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TRACE ELEMENTS INVESTIGATIONS
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SECOND INTERIM REPORT
BLACK SHALE INVESTIGATIONS (CHATTANOOGA)

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Louis C. Conant

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BLACK SHALE INVESTIGATIONS - SECOND INTERIM REPORT

Louis C. Conant

Abstract

The Chattanooga shale in east central Tennessee is divisible into five lithologic units which persist over large areas with only slight changes in thicknesses. In most areas the beds are nearly flat and free of faults. The shale probably contains much fine quartz silt and some clay, and appears to have accumulated slowly in a broad, quiet, shallow sea. The abundant plant matter may have caused the deposition of the uranium, and the slow accumulation of detrital matter probably caused its concentration.

A large area has been studied systematically, but only a small part of the samples have been assayed. Conclusions regarding the uranium content are uncertain because of various sources of errors which are discussed. Evidence suggests strongly that the grades of the various units differ markedly, but that a given unit has a nearly constant grade over a large area. A 7-foot unit of black shale near the top seems to contain about 0.008 percent uranium, and a 17-foot interval near the top about 0.007 percent. A 17-foot bed of such shale would contain about 2,265 tons of uranium per square mile. Incomplete data indicate that such shale underlies several hundred square miles near the Eastern Highland Rim and underlies a much greater area farther east but at depths of 300 to 2,000 feet.

An experimental adit indicates that the shale can be mined easily. Stripping operations are impracticable in most of Tennessee because of heavy overburden of Fort Payne chert, but appear possible in parts of Kentucky.

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Introduction

Investigations by earlier workers 1/ have indicated (1) that the

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1/ Slaughter, A. L., and Clabaugh, S. E., Trace Elements Investigations Report 1.

Brill, K. G., Jr., Nelson, J. M., and Prouty, C. E., Trace Elements Investigations Report 8.

Nelson, J. M., and Brill, K. G., Jr., Radioactivity of the Chattanooga shale east of the Mississippi and south of the Ohio Rivers: Trace Elements Investigations Report 22.

Chattanooga shale of east central Tennessee is the most radioactive of the black shales of the eastern United States, and (2) that the uranium is not directly related to the phosphatic material in the shale.

This report covers more detailed investigations which started in October, 1947, under the general supervision of L. C. Conant. Andrew Brown has been in charge of drilling and adit work, and W. H. Hass has studied the paleontology and stratigraphy. Most of the sampling and mapping have been by R. C. Robeck, R. E. Smith, Andrew Brown, L. C. Conant, and W. A. Heck, assisted by several other geologists who had short-term assignments on the project. Robeck has made Geiger counts on many of the outcrops. All of these men have contributed materially to the information in this report.

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Scope of present investigations

The present investigation was planned as a thorough study of the black shale in order to learn as much as possible about (1) the distribution and quantity of uranium in the shale, and (2) the stratigraphy, origin, and general geology of the shale.

To achieve the first objective, samples have been taken at about 5-mile intervals along most of the Eastern Highland Rim, at about 5- to 8-mile intervals in the Sequatchie Valley of eastern Tennessee, and at much closer intervals (about 3 miles) in parts of Block 1 (see accompanying map) where the first work was done. Block 1 was chosen for the first work because previous investigations had indicated a relatively high concentration of uranium in that general area and because of the many good outcrops. Four good cores of the shale were obtained at depths of 55 to 360 feet which afforded fresh samples of the rock for analysis as well as additional information about the subsurface distribution of the uranium and about the stratigraphy. The drilling contract was cancelled in the summer of 1948 at the request of the Atomic Energy Commission. An essentially complete core of the Chattanooga was obtained from the Magnolia Oil Company's No. 1 Patterson test well at Gruetli, Grundy County (south edge, Block 2, locality 10M-1 on map). This core was obtained through the generosity of the Magnolia officials. Later a gamma-ray log was made of the well at the request of the Geological Survey and it has been used in establishing correlations between such logs and the uranium content of the rocks. In Block 1 a 100-foot adit was driven in the Top Black shale (locality LC-201) on a repay basis by the

Tennessee Valley Authority in order to get bulk samples of the fresh shale and to learn something of the mining characteristics of the Chattanooga.

To realize the second objective, that of studying the stratigraphy, origin, and general geology of the shale, many sections have been studied and correlated. Microscopic fossils, known as conodonts, have been used to zone the Chattanooga shale, to determine its geologic age, and to provide a basis for correlating the beds exposed at one place with those exposed at other places. The shale has also been mapped in considerable detail in some of the areas studied. One of the main purposes of the geologic studies is to learn the conditions which prevailed when the shale was accumulating, as such information may help in prospecting and may shed light on uranium-bearing black shales elsewhere in the world.

The areas of investigation in Tennessee are shown on the accompanying map. Blocks 1, 3, 4, and 5 have been studied and sampled systematically; Blocks 6 and 7 have been sampled systematically but studied only slightly. Reconnaissance trips have been made in search of possible stripping areas in the folded section of eastern Tennessee and in several parts of Kentucky and Indiana.

Topography

Much of central Tennessee is a lowland commonly known as the Nashville Basin, and is underlain by limestones which are below and older than the Chattanooga shale. Except for three narrow valleys which drain the area, the Basin is completely surrounded by a relatively smooth upland area known as the Highland Rim which, on the east side, stands at elevations of about 1,000 feet, some 500 feet above the Basin. The edge of the Highland Rim is formed by the resistant Fort Payne chert which overlies the Chattanooga shale. The slope from the Rim to the Basin is steep nearly everywhere, so that the Chattanooga shale is commonly well exposed in the road cuts and in the numerous waterfalls of the area. The Caney Fork River, one of the larger streams that flow from the Highland Rim into the Basin, has cut a long, narrow, steep-sided valley which exposes the Chattanooga shale for some 25 miles back into the Rim. This large re-entrant has afforded an excellent opportunity to study the shale for many miles east of its general outcrop area.

The Sequatchie Valley is a long narrow valley whose northern half is in Tennessee (Block 3). It is the breached crest of a sharp anticline which has been eroded to depths of 1,500 to 2,500 feet below the surrounding Cumberland Plateau.

General geology

Stratigraphy of the Chattanooga shale

The Chattanooga shale of the Eastern Highland Rim in the vicinity of Block 1 consists of five lithologic units. These units as a whole, and some of their contained beds, persist for many miles with relatively slight variations in thicknesses. The field names of the units are given in the table on the following page. Incomplete chemical analyses suggest that the uranium content of a given unit is also essentially uniform for many miles, but that the uranium content of the various units is appreciably different.

The chief animal remains are those of fish, conodonts, and lingula-like brachiopods. The tiny conodonts are complex tooth-like structures composed of apatite, are of great diversity, and are the unknown parts of an undetermined type of animal. The conodonts permit detailed stratigraphic correlations, but the lingula-like shells are of little stratigraphic value. Both the conodonts and the brachiopods indicate that the shale was deposited in salt water. The conodonts indicate that most of the 30 feet of black shale in Block 1 is of Upper Devonian age, and that only the top is of Mississippian and of transitional Devonian or Mississippian age.

The following table summarizes data about the Chattanooga and Maury shales that are especially applicable to that part of the Highland Rim in the vicinity of Block 1.

Lithologic units of the Chattanooga shale and the Maury shale

Name	Approximate thickness (feet)	Assigned sample numbers	Average uranium content (percent)
Maury shale	2	1-10	0.002*
Chattanooga shale			
Upper Black shale	17	11-40	.007
Top Black shale	7	11-20	.008
Upper siltstone	2	21-30	.005
Middle Black shale	8	31-40	.007*
Middle Gray siltstone	7	41-50	.003*
Lower Black shale	7	51-60	.004*

*Estimated average, not actually calculated.

The Chattanooga contains three black shale units (Lower, Middle, and Top) separated by siltstones. The fresh shales generally are massive beds of black rock which assume a fissile character when weathered. A few thin partings of silt are present, and marcasite (or pyrite) is common as paper-thin stringers, thin layers, and nodules up to an inch in diameter. The black shales are sufficiently rich in kerogen to emit a petroliferous odor when broken, and thin layers or lenses of pure bitumen are present locally. The three shale units are so similar that any one of them could hardly be distinguished in an isolated outcrop or core fragment except by a study of its conodonts.

At the base of the Lower Black shale, resting on the Ordovician limestones, is a thin sandstone bed, as much as several inches thick but commonly only about one inch thick, which is noteworthy for its persistence and thinness. In a few places it is absent. This sandstone resembles the Hardin sandstone which is as much as 15 feet thick on the west side of the Basin, but in this report it is termed the basal sandstone as it has not been traced from one side of the Basin to the other.

The Middle Gray siltstone consists chiefly of light- to medium-gray beds of siltstone together with a few thin beds of black shale. A bed of bentonite (altered volcanic ash) 1 to 2 inches thick is generally present near the top of the Middle Gray siltstone. It has been found throughout most of the Eastern Highland Rim area, locally in the northern part of the Sequatchie Valley, and in the cuttings from several oil test wells between those two areas. The bed ranges from 0.05 to 0.15 foot in thickness, and apparently had an eastern or southeastern source as it thickens in that direction. The volcanic ash apparently settled in quiet water for it is persistent and free of ordinary sedimentary materials. It is missing, however, in an area of 100 square miles in the vicinity of Woodbury, Cannon County, where it was apparently eroded before deposition of the Middle Black shale.

An unconformity has been seen at the top of the Middle Gray siltstone in a few places. It is recognized as a low-angle truncation of the Middle Gray beds, with as much as a third or more of that unit being cut out. In most of the outcrops, however, no evidence of the unconformity has been found and if one does exist it is of minor importance as the bentonite is known to be present within 1.5 feet of the top of the Middle Gray.

The Upper Black shale consists, in most of the area under consideration, of three persistent lithologic units which have been termed the Middle Black shale, the Upper siltstone, and the Top Black shale. At the top of the Middle Black shale another unconformity has been observed at a few places, but nowhere does it seem to cut more than a foot or so into the Middle Black shale.

The Upper siltstone is actually a black shale zone in which silty layers as much as 1 to 3 inches thick are more common than in the more massive black shales above and below. At the base of this member is a persistent bed of siltstone or very fine sandstone, as much as 3 inches thick, which is strongly laminated and finely cross-bedded. This bed has been informally termed the "varved" bed because of its strikingly laminated character.

The Top Black shale is the most massive of the shale units, the perceptible silt partings being as much as a foot apart. At the top of this unit in Block 1 is a tongue, or wedge, of black shale, a foot or less thick, which abounds in phosphate nodules commonly 1 to 12 inches in longest diameter. This tongue thins to the south and is not present in the southern three-fourths of Block 1, but to the north in the latitude of Cookeville, near the north edge of Block 4, it is several feet thick.

Stratigraphy of overlying beds

The Maury shale which immediately overlies the Chattanooga is a thin bedded silty clay, 1 to 2½ feet thick, that contains a few phosphatic nodules. It is commonly described in the literature as being glauconitic, but that mineral is either rare or absent in the Maury of the Eastern Highland Rim area. The dry fresh rock has a light bluish gray color but on a weathered surface it has a greenish cast. Even though it is only 2 feet thick, the Maury is persistent throughout the Tennessee area which is under consideration. Because it more closely resembles the underlying Chattanooga shale than the overlying Fort Payne chert, some workers have regarded it as a member of the Chattanooga, but it is here considered to be a seperate formation.

The Fort Payne chert is a siliceous limestone 150 to 200 feet thick and is especially resistant to weathering because of the massive beds of chert. It is of interest here primarily because of its effect on the exploitation of the underlying Chattanooga shale. Briefly, (1) it causes the shale to be overlain in most places by 100 to 200 feet of material, (2) it is difficult to penetrate in drilling, (3) it is a formidable obstacle to stripping operations, and (4) it affords a strong roof for mining. Locally on the Eastern Highland Rim a weaker rock as much as 50 feet thick, composed of fossiliferous silty and sandy beds, and layers of crinoidal limestone some of which is siliceous, is present between the Maury and the typical Fort Payne chert. Farther north, especially in Kentucky and Indiana, the black shale is overlain by weak silty shales known as the New Providence shale.

Conodont studies show that all of the Chattanooga up to the base of the phosphate is of Upper Devonian age, that the phosphatic tongue is of transitional Devonian or Mississippian age, and that the Maury is of Mississippian age. No other fossils in the shale have been used for making stratigraphic correlations.

Structure

Throughout the Eastern Highland Rim the easterly regional dip is about 30 feet per mile, but many small gentle folds are present. Questionable high-angle faults having a few feet of displacement have been observed at a few places. Low-angle faults have been observed in the southern part of Block 1 near Horseshoe Falls where only a foot or two of disturbed black shale is present between the overlying and underlying limestones. The shale has been affected elsewhere in the area, as shown by drill cores LC-108 and LC-113A in which slickensides were found in the Lower Black shale.

Under much of the Highland Rim area and the Cumberland Plateau farther east, the shale is at depths of 300 to 2,000 feet and lies essentially flat except for many gentle flexures.

In the Sequatchie anticline the Chattanooga, along with the other rocks, has been arched upward sharply. A large fault conceals the shale on the west side of the valley, but on the east side the shale has easterly dips of 5 to 25 degrees. Numerous low-angle faults are also present and the beds are much contorted locally by drag folding.

Composition of the shale

The Chattanooga shale has a relatively small amount of clay mineral, as indicated by chemical analyses. Workers at both Battelle Memorial Institute and the Y-12 laboratory at Oak Ridge report orally that the shale contains only about 10 percent alumina, which is about one-fourth to one-half the amount which clay minerals possess. Analyses indicate that much quartz is present as silt, and this is substantiated by drilling experience at the adit where ordinary steel bits lost their gauge in one 2-foot run.

To date two sets of Fischer oil assays on samples of the Chattanooga shale (localities LG-55 and LG-102) indicate that 8 to 12 gallons of oil per ton of rock is present, in addition to 15 percent residual carbonaceous content. Work at Battelle indicates that considerably more oil is recoverable than the Fischer assays suggest, but to recover this additional oil may require higher temperatures than uranium extraction will permit. The nature of the residual carbonaceous content is unknown, but it probably consists chiefly of microscopic spores and comminuted plant fragments.

The light- and medium-grey silty beds have not yet been studied in detail, but they are probably composed largely of quartz silt and very fine quartz sand.

In the Tennessee portion of the Sequatchie Valley (Block 3) the Maury shale, Upper Black shale, Middle Grey siltstone, and Lower Black shale have been recognized. Generally the shale is so badly contorted and sheared that no detailed measurements of the several units can be made, but stratigraphic studies indicate that the main mass belongs to the Upper Black shale unit. At some localities in the southern part of Block 3 the Middle Gray siltstone and Lower Black shale are not present.

