears from scattered analyses to be less than the average for the Gassaway member or for the lower black unit of the Dowelltown member (Cuttitta, 1951).

A rough correlation between the relative blackness of the shale and its uranium content was noted in the field; in general, the darker the color, the higher the uranium content. Reflectance studies by Flanagan (1953), p. 163-164 and Bates, Strahl, Short, and others (1954) confirm this relationship.

The color of the shale is a factor of its carbon and sulfide content. One of the first correlations noted by students of uraniferous black shales was that between uranium and carbonaceous material, particularly bituminous material (McKelvey and Nelson, 1953, p. 35-53). Analyses of 24 samples taken in 1948 from various localities and different units of the Chattanooga shale show a direct relation between the contents of total sulfur and uranium. Recent studies by Bates, Strahl, Short, and others (1954) show high correlations between uranium and pyrite and uranium and carbon, and low correlations between uranium and the other components of the shale. It thus seems clear that the concentration of uranium in the Chattanooga is associated with pyrite and carbonaceous materials, and not with other constituents of the rock.

ORIGIN OF URANIUM IN THE SHALE

The hypothesis that uranium in black shales was concentrated by means of upwelling of currents from oceanic depths upon a continental shelf (McKelvey,

Everhart, and Garrels, this volume) can hardly be applicable to the Chattanooga shale. Although the southeastern limit of the Chattanooga sea cannot be determined because of later structural changes, the preponderance of evidence points to deposition of the shale in a landlocked, comparatively shallow sea. The uraniferous Eastern Highland Rim-Walden Ridge area was apparently in the central and deepest part of this sea, as evidenced by the small amount of coarse clastic material it contains and the fact that the shale is noticeably sandier toward the west (Mellen, 1947, p. 1811) and north (Maher, 1954). Lack of circulation on the bottom of such a sea would provide anaerobic conditions and permit carbonaceous material, which has a strong affinity for uranium, to accumulate.

The relatively nonuraniferous gray beds in the upper siltstone have been generally considered to represent periods when additional clastic material was brought into the sea. These beds, however, are best developed near Smithville and thin in all directions from that central area. They thus may represent periods during which the reducing conditions within the sea were halted for short periods and replaced by oxidizing conditions. This could have been accomplished by (1) periods of storm which would have introduced oxygen into the water, (2) influx of water into the epicontinental sea which would have provided more bottom circulation, or by (3) conditions unfavorable for plant life in the sea and on the surrounding land. The same hypothesis may, to a certain extent, be applicable also to the middle gray unit of the Dowelltown member.

Phosphate is formed in shallower, better aerated water than the nonphosphatic black shales (McKelvey, Everhart, and Garrels, p. 41, this volume). Thus the extreme reducing conditions which permitted concentration of uranium in the shales of the Eastern Highland Rim-Walden Ridge area probably did not prevail west of the Nashville dome when the phosphatic part of the Chattanooga shale was deposited there, nor in the northeast when the phosphatic zone was laid down. This change in environment could account for the lower uranium content of those units as compared to the blacker shales.

The suggestion (McKelvey, Everhart, and Garrels, p. 41, this volume) that the high uranium content of certain black shales represents concentration of only normal quantities of the element in sea water over tremendously long periods of geologic time, and that no particularly uraniferous source material is necessary, may not apply to the Chattanooga shale; other black shales formed under much the same conditions are not nearly so uraniferous. It has been suggested that the granitic landmass of Appalachia east of the Chattanooga sea could have provided more than average

amounts of uranium; another possible source is volcanic ash. The bentonite bed in the Chattanooga shale is evidence of volcanic activity, and Rich (1951, p. 2017-2040) has noted that some of the clastic material throughout the Chattanooga shale is of possible volcanic origin. It is altogether likely that small quantities of ash fell into the sea almost continuously during Chattanooga time and increased the amount of uranium available for concentration. Streams also could have brought in ash from the surrounding land.

CONCLUSIONS

Conclusions drawn from field and laboratory studies of the Chattanooga shale in the Eastern Highland Rim and Walden Ridge are:

1. The Chattanooga shale differs from "typical" uraniumiferous black shale in its low content of phosphate and oil.

2. Only the upper, or Gassaway, member of the formation is of present interest as a potential source of uranium.

3. The phosphatic part of the shale contains considerably less uranium than the other black units of the formation.

4. The uranium in the shale is associated with carbon and pyrite, and no relationship between uranium and other constituents has been observed.

5. The uranium was probably concentrated under anaerobic conditions in the central part of a practically landlocked sea. Some of the uranium may have entered the sea in volcanic ash.

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