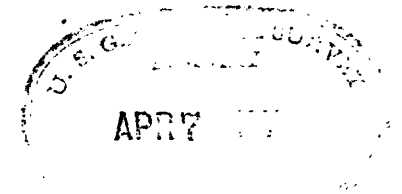
UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

PRELIMINARY REPORT ON THE ECONOMIC POTENTIAL OF THE CHATTANOOGA SHALE IN TENNESSEE DATA AS OF 1962



By

Andrew Brown

With a section on

The precision of determination of uranium in Chattanooga shale

By

Irving May

Open-File Report No. 75-135
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Note: This report is incomplete, lacking copies of figures 1-3, 23, and 26, which disappeared after the death of the author and cannot be located in the files of the U.S. Geological Survey.

This report is preliminary and has not been edited or reviewed for conformity with U.S. Geological Survey standards and nomenclature.

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Illustrations

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Economic potential of the Chattanooga shale in Tennessee

By Andrew Brown

Abstract

The Geological Survey's investigations of the Chattanooga shale in Tennessee and adjacent states on behalf of the U. S. Atomic Energy Commission consisted mostly of geologic studies and routine analyses of samples for uranium. In the course of the studies, however, other investigations were made, primarily to find answers to specific problems that arose from time to time. The large amount of analytical and related data obtained is here reported, with sufficient explanatory material to bring the data into proper perspective. Although the Survey has not made a comprehensive overall study of the geology, geochemistry, mineralogy, and petrography of the shale, sufficient information has been obtained to provide a sound basis for possible mining and processing of the shale in the future.

In addition to uranium, recovery of which was the objective in early studies, the Chattanooga shale contains thorium, in quantities (7 to 11 ppm) about equal to the crustal abundance of that element, and certain trace elements which are present in sufficient concentrations to make possible their recovery on a by-product basis. Among these are manganese, copper, nickel, molybdenum, cobalt, scandium, and possibly, on the basis of earlier work on the shale in Kentucky, silver and gold. Further, over large areas the shale will yield on destructive distillation approximately nine gallons per ton of oil. Preliminary studies have been made by other organizations on the recovery of the heat values in the shale as pipeline gas rather than oil; these studies are summarized, although they have not progressed to the point where definite conclusions can be drawn.

As the mineral contents and heat values in the shale are at best marginal, any evaluation of the economic potential of the rock must be predicated upon the recovery, not of any one constituent, but of as much as the combined values as possible. This condition presents certain problems, particularly as to the effect of the treatment necessary for recovery of the heat values on the possible recovery of the mineral content.

Although the Survey's investigations included parts of Kentucky and Alabama, estimates of the resources of the shale are limited to defined parts of the Northern and Eastern Highland Rims, the Cumberland Plateau, and Walden Ridge, all in Tennessee. In that state the shale comprises two members—the upper or Gassaway member, and the lower or Dowelltown member. The Gassaway member, except in the Northern Highland Rim, comprises a lower black unit, a thin middle unit of alternating beds of gray and black shale, and an upper unit of black shale; in the northern part of the state this upper unit includes locally at its top a phosphatic zone. The member contains from 20 to 25 percent organic matter, and its combined potential is much higher than that of other parts of the shale.

The Dowelltown member comprises two units; a lower unit of black shale, which contains about 10 to 17 percent organic matter; and an upper unit of gray claystone. Locally the lower unit of the member is as much as 8 feet thick and contains about 30 ppm uranium—about half the content of the Gassaway member—and about the same oil yield—about 9 gallons per ton. Its position below the almost barren (except for a relatively high thorium content) upper unit, which is as much as 10 feet thick, makes its utilization doubtful.

The Chattanooga member, which is the only part of the shale likely to be mined and processed in the foreseeable future, ranges in thickness in Tennessee from 6 to more than 20 feet. Its uranium content is highest in Walden Ridge, where it is about 70 ppm, and is somewhat less northeastward from that area. The oil yield follows a different pattern; it is almost negligible in Walden Ridge and comparatively low--about five gallons per ton--in the southern part of the Eastern Highland Rim; it increases to the north, however, and the shale in the northern part of the Eastern Highland Rim, and in the Northern Highland Rim and Kentucky, yields about nine gallons to the ton. The different patterns of distribution are interpreted as due to a positive correlation of uranium content with the total amount of organic matter in the rock, as well as to nearness to the shore line of the Late Devonian sea, whereas the oil yield is correlatable not with total organic matter, but with the percentage of sapropelic material in the organic material. The uranium content is highest near the shore line and therefore closest to a source area, but the oil yield is highest nearer the center of the sea.

Much of the data used in the preparation of this report was necessarily taken from analyses of outcrop samples, many of which show the effects of weathering on both uranium content and oil yield. Comparison of analyses of outcrop samples with those of drill cores, which may be presumed to be unweathered rock, shows that waterfall exposures, of which there are many in the Eastern Highland Rim, have apparently lost as much as 20 percent of their original uranium content, and that some bluff exposures and road cuts have lost less amounts; also, at some bluff exposures there has been a redistribution of the uranium toward the bottom of the outcrop. At such localities the uranium loss appears to be due primarily to water running over the outcrop; the mobility of the element in water, particularly alkaline waters such as those from the limy rocks overlying the Chattanooga, has been demonstrated.

Loss of oil yield through weathering follows a different pattern from that of uranium loss. Apparently it is a slower process, due in part to absorption of water by the clay minerals in the shale, in part to actual loss of kerogen through its removal as bicarbonate by the alkaline waters. Waterfalls, in which uranium loss is high, show little loss of oil yield as do most bluff exposures. The heaviest loss is in road cuts in steep hillsides, in which the present outcrop is not far behind the original outcrop, and at which weathering processes have been operative for decades or centuries.