Conditions of deposition

Whether the Chattanooga sea was shallow or deep has been the subject of much speculation for a long time. In the areas under investigation the evidence is not conclusive but strongly suggests that deposition took place in a large body of quiet and shallow water. To be sure, the fineness of the sediments, the apparent slow rate of deposition, the persistence and uniformity of a thin bed of bentonite over several thousand square miles, and the general absence of such common shallow-water features as ripple marks, mud cracks, and scour channels all suggest deep and quiet water. These are negative indications, however, and do not counterbalance the opposing evidence. Shallow water, probably less than 100 feet deep, is indicated (1) by local unconformities which do not cut deeply into the underlying beds, (2) by lingula-like fossils which range throughout the black shale, and (3) by the presence of the black shale near the base of the formation. If the unconformities reflect major crustal movements, it is hard to believe that the sea bottom was raised locally two or more times from appreciable depths to water level but nowhere more than a few feet above that level. The lingula-like fossils resemble living shallow-water *Lingula* and suggest strongly that the water in which they lived was shallow. The presence of the black shale at the base of the formation or within a few inches of it, suggests that its deposition commenced almost immediately after submergence. If deep water were required for black shale accumulation, it seems likely that much more than an inch of the basal sandstone would have accumulated during the long period of slow submergence which is almost necessarily assumed.

The general absence of ripple marks may be explained by the fineness of the silt which would not assume or retain ripple structure. The "varved" bed, however, at the base of the Upper siltstone, appears to have fine ripple structures and other cross-bedding.

The facts lead almost inevitably to the conclusion that the sediments accumulated slowly in quiet but shallow water in a large sea essentially free of currents. A shallow quiet sea extending for hundreds of miles in length and breadth seems to require a climate unlike that of today, as storms like those of today would probably have generated currents on a much larger scale than appear to have existed in the Black shale sea. Further considerations of such conditions would lead into fields of speculation which, though tempting, are out of place here.

The shale formation is much thicker to the east, from whence most of the detrital sediments probably came. The Cincinnati arch, including the Nashville arch, was probably a gentle swell during the Devonian period and would explain the thinning of the black shale formation toward the crest of the arch and the fact that the lower units are probably less extensive in that direction. The thinness and fineness of the sediments are explained by assuming that they were deposited a long way from the hypothetical eastern or southern land source of most of the sediments of the region, and that only small amounts of detrital sediments came from the nearby arch. More distant western sources of sediments were probably cut off by the arch.

The abundant plant matter may be both marine and non-marine. It is interesting in this connection to recall that the Devonian period was the time when plants are believed to have first established themselves on the continents. Such new plant life and the resultant organic acids conceivably could have extracted the uranium actively from the soils and rocks on the continents and aided its transfer to the sea. The broad, shallow, inland sea was probably so foul with the decomposition products of marine plants and of primitive land plants that few marine animals could live in it. Some of the abundant organic material in the water may have had an affinity for the uranium and absorbed the metal thus causing its accumulation on the sea bottom. It has also been suggested 2/ that clays of the montmorillonite group can

2/ Frederickson, A. F., Some mechanisms for the fixation of uranium in certain sediments: Science, new ser. vol. 108, pp. 184-185, Aug. 20, 1948.

take uranium atoms into their molecules by some kind of base exchange mechanism. As it is not known what kind of clay mineral is present in the shale, further speculation along this line would seem useless at this time.

All evidence suggests that the Chattanooga sediments in east-central Tennessee accumulated very slowly, and it seems reasonable to suppose that these shales are relatively rich in uranium mainly because they represent an accumulation throughout a long geologic time. Other things being equal, the uranium content would be expected to be lower in those sediments that accumulated rapidly, for the quantity of uranium present in the sea at any one time must have been very small. The low uranium content of the Middle Gray silt might, therefore, be explained by dilution, by lack of suitable organic matter, or by more active erosion of the land and a clearing of the sea water.

Economic geology

Sampling and numbering system

Samples of outcrops and cores on which analyses were made commonly came from intervals of 2 feet or less and, so far as practicable, are from corresponding intervals. Areas of investigations have been termed Blocks; in Tennessee these were numbered at first essentially in the order of their investigation, but later a 15-minute coordinate system was adopted. Both these systems are shown on the accompanying map. Block 2 was chosen as an area which would be examined entirely by samples from drill holes, but when the drilling contract was cancelled this area was left unexplored except for two cores, one of which is from the Magnolia Oil Company's well at Gruetli. In Blocks 1, 3, and 5 the first two symbols of the sample numbers indicate the Block; LC samples are from Block 1 but include samples from two localities in Block 5 and the one Survey drill hole in Block 2; R-S samples are from Block 3 (the Sequatchie Valley); and R-C samples are from Block 5. These letters are followed by numbers which designate specific outcrops or holes, such as LC-10, LC-102, R-S2, R-C6, etc. Sample localities from the 15-minute coordinate blocks are designated by those coordinates, as shown on the accompanying map, giving 14B-2 etc. The locality designations are followed by numbers which indicate the stratigraphic intervals represented by the samples, giving LC-10-11, LC-10-12, R-S2-12, R-C6-13, etc. The key to the stratigraphic intervals is given in the table on page 8. Interval 11 was reserved for the phosphatic zone at the top of the Top Black shale, but later, when thicker sections of that zone were encountered, the number was expanded by using 11A, 11B, etc.

Special samples for the research laboratories have been numbered less systematically, but gradually a system has evolved which should prove to be both satisfactory and flexible. A sample that exactly duplicates an earlier routine sample is given a number 100 higher. Thus, a special sample which exactly duplicates B-C2-13, is numbered B-C2-113. A later special sample from the same interval is B-C2-213, and a third special sample (not yet taken) would be B-C2-313. If a special sample does not exactly duplicate an earlier interval it is numbered -101 (LC-33-101). A special sample from another part of the same outcrop is numbered -102 (LC-33-102), etc. Where samples are split and sent to two or more laboratories the letter B, L, or M is added indicating that it is sent to Battelle, Laurence (for pickup by Oak Ridge), or Monroe (for U. S. G. S. laboratory). Thus, there are B-C2-113B, B-C2-113L, and B-C2-113M.

At first the Maury and all parts of the Chattanooga were sampled with equal diligence, but as analyses have consistently shown that the Maury and the Middle Gray siltstone are too low grade to be of much interest, close sampling of those units has been discontinued except at widely spaced exposures.

Uranium of the shale

Only a small part of the samples thus far collected have been assayed for their uranium content, and most of these are in Blocks 1 and 3. Analyses of given shale units show somewhat more variation than the widespread uniformity of the shale would lead one to expect. The average of all the analyses for a given stratigraphic unit, however, is about the same as the analyses of the cores and other really fresh samples which have been tested. The accompanying tables "Summary of thicknesses and analyses" present most of the analytical data at hand. In nearly every case chemical determinations have been used instead of Geiger-count determinations, where both were available. The table on page 8 shows the averages of the analyses of samples from the different lithologic units.

Insufficient analyses are at hand to justify any conclusions regarding the horizontal distribution of the uranium in any given layer. Differences in analyses from different outcrops of the same units may reflect one or more of the following factors: (1) true difference in uranium content, (2) analytical errors, (3) sampling errors, and (4) weathering of the rocks.

The first possibility, true difference in uranium content, awaits the evaluation of the other three factors.

Analytical inconsistencies are entirely likely and even expectable, especially for material of low grade. As the analyses can only be considered accurate to within plus or minus 0.001 or 0.002 percent, it is obvious that analyses on the order of 0.006 are especially susceptible to this limitation of accuracy. Check analyses have also revealed some discrepancies of greater magnitude.

Sampling, even though done painstakingly and carefully on the outcrop, may introduce certain variables. For example, if the uranium is associated with bitumen, which is present throughout the rock but is locally concentrated into short thin layers only a few millimeters thick at the most, a given sample, say interval 13, could run somewhat high or low depending on whether any bitumen layers were present at the exact place the sample was taken. Or, a small but significant quantity of the brittle bitumen could be lost while the sample is being hammered out.

Weathering is suspected of altering the uranium content of the outcrops, as the metal is known to be readily soluble in dilute acids. Groundwater, therefore, containing CO_2 absorbed from the atmosphere and organic acids obtained from the soil may leach the uranium from the shale at one place and conceivably cause secondary enrichment at another place. Some of the analyses strongly suggest that such weathering factors are present, for example, at 10-10 where outcrop samples of the Top Black shale average 0.0114 percent uranium, but the nearby core samples (10-102) average 0.0074, and samples from the adit, 100 feet away, average about 0.009 percent.

Because of all these possible variables, it is not safe to conclude, on the basis of data now available, that a given shale unit is significantly richer or leaner at one outcrop than at another. A program for detailed sampling at several places is being considered which would not only shed light on the possible field variables but would also test the reliability of the laboratory analyses. This in turn would permit safer conclusions regarding distribution of the uranium. Until it is evident that slightly different analytical values are significant, it seems better to disregard them and to deal only with average values in estimating the uranium grades and tonnages of the several stratigraphic units of a given area.

Reserves

A cubic foot of shale in place weighs about 140 pounds. A cubic yard, therefore, weighs about 1.9 short tons, a 1-yard bed occupying an acre contains about 9,190 tons, and the same bed over a square mile contains about 5,880,000 tons of shale. At 0.007 percent uranium, the approximate grade of the Upper Black shale analyses thus far reported, a 1-yard bed over 1 square mile would contain about 400 tons of metallic uranium, and the entire 17 feet of the Upper Black shale would contain about 2,265 tons of uranium per square mile. In about 70 square miles in the northern 6 miles of Block 1, where samples are most closely spaced, where the shale outcrops are above reservoir level, and where the shale is essentially uniform in grade and thickness, there appears to be about 150,000 tons of uranium.

To the north, in Block 4, no analyses are available, but the beds of that area have thicknesses comparable to those in Block 1. Geiger field counts suggest that the grade of the shale in the two Blocks is about the same, and an older sample locality (S-100), just north of Block 4, shows similar grades. It seems reasonably safe to predict, therefore, in advance of laboratory analyses, that in the part of Block 4 which lies west and south of Cookeville about 100 square miles are underlain by shale containing an additional 225,000 tons of uranium.

To the south and west, in Block 5 to about the latitude of Woodbury, a comparable area is underlain by nearly as much Upper Black shale, and Geiger field counts and a few chemical analyses indicate it has a uranium content approximately equal to that of the Upper Black of Block 1. It is predicted, therefore, that the Upper Black shale of this area contains 200,000 tons of uranium.

In Block 3, the Tennessee portion of the Sequatchie Valley, the Upper Black averages 13 feet thick and contains about 0.008 percent of uranium. It seems likely, therefore, that in Block 2, (the large area between Block 3 and Blocks 1 and 5) there are shales of grade and thickness comparable to those of the adjacent Blocks. This belief gets strong support from the Gruetli well (10H-1) where the upper 15 feet of the shale contains 0.008 percent uranium. It is further predicted, but with much less certainty, that an additional 1,500 square miles in Block 2 contains on the order of 3,000,000 tons of uranium at depths of 300 to 2,000 feet.

It is probable that shale of comparable grade and thickness underlies other areas in east-central Tennessee.

Mining conditions

The adit has indicated that the shale can be drilled and blasted with no serious difficulty, and that it can be removed without taking the overlying phosphatic wedge or the Maury siltstone. The Fort Payne chert is a good roof rock which may be expected to require relatively little support and to permit relatively little surface water to reach the mining level.

A southwestward extension of the DeKalb-White County line in Block 1, as shown on the accompanying map, marks the approximate line northwest of which the Chattanooga shale is above flood level of the Center Hill Reservoir. From this line northwest about half the distance to the corner of Block 1 the shale is overlain generally by about 150 to 200 feet of the Fort Payne. Farther northwest the overburden becomes gradually thinner, and probably averages 100 to 150 feet near the northwest corner. In the southeast part of Block 4 are other areas having 150 to 200 feet of overburden, but in the vicinity of 13M-10 (see map) the area is much more dissected by streams than is apparent from the map, so that most potential mining areas would be a mile or more long but only a few hundred feet wide. In the general vicinity of 13M-10 the overburden probably averages between 100 and 150 feet.

A search has been made in the areas of intensive work for potential stripping areas, but the Fort Payne is so resistant that almost everywhere it is present, it forms a cap at least 75 feet thick and is a formidable obstacle to stripping.

In northern Kentucky, where weak shaley beds instead of the Fort Payne chert overlie the black shale, a few hundred million tons of the shale could be obtained at several places by stripping 50 feet or less of shale overburden. Samples of the black shale from these areas have not yet been assayed.

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TABLE 1 SUMMARY OF THICKNESSES AND ANALYSES

Block 1: LC-1 through LC-105A; Block 2: LC-113A and 10M-1 (Gruetli)

Sample	LC-1 Thickness	LC-1 % Uranium	LC-1A Thickness	LC-1A % Uranium	LC-1B Thickness	LC-1B % Uranium	LC-2 Thickness	LC-2 % Uranium	LC-4 Thickness	LC-4 % Uranium
1	1.2	.002	1.2	.002			0.9	.002	1.12	.002
2	1.3	3	1.3	6			1.4	2	0.95	3
Maury	2.5		2.5				2.3		2.07	
11	1.5	.009	1.5	.009	1.5	.008	0.26	.006	0.3	.004
12	1.5	8	1.5	3	1.5	8	1.63	7	1.22	10
13	1.5	7	1.5	9	1.5	8	2.0	7	2.0	8
14	1.95	6	1.95	7	1.95	7	1.49	8	1.04	8
15							1.57	6	2.0	8
16									1.43	7
17										
18										
Top Black	6.45	.0073	6.45	.007	6.45	.0077	6.95	.0069	7.99	.0068
21	1.45	.004	1.45	.007	1.45	.006	1.65	.005	2.0	.006
22	1.0	2	1.0	5	1.0	4	0.84	4	0.87	4
Upper silt	2.45	.0031	2.45	.0061	2.45	.0051	2.49	.0046	2.87	.0053
31	1.7	.004	1.7	.005	1.7	.006	1.95	.007	1.83	.003
32	1.8	7	1.8	6	1.8	6	1.7	7	2.0	7
33	1.4	7	1.4	6	1.4	7	1.7	7	2.0	8
34	1.77	7	1.77	7	1.77	7	1.84	6	1.84	4
35	0.73	8	0.73	2	0.73	6				
Middle Black	7.4		7.4		7.4		7.19		7.67	
Upper Black	16.3	.0063	16.3	.0063	16.3	.0067	16.63	.0065	18.53	.0061
41	1.9	.003	1.9	.002	1.9	.002	0.82	.003	0.78	.006
42	1.85	3	1.85	2	1.85	3	2.0	4	1.44	4
43	1.85	6	1.85	2	1.85	2	2.0	3	1.55	3
44	1.9	8	1.9	2	1.9	2	2.0	3	1.96	3
45	1.85	3	1.85	4	1.85	3	2.0	3	1.82	4
46							0.63	4	1.62	2
47									0.6	3
Middle Gray	9.35		9.35		9.35		9.45		9.77	
51	1.8	.006	1.8	.004	1.8	.004	2.0	.004	2.0	.004
52	1.95		1.95	5	1.95	7	2.0	3	1.83	5
53	1.8	3	1.8	4	1.8	5	1.19	5	1.31	5
54	0.8	3	0.8	3	0.8	3	2.0	5	1.63	3
Lower Black	6.35		6.35		6.35		7.19		6.77	

Sample	LC-6 Thickness	LC-6 % Uranium	LC-15 Thickness	LC-15 % Uranium	LC-8 Thickness	LC-8 % Uranium	LC-10 Thickness	LC-10 % Uranium	LC-11 Thickness	LC-11 % Uranium
1	0.95	.004	1.32	.003			2.06	.002	2.03	.004
2										
Maury	0.95		1.32				2.06		2.03	
11	0.37	.005	0.5	.005			0.5	.006		
12	1.85	6	1.06	7	0.83	.008	1.6	11	2.0	.007
13	1.9	7	2.0	7	2.03	9	1.6	12	2.0	7
14	1.15	5	1.88	5	2.0	8	1.5	11	1.38	5
15			2.0	5	1.39	7	2.0	13	1.0	5
16										
17										
18										
Top Black	5.27	.0061	7.44	.0058	6.25	.0081	7.2	.0114	6.38	.0064
21	1.94	.005	1.97	.004	1.0	.005	2.2	.006	2.0	.005
22	0.9	6			1.49	5	1.15	5	1.67	6
Upper silt	2.84	.0053	1.97	.004	2.49	.005	3.35	.0056	3.67	.0054
31	2.08	.003	2.25	.005	2.0	.005	0.7	.006	2.0	.006
32	1.5	5	1.93	6	2.0	7	1.8	9	1.37	6
33	1.65	7	2.0	7	2.0	8	1.4	9		
34	1.5	7			1.52	8	2.0	8		
35	2.0	7			1.18	9	2.0	9		
Middle Black	8.73		6.18		8.7		7.9		3.37	
Upper Black	16.84	.0057	15.59	.0056	17.44	.0072	18.45	.0091	13.42	.006
41	1.22	.004	1.4	.004			2.0	.001	2.32	.003
42	1.93	3	2.0	3			2.0	4	1.62	3
43	1.91	2	1.83	2			2.0	1	1.33	3
44	1.45	2	1.96	2			2.0	3	1.44	2
45	1.76	3	1.79	4			1.7	1		
46	1.46	3								
47	0.92	2								
Middle Gray	10.65		8.98				9.7		5.71	
51	1.64	.003	2.1	.005			1.25	.002	1.23	.001
52	2.0	7	2.0	5			1.5	5	1.25	3
53	1.3	5	2.0	5			1.15	4		
54	1.78	4					0.9	3		
Lower Black	6.72		6.1				4.8		[illegible]	

Sample	LC-12 Thickness	LC-12 % Uranium	LC-17 Thickness	LC-17 % Uranium	LC-30 Thickness	LC-30 % Uranium	LC-33 Thickness	LC-33 % Uranium	LC-50 Thickness	LC-50 % Uranium
1	1.95		1.97	.002	1.88	.002	1.37		1.8	.003
2										
Maury	1.95		1.97		1.88		1.37		1.8	
11	0.15		0.1	.007						
12	2.0		2.0	5	1.33	.009	1.61	.007	1.82	.011
13	2.0		2.0	5	2.0	7	2.1	11	2.0	13
14	1.9		1.7	9	1.63	5	1.41	9	1.85	11
15	0.82		1.3	8						
16										
17										
18										
Top Black	6.87		7.1	.0065	4.96	.0068	5.12	.0091	5.67	.0117
21	1.9	.005	1.33	.007	1.19	.005	1.58	.007	1.35	.009
22	0.29	4	1.03	6	1.31	5	1.27	4	1.22	7
Upper silt	2.19	.0048	2.36	.0065	2.50	.005	2.85	.0056	2.57	.008
31	1.88	.007	2.0	.006	2.06	.005	1.97	.006	2.01	.009
32	1.47	7	2.0	5	2.02	5	1.52	5	2.01	9
33	1.9	6	2.0	5	2.0	6	1.92	7	2.01	9
34	2.06	7	1.55	8	1.65	7	1.62	8	2.01	10
35							1.5	7	2.01	11
Middle Black	7.31		7.55		7.73		8.53		10.05	
Upper Black	16.37		17.01	.0062	15.19	.0053	16.5	.0072	18.29	.010
41	0.7	.004	0.7	.004	1.7	.004	1.26	.004	0.87	.003
42	0.9		1.85	4	2.0	3	1.93	5	2.0	4
43	1.85	2	1.85	4	2.0	3	1.37	3	2.0	2
44	1.85	2	1.85	4	1.67	3	1.93	3	2.0	2
45	1.85	3	1.85	4	1.9	3	1.76	3	2.0	4
46	1.85	3	1.19	2			2.18	3	1.89	1
47										
Middle Gray	9.0		9.29		9.27		10.43		10.76	
51	0.74	.005	1.95	.005	1.83	.003	1.69	.004	1.64	.004
52	2.0		2.0	8	1.68	6	1.5	6	1.81	6
53	2.0	4	2.0	8			2.0	8	1.8	4
54	2.0	4					1.28	4	1.8	3
Lower Black	6.74		5.95		3.51		6.47		7.05	

Sample	LC-51 Thickness	LC-51 % Uranium	LC-55 Thickness	LC-55 % Uranium	LC-56 Thickness	LC-56 % Uranium	LC-101 Thickness	LC-101 % Uranium	LC-102 Thickness	LC-102 % Uranium
1	1.24	P [illegible]	1.8						0.5	.002
2										
Maury	1.24		1.8							
11			0.8		2.0	.007			0.25	.003
12	1.75	.009	1.3		2.0	3			1.95	7
13	1.8	9	1.35		2.25	5			2.0	9
14	1.98	9	1.75				4.0	.009	1.9	7
15			1.2				1.5	6		
16			1.2							
17										
18										
Top Black	5.53	.009	7.6		6.25	.005			6.1	.0074
21	1.58	.008	2.1		2.5	.002	2.0	.005	1.3	.006
22	1.4	9							1.2	5
Upper silt	2.98	.0084	2.1		2.5	.002	2.0	.005	2.5	.0055
31	1.82	.007	1.9		2.0	.003			1.8	.007
32	1.84	7	1.9		2.0	1			1.5	7
33	1.71	8	2.0		2.0	4			1.8	7
34	1.47	9	1.9		1.65	4			2.0	8
35	1.6	7								
Middle Black	8.44		7.7		7.65				7.1	
Upper Black	16.95	.0081	17.4		16.40	.0036			15.7	.007
41	1.92	.004	0.5						2.0	.002
42	1.83	5	2.0						1.8	3
43	1.58	3	2.0						2.0	3
44	2.04	4	2.0						2.0	3
45	1.38	3	2.0						1.81	3
46	1.76	3								
47										
Middle Gray	9.51		8.5						10.36	
51	1.55	.004	2.0		2.09	.001			1.24	.004
52	1.7	7	1.9		2.09	3			1.9	4
53	1.76	6	1.8		2.1	2			2.6	4
54	1.69	5								
Lower Black	6.5		5.7		6.28				5.74	

Sample	LC-103 Thickness	LC-103 % Uranium (P)	LC-105A Thickness	LC-105A % Uranium P	LC-105A % Uranium C	LC-113A Thickness	LC-113A Uranium P	LC-113A Uranium C	10M-1 (Gruetli) Sample	10M-1 Thickness	10M-1 % Uranium
1	0.3	.003	1.25	.005	.001						
2											
Maury			1.25								
11											
12	2.5	.010	1.6	.009	.006	2.1	.009	.004	1	2.0	.012
13	2.0	9	1.15	10	7	1.1	8	3	2	1.5	9
14	1.7	7	1.2	10	5	2.5	6	2	3	1.0	11
15			1.05	7	4	1.0	8	3	4	1.5	10
16						2.0	8	3	5	1.5	9
17						1.0	8	4			
18						1.8	7	3			
Top Black	6.2	.0088	5.0	.009	.0056					7.5	.0103
21	1.1	.005	1.35	.006	.003						
22											
Upper silt	1.1	.005	1.35	.006	.003						
31	1.9	.006	2.1	.014	.004				6	2.0	.006
32	3.1	7	1.7	7	4				7	1.5	7
33	2.0	8	1.3						8	2.0	6
34			1.6	8	4				9	2.0	6
35			0.95								
Middle Black	7.0		7.65							7.5	
Upper Black	14.3	.0076	14.0			11.5	.0075	.003		15.0	.0082
41	1.9	.004	2.05	.004	.002	1.3	.004	.001			
42	2.3	4	2.1	4	1	2.0	4	1			
43	2.3	2	2.0	4	1	1.5	4	1			
44	2.5	3	2.05	4	1	1.6	3	1			
45			1.4	4	1	2.0	3	1			
46											
47											
Middle Gray	9.0		9.6			8.4					
51	1.9	.005	1.95	.005	.002	2.0	.005	.002	10	2.5	.003
52	2.0	6	2.0	7	3				11	2.0	3
53	1.0	6	1.9	5	2				12	2.0	3
54	1.5	5							13	1.5	2
Lower Black	6.4		5.85							8.0	

Chemical analyses, chiefly fluorimetric, are shown except where indicated differently at heads of columns.

P = percent equivalent uranium, determined by Geiger counts.

C = percent equivalent uranium, determined by chemical (fluorimetric) analyses.

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