A guide to the amount of weathering of outcrop samples is the water content obtained by the Fischer assays for oil, and particularly the oil-water ratio of the assays. The oil-water ratio of drill-hole samples and of some outcrop samples is invariably more than 1, and may run as high as 4 or 5; whereas the ratio for weathered samples is less than 1. Additional work, using more samples, might make it possible to obtain from the oil-water ratios at least semiquantitative data on weathering effects, rather than the largely qualitative data now available. For the present, however, estimates of both the uranium content and the oil yield of the shale should be based on core samples taken from below the water table.

The total uranium content of the Gassaway member of the Chattanooga shale in the Northern Highland Rim, the Eastern Highland Rim, the Cumberland Plateau and Walden Ridge as restricted in the text is estimated at 8,142,000 tons. The thorium content for the same area, where the range is from about 7 to 11 ppm, is estimated at about 1,100,000 tons. The oil yield in the Eastern and Northern Highland Rims is estimated at about 12.4 billion barrels; no estimates are given for the Cumberland Plateau and Walden Ridge, because of the low oil yield in the Ridge and the lack of data on the Plateau.

The area of highest uranium content and that of highest oil yield overlap in DeKalb and adjoining counties in the Eastern Highland Rim, where an area of about 500 square miles in which the Gassaway averages about 14 feet thick is estimated to contain about 840,000 tons of uranium, 76,000 tons of thorium, and should yield about 3 billion barrels of oil. This high-yield area probably could be extended a considerable distance eastward if more data were available. Another area of comparatively high combined potential is about 500 square miles in northern Davidson, southwestern Sumner, and southeastern Robertson Counties, in the Northern Highland Rim north of Nashville. In this area the Gassaway has a remarkably uniform thickness of 10 to 12 feet, and has a uranium content of about 55 ppm and an oil yield of 9 gallons per ton. Resources are estimated at 660,000 tons of uranium, 54,000 tons of thorium, and an oil yield of 2.2 billion barrels.

Should it be decided to recover the heat values in the Chattanooga shale as gas rather than oil, the rather sparse data indicate that the Gassaway member, in the same areas in the Northern and Eastern Highland Rims for which oil yield is estimated, might yield approximately 162 trillion standard cubic feet of gas having a heating value of 1,035 Btu SCF. No attempt has been made to estimate the resources of the trace elements in the shale; as the information on most such elements is from semiquantitative spectrographic determinations, the estimates could not be sufficiently precise to have much usefulness.

Introduction

The Geological Survey's investigations of the Chattanooga shale began in 1947 under the sponsorship of the U. S. Atomic Energy Commission and were directed toward the discovery of a large tonnage of uranium reserves. At that time the large deposits of uranium in the Colorado Plateau and elsewhere had not been discovered, and so urgent was the need for uranium that it was considered that the Chattanooga, despite its generally low concentrations of uranium, might be used as a source of the metal. In later years the emergence of the United States as a "have" rather than a "have-not" nation in uranium resources has relegated the Chattanooga shale to a marginal or submarginal status under present conditions.

The purpose of this report is to make available the Geological Survey's analytical data on the Chattanooga shale in Middle and East Tennessee and parts of Kentucky and Alabama, with sufficient explanatory material to correlate the data with the geology of the formation, which has been reported by Hass (1956), Brown (1956), Glover (1959), and Conant and Swanson (1961). None of these reports touched upon the uranium potential of the shale except incidentally, largely because such data were classified until the reports were either completed or well under way.

The Survey's first investigations of the Chattanooga shale were in the Smithville area, mostly in DeKalb County, Tenn., where unpublished reconnaissance studies of A. L. Slaughter and K. G. Brill showed that the shale was more radioactive than in other areas underlain by the Chattanooga. The studies were extended later throughout the Western and Northern Highland Rims and Walden Ridge in Tennessee and into southern and central Kentucky and northern Alabama. The program consisted of mapping, measuring, and sampling numerous outcrops of the shale, and of making radioactivity determinations and chemical analyses of the samples for uranium content. In 1948 the sampling was supplemented by a small drilling program and by the driving of a 100-foot adit for obtaining large samples of unweathered shale, both programs being carried out by the Survey. In 1953 the U. S. Bureau of Mines enlarged the adit, and drilled 61 core holes in Tennessee and 3 in Alabama. About 1955 the adit was destroyed by open-cut mining operations.

Until about 1954 the Survey did little geochemical and mineralogic work on the Chattanooga shale. Early geochemical and mineralogic studies were made by the Battelle Memorial Institute of Columbus, Ohio; later the Division of Research of the U. S. Atomic Energy Commission sponsored an intensive study of the chemistry, mineralogy, and petrography of uranium-bearing shales, with particular emphasis on the Chattanooga, by the Pennsylvania State University. The results of this investigation, which was limited almost entirely to the upper or Gassaway member of the Chattanooga shale, are reported by Bates (1956), Bates and Strahl (1957), Strahl (1958), and Kinney (1957, 1958). The University of Tennessee also made a geological and geochemical study of the shale, which is reported by Stockdale and Klepser (1959).

Since 1954 the Survey has made a number of studies directed mostly but not entirely toward evaluation of the shale as a source of uranium and oil; these have been reported by Breger, Meyrowitz, and Deul (1954); Breger (1955); Breger and Schopf (1955); Deul (1957); and Breger and Brown (1962). More extensive studies of the geochemistry of the shale are reported by Swanson (1960, 1961). An investigation of the thorium potential of the shale made in 1960 and 1961 is incorporated in this report.

The objective of this report is an evaluation of the Chattanooga shale as a possible source of uranium, oil, thorium, gas, and certain trace elements. It is not intended to be a comprehensive report on the composition and geology of the shale, as studies of that nature were not included in the Survey's part of the Atomic Energy Commission's program on the Chattanooga. For that reason most of the Survey's analytical data was obtained in the search for answers to specific questions rather than as part of an overall program, and there are gaps in the information that it has not been possible to fill by later work. Thus it is entirely possible that the report poses as many questions as it answers; but it is believed that presentation of the data that are available serves a useful purpose not only at the present time, but in the event that further work on the shale is indicated.

Acknowledgements

So many persons have contributed to this study that it is impossible to name all of them; the list includes all those who took part in the field work on the shale under the direction of Louis C. Conant. The assistance of these men, who are listed by Conant and Swanson (1961, p. 4-5) is gratefully acknowledged. For help in assembling and evaluating the data presented herein thanks are due L. R. Page, who encouraged and assisted the author in bringing together the analytical and other information; to R. A. Laurence, who was associated with the shale program from its inception and who read the manuscript in draft stage and offered many useful suggestions; and to the late W. H. Hass, whose studies of the paleontology and stratigraphy of the shale have been drawn upon freely. Personnal of the Survey's Washington laboratories, particularly F. S. Grimaldi, Irving May, Z. S. Altschuler, and Mrs. Alice Weeks, have been most helpful in the chemical and mineralogical problems involved. The cooperation of Paul C. Richards, in charge of the Survey's mapping program in Kentucky, in providing cores of two drill holes that penetrated the Chattanooga in Logan and Simpson Counties, Kentucky, has been of great help in adding to the knowledge of the shale in that State. The assistance of Mr. Robert J. Hickman of the U. S. Bureau of Mines in locating accurately the holes drilled in Tennessee in 1953 is also gratefully acknowledged.

Particular thanks are due V. E. Swanson, T. M. Kehn, and Irving Breger of the Survey, whose assistance has gone far beyond that which reasonably could have been asked or expected. Swanson, who participated in field work on the shale in the later stages of the program and who has made an intensive study of the geology and geochemistry of the formation, has been most generous in providing data in his possession and much helpful counsel. Kehn, who logged the cores of many of the holes drilled in 1953, logged the cores of the two holes drilled in southern Kentucky in 1962, and provided useful suggestions on the overall stratigraphy of the formation. Breger's work on the geochemistry of the shale, particularly as related to the organic constituents, has been drawn upon freely, and his counsel has been invaluable. The assistance given the author by these three scientists has been such that it is difficult indeed to give them the acknowledgement which is their due.

Area of investigations

The area covered by the Geological Survey's investigations of the Chattanooga shale is shown in figure 1*, which shows also outcrop localities and drill holes in that part of the region outside the area of more intensive investigations in Tennessee, which is shown in figure 2.*

* Figure 1. Map showing parts of Kentucky, Tennessee, and Alabama covered by the Survey's investigations of the Chattanooga shale, and key localities.

* Figure 2. Map showing area of intensive investigations of the Chattanooga shale in Tennessee, and localities.

The Smithville area, in which much of the earlier investigations and most of the drilling in 1953 was centered, is shown on a larger scale in figure 3.*

* Figure 3. Map of the Smithville area, DeKalb, Cannon, and White Counties, Tenn., showing outcrop of Chattanooga shale, sampled outcrops, and drill holes.

The investigations were carried on in parts of four physiographic provinces: the Nashville Basin, the Highland Rims, the Cumberland Plateau, and the Appalachian Valley-and-Ridge provinces. The last-named province, lying east of the Cumberland Plateau, contains a few exposures of the Chattanooga shale but as it is of no importance from an economic standpoint, is discussed only slightly.

* Figures missing.

The Nashville Basin is floored by limestones and related rocks of Ordovician age, and stands generally 400 to 500 feet above sea level. Structurally, it is the eroded crest of the Cincinnati Arch. The Chattanooga shale, of Devonian age, once covered the present basin but has been removed by erosion except for outliers of the Highland Rims.

The Highland Rims surround the Nashville Basin on all sides, standing generally about 400 to 600 feet above the basin and 800 to 1,100 feet above sea level. It is upheld by the highly resistant Fort Payne chert of Mississippian age or its equivalents, which protect the steep escarpments that are particularly pronounced in the Eastern Highland Rim. The Chattanooga shale is exposed in the escarpment above the Ordovician limestones and below the Fort Payne, generally about 60 to 100 feet below the top of the escarpment.

The Highland Rim is divided into four segments: the Eastern, Northern, Western, and Southern Highland Rims (see fig. 1*). As usually described, the Northern Highland Rim is separated from the Eastern and Western segments by the Cumberland River. The Southern Highland Rim is mostly in Alabama, and is separated from the Eastern and Western Highland Rims by the Elk River. For the purposes of this report the Western and Southern Highland Rims are of minor importance; in the Western Highland Rim the Chattanooga shale thins southward to extinction, and little data on the shale in the Southern Highland Rim are available. Most of the geological and geochemical data, and all of the resource estimates, are limited to the Eastern and Northern Highland Rims.

* Missing.

Because of changes in the characteristics of the shale in the northern part of the Eastern Highland Rim as defined above, for the purposes of this report the boundary between the Northern and Eastern Highland Rims is redefined as the line of Roaring River, a westward-flowing tributary of the Cumberland River in Overton and Jackson Counties, Tenn. The area north of Roaring River, usually considered as part of the Eastern Highland Rim, is here placed in the Northern Highland Rim. Similarly, as the Western Highland Rim is of little interest but as the shale in Cheatham and Davidson Counties is essentially a continuation of that north of the Cumberland River, the boundary of the Northern Highland Rim is placed at the southern boundaries of those counties.

The Cumberland Plateau is east of the Eastern Highland Rim in Tennessee, and south of the Southern Highland Rim in Alabama. In Tennessee it stands about 800 feet or more above the Highland Rim and 1,800 to 2,000 feet above sea level; in Alabama the altitudes are somewhat lower. The Plateau is upheld by rocks of Pennsylvanian age which contain valuable coal beds. The eastern boundary of the Plateau is the Cumberland Front, which abuts the Tennessee River valley in Tennessee but is not so distinctly marked in Alabama.

Southeast of Cumberland County, Tenn., the Cumberland Plateau is broken by the Sequatchie Valley, representing the eroded trace of the Sequatchie Fault. Because conditions in Walden Ridge are widely different from those in the Cumberland Plateau proper, the Ridge is discussed separately in this report.

Analytical data

During the field work on the Chattanooga shale approximately 3,000 samples were taken from about 250 outcrops, 75 drill holes, and an adit. All of the samples were tested for total radioactivity and were analyzed chemically for uranium. When the program began practically no analytical work had been done on samples containing uranium in concentrations as low as those in the Chattanooga, and the Survey laboratories were forced to attack the problem practically from the beginning. By 1952 methods had been worked out which gave reliable chemical analyses within a precision of $\pm$ .0010, or 10 ppm; these methods have been reported by Grimaldi and others (1954).

In 1953 the Atomic Energy Commission requested that uranium analyses of the Chattanooga shale be made to a precision of $\pm$ .0005 or 5 ppm, and all analyses made after that year are to this precision. Tests of the precision of the analyses are reported by May in a later section of this report.

All uranium analyses used in this report were made to a precision of 5 ppm except a few made in 1952 to a precision of 10 ppm, which are noted in the tables. The data used include about 1,180 samples, taken from 47 outcrops and 67 drill holes which, when the rather remarkable uniformity of the shale over considerable areas is taken into consideration, give good coverage of the area studied. The localities are shown in figures 1* and 2* and in figure 3*, which shows on a larger scale the Smithville area in which the earliest work was done and in which most of the drilling by the Bureau of Mines in 1953 was concentrated.

Complete chemical analyses were made of shale samples from 9 localities, and semiquantitative spectrographic analyses were made of samples from 16 localities. Analyses for thorium were made of samples from 9 localities, and pyrolitic oil yield was determined on samples from 34 localities.

* Missing.

Stratigraphy

Formations underlying the Chattanooga shale

In the Eastern and Southern Highland Rims the Chattanooga shale rests unconformably on the Lieper's and Catheys limestones of Ordovician age. In the Northern Highland Rim the underlying rocks are the Richmond group of Ordovician age and the Brassfield, Osgood, and Bledsoe formations of Silurian age. In Walden Ridge the shale is underlain by the Richmond group and the Brassfield formation. For the Nashville Basin Wilson (1949) has shown that during Ordovician and Silurian time the present basin was covered by a thick sequence of sediments, mostly limestones. The area was then uplifted above sea level and subjected to continuous erosion during much of Silurian time and all of Early and Middle Devonian time. By Late Devonian time it had been reduced to a peneplain, bounded on the southeast by a granitic landmass that extended southwest through what is now western North Carolina to the vicinity of the present Birmingham, Alabama. Northwest, and southwest of Birmingham the present cover of coastal plain deposits makes tracing of the Devonian shoreline difficult, but from the fact that the Chattanooga shale has not been found in the Mississippi subsurface except in the northeastern corner of that state, it appears that the bounding landmass turned north and met Ozarkia, which extended north through Tennessee not far from the present course of the Tennessee River where it separates West from Middle Tennessee. To the north, the peneplaned area that was covered by the Late Devonian epicontinental sea included much of the present Central United States and extended far west of the

Mississippi River. The extent of this sea is shown in figure 4 adapted

Figure 4. Probable extent of Late Devonian and Early Mississippian sea in parts of the Eastern United States, from Conant and Swanson.

from Conant and Swanson (1961, pl. 14), which shows also the area covered in Late Devonian time by deltaic sediments and that covered by marine deposits.

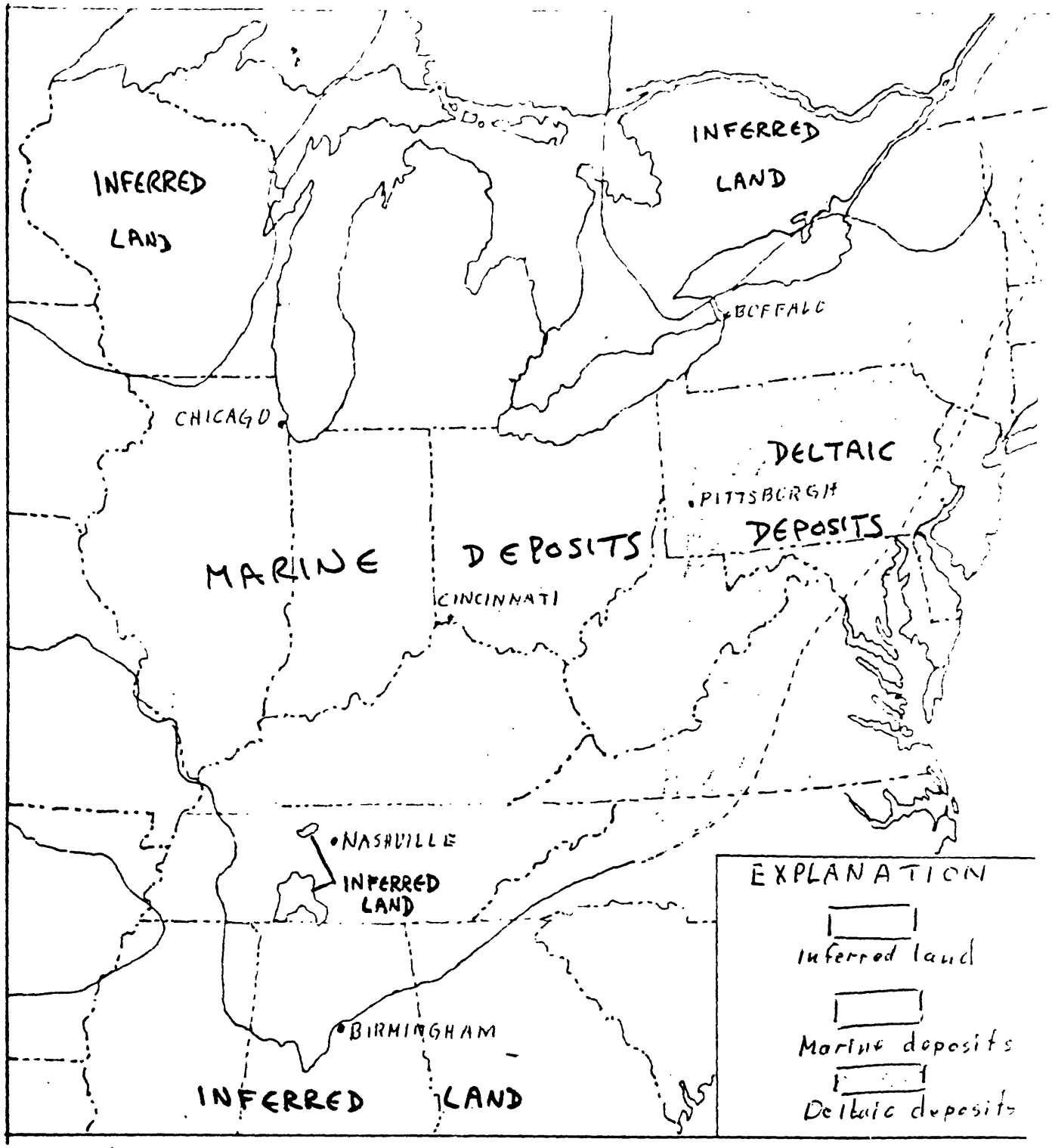

Fig. 4—Map showing probable extent of Late Devonian and Early Mississippian sea in parts of the Eastern United States, from Conant and Swanson, 1961, pl. 14.

Fig 4 (Light pattern) 20A (Darker sand pattern)

Chattanooga shale

General statement

Previous reports on the Chattanooga shale treat it primarily as a formation comprising two members—the lower or Dowelltown member and the upper or Gassaway member. The Dowelltown member in turn is divisible into two units—a lower or black unit and an upper or gray unit. The Gassaway member is divisible into three units—a lower black unit, a middle unit of alternating black and gray beds, and an upper unit of black shale. In addition, the upper unit of the Gassaway contains locally at its top a phosphatic zone. Each of these units differs from the others in its economic potential, particularly as a source of uranium, and for that reason is discussed separately. These units are shown in the stratigraphic section (fig. 5). As a corollary to this

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Figure 5. Stratigraphic section of the Chattanooga shale.

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method of treatment, the stratigraphic section of this report is longer and more detailed than would ordinarily be given in a report of an economic nature. Resource estimates for the formation as a whole would be not only useless but possibly misleading, are therefore not given; instead, estimates are made for the lower unit of the Dowelltown member; the upper unit of the Dowelltown member; and the Gassaway member as a whole, for the reason that in any future mining operation that member probably would be taken in its entirety. However, for a limited area in which the upper unit of the Gassaway member is of mineable

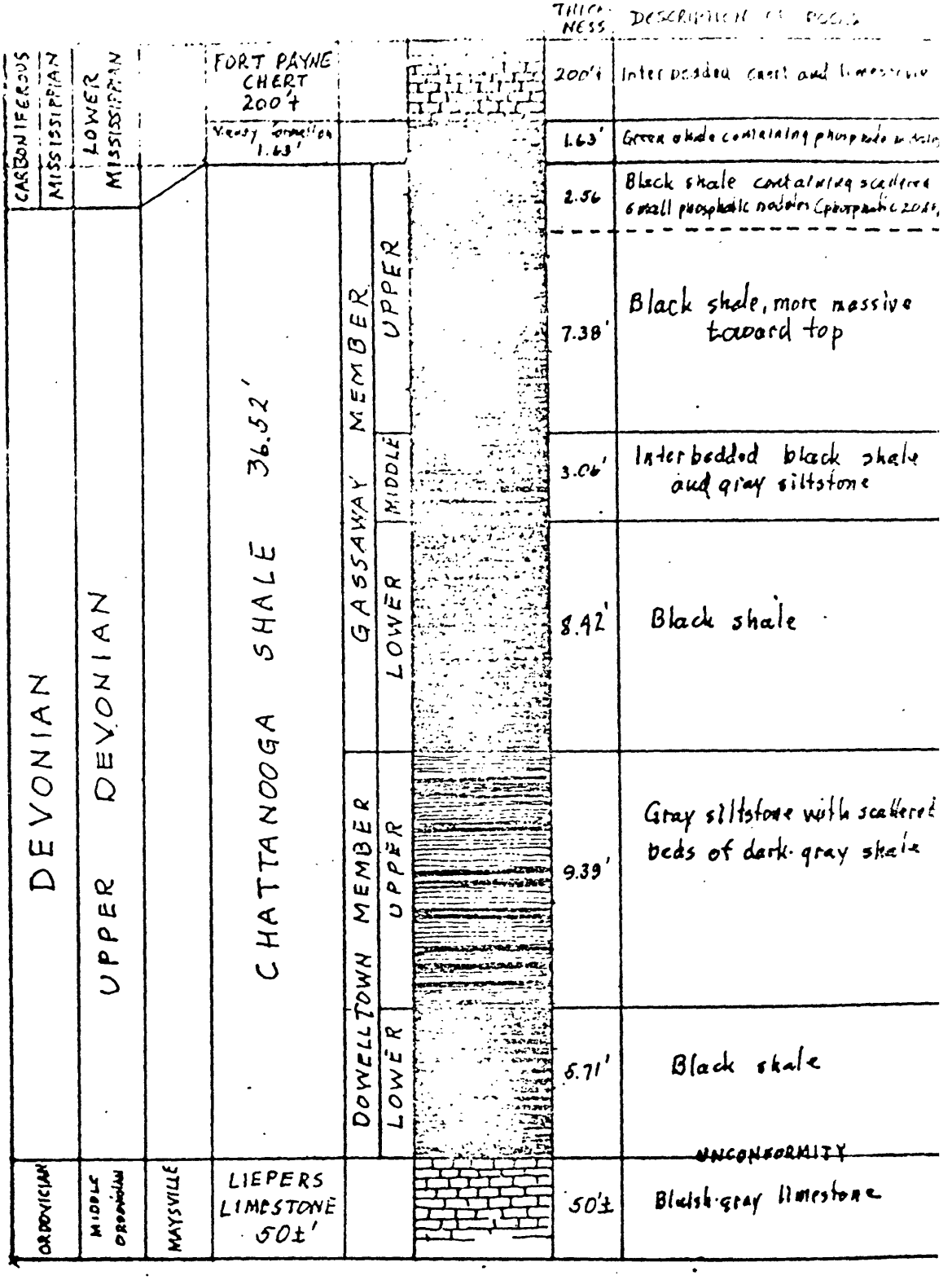

Fig. 5:--Stratigraphic section of the Chattanooga shale at locality 9, White County, Tennessee. At this locality all units of the shale, and the phosphatic zone, are present.

thickness and has comparatively high uranium content and oil yield. estimates for that unit are given also.

The Chattanooga shale in the area covered by this report is the southern and southeastern part of a vast area underlain by carbonaceous shales laid down in the Late Devonian epicontinental sea (fig. 4) and designated by various names--the Antrim shale in Michigan, the Ohio shale in that state, and the New Albany shale in Indiana. All of these formations are correlative and form a continuous sheet in the region. The peneplained surface on which they were deposited was not of course absolutely level, and the waters of the sea, moving in from the north, encroached gradually to the south and southeast. Probably they formed first a series of marshy lakes (Theissen, 1925, p. 24-25), which later coalesced as the sea level rose to form a vast body of shallow water in which bottom circulation was poor, and therefore in which reducing conditions prevailed. Probably the last part of the region covered by the sea, as shown by the fossil evidence, was in Tennessee and Alabama. In the lower part of the New Albany shale of Kentucky and Indiana fossils of Genesee age, classed by Cooper (1942, p. 1773) as being of latest Middle Devonian age, have been found; in Tennessee similar fossils have been found only in Macon and adjacent counties in the Northern Highland Rim, in the Trousdale formation of Pohl (1930). Cooper reports one fossil of Genesee age from an unnamed locality in Alabama. Except for the small areas which contain Genesee fossils the Dowelltown member of the Chattanooga shale in Tennessee and Alabama is in general equivalent to the Finger Lakes, Chemung, and basal Cassadega stages of the Upper Devonian of New York (Hass, 1956).

Deposition of the Chattanooga shale in Tennessee and adjacent states covered such a long period of time—the generally accepted figure is about 5 million years—that any interpretation of depositional conditions must of necessity be highly generalized. One postulated reconstruction of the Tennessee and Alabama portions of the Late Devonian sea (fig. 6) shows the approximate southeastern, southern, and western

Figure 6. Sketch map showing probable land and sea areas in Late Devonian time in Tennessee and adjacent states.

shorelines of the sea at its greatest extent; land areas separating the sea in Alabama from that in Tennessee during Dowelltown time and early Gassaway time; and an area in Lewis, Lawrence, Wayne, and Giles Counties, Tennessee, and Limestone County, Alabama, that was never covered by the sea. This area, designated the Hohenwald Platform by Conant and Swanson (1961, fig. 13) is named for the town of Hohenwald, Tennessee, and can be delimited with a high degree of accuracy. Figure 6 is taken largely from Conant and Swanson (1961, pl. 14 and fig. 13); the postulated land area in northern Alabama during Dowelltown time, however, is smaller than that shown by them or by Glover (1957, fig. 16). This change was made after comparison of the cores from three drill holes in Blount County, Alabama, with those from holes in Tennessee in which the members of the Chattanooga shale are clearly distinguishable, and on the basis of chemical analyses of the cores from drill hole C64. Differences in the gross composition of the shale as shown by the analyses (which were not available when Glover wrote his report)

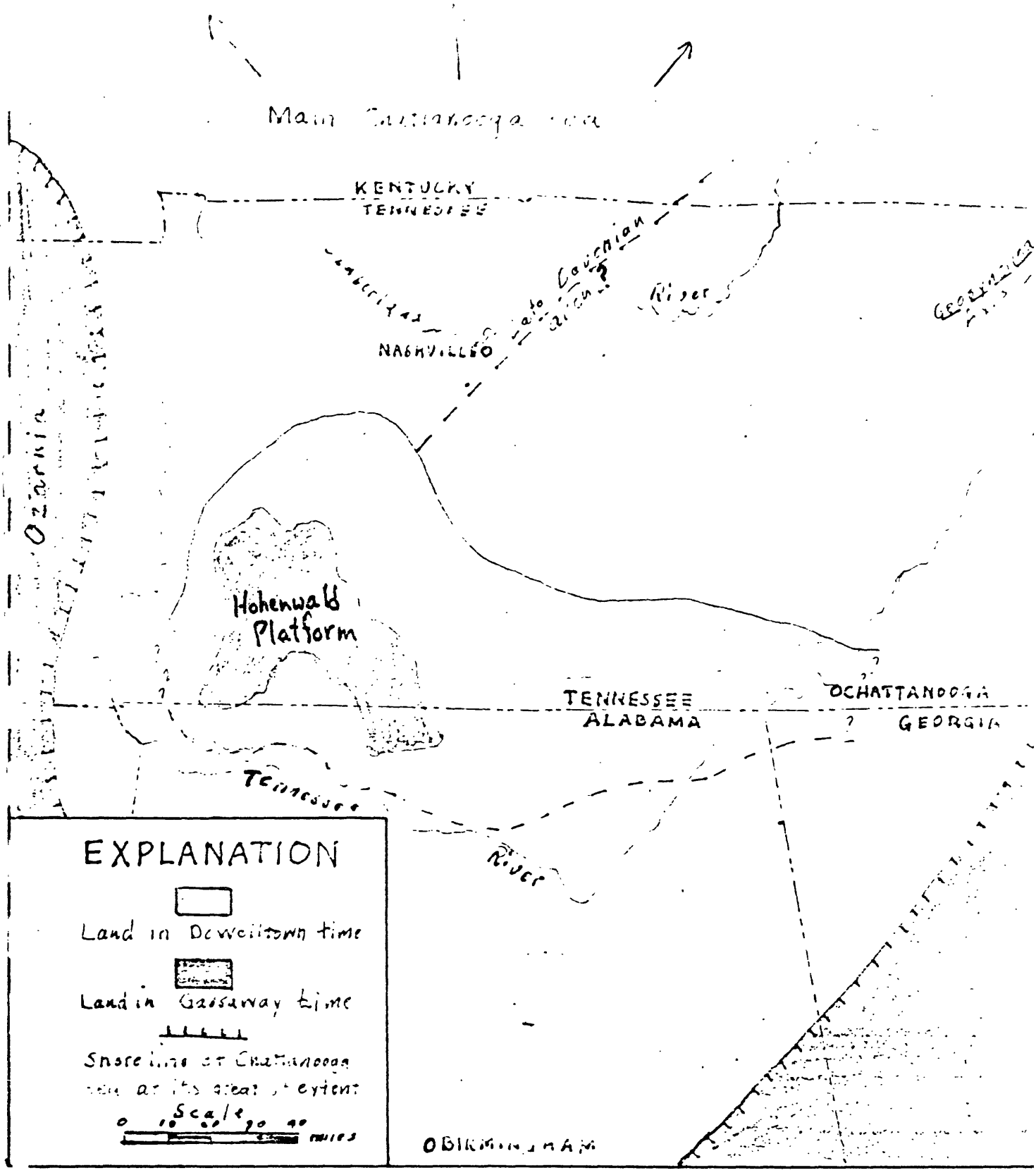

Fig. 6:--Sketch map showing probable land and sea areas in Late Devonian time in Tennessee and adjacent states

16

(Light pattern)

24A

(Darker pattern)

indicate strongly that the upper 11.95 feet of the shale at this locality is the Gassaway member and the lower 7.4 feet is the Dowelltown member, instead of the entire section being Gassaway as Glover considered it. Therefore the southern boundary of the land area in Dowelltown time has been moved northward.

Figure 6 shows also the general course of a Late Devonian arch extending northeast from the Hohenwald Platform into Kentucky. Along this ridge the Dowelltown member of the Chattanooga shale is thin and locally absent, but thickens to both the northwest and southeast. Also shown is the direction of the Late Devonian geosyncline in which the Late Devonian deposits are thickest (Conant and Swanson, 1961, p. 51, fig. 13). The geosyncline enters the area of this report slightly if at all, but its influence extended far enough south to account to some degree for the thickening of the Chattanooga shale northward in the Walden Ridge area, particularly at drill hole C50 (see fig. 2*).

It cannot be emphasized too strongly that figure 6 attempts to show in a highly generalized way only the shorelines of the Late Devonian sea at its greatest extent in Dowelltown and Gassaway times, and that the shorelines in all likelihood were far more irregular than is indicated by the lines on the map. Further, as the sea advanced southward over a peneplaned but not level surface, the shoreline at any given time was irregular, marked by many estuaries or small embayments. Although the uniformity in composition and general characteristics of the units of the Chattanooga shale over large areas is truly remarkable, small but possibly significant differences have been noted at a number of localities and in more than one unit of the shale. It is reasonable to assume, although sufficient information to prove the case is lacking, that these differences may be explained in part by the location of the shoreline at the time the affected unit was being deposited.

* Missing.

The sediments that entered the Chattanooga sea were extremely fine-grained and could have been transported by either wind or water. In Tennessee the primary source of the sediments was the landmass to the southeast, that is interpreted as consisting of granitic rocks standing not much above sea level; had they been high, more and coarser detrital material would have been brought into the sea. The shales in Alabama, however, are sandier than those in Tennessee, and the detrital material is coarser.

In both Alabama and Tennessee [deposition] the consensus is that deposition was continuous, except locally, throughout not only Late Devonian time but also throughout Mississippian time, when the muds of the Chattanooga sea were covered and compacted by the younger formations.

Dowelltown member

In Alabama and the Northern Highland Rim of Tennessee the Dowelltown member consists of dark-gray shale; in the Eastern Highland Rim and the Cumberland Plateau, including Walden Ridge, it is divisible into two units; a lower unit of black shale, and an upper unit of gray claystone. [The economic potential of the member is limited largely to areas in which the units are distinguishable.]

Lower unit

The lower unit of the Dowelltown member is a dark-gray to black fine-grained carbonaceous siltstone that breaks with a conchoidal fracture and that when freshly broken emits a petroliferous odor. As a distinguishable unit it is present only in the Eastern Highland Rim, in the Cumberland Plateau, and in Walden Ridge. It is thickest--8 to 10 feet--along the Highland Rim escarpment in Coffee and Cannon Counties, Tennessee, and the original area of greatest thickness probably included most of the present Nashville Basin. It did not extend as far west, however, as locality 185 (see fig. 2)*, which contains only upper Dowelltown beds. The unit thins eastward; it is absent in the southern part of Walden Ridge, and only 2 to 3 feet thick at the northern localities. In the latitude of northern Franklin and Marion Counties it thins southward to extinction, and north of the Roaring River line it cannot be identified because of facies changes.

* Missing.

The generalized isopach map of the lower unit of the Dowelltown member (fig. 7) reflects the sparse data for certain parts of the area,

Figure 7. Generalized isopach map of lower unit of the Dowelltown member.

particularly in eastern Putnam and White Counties and western Cumberland County. The only precise data are those from drill hole C211, where the unit is 2 feet thick. Total thicknesses of the Chattanooga shale in the area north of locality C211 as shown by oil-well logs (Milbous, 1959), and evidence that the Gassaway member maintains a fairly uniform thickness in that direction whereas the thickness of the total formation decreases, indicate that in much of the area the Dowelltown member is thin, and the lower unit very thin or locally absent.

The lower unit of the Dowelltown member is virtually homogeneous. The characteristics of the shale, and the fact that the embayment in which it was deposited was landlocked or at least barred on all sides except the north and possibly was barred to some extent on the north side, indicate deposition in a barred basin. Into such a basin but little detrital material was introduced, and strongly reducing conditions prevailed in the bottom muds.

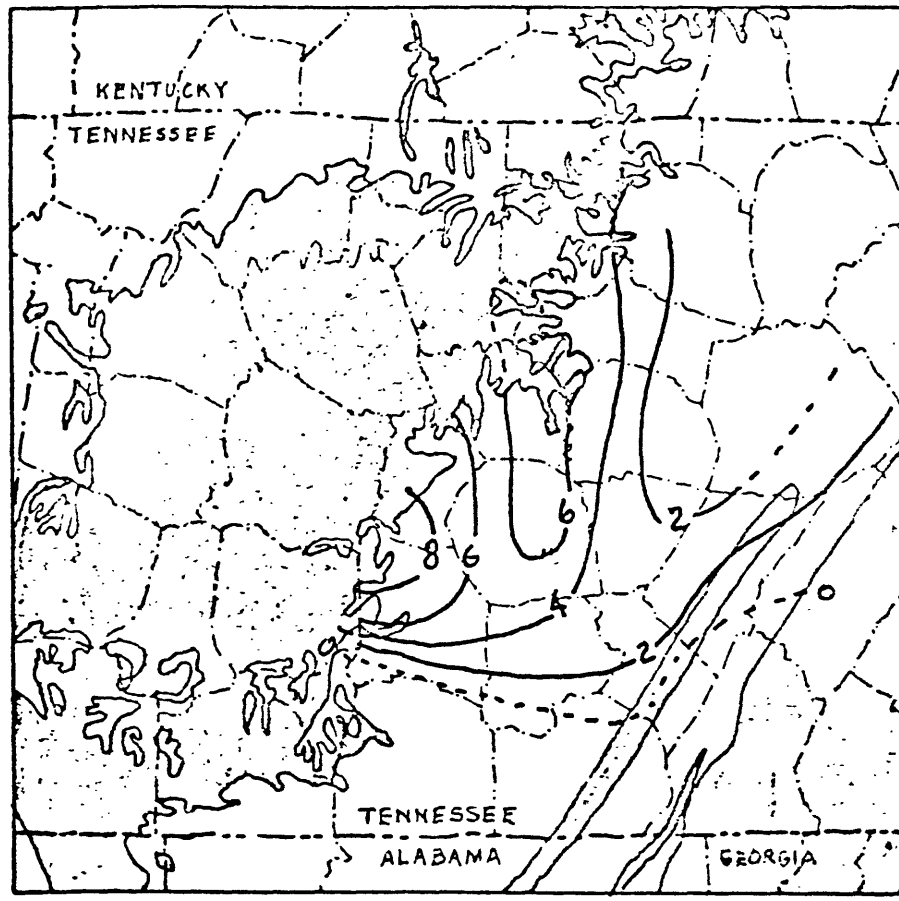

Fig. 7.--Generalized isopach map of the lower unit of the Dowelltown member of the Chattanooga shale

Isopach interval, 2 feet.

Upper unit

The upper unit of the Dowelltown member is a medium- to light-gray claystone which contains a number of beds of dark-gray shale 1 to 3 inches thick. It rests conformably upon the lower unit and covers a larger area, thus representing a slight enlargement and possibly a slow subsidence of the Dowelltown sea.

The thickest remaining exposure of the upper unit of the Dowelltown member is at locality 185 in southeastern Williamson County (see fig. 2) where the unit is 13 feet thick. It is 8 to 10 feet thick in DeKalb and Cannon Counties in the Eastern Highland Rim, and thins southward to extinction a short distance south of the southern limit of the lower unit. It also thins northward from the Smithville area to the Roaring River line, where it becomes indistinguishable. To the east, it is 8 feet thick at locality C211 and 11 feet thick at locality C50; these thicknesses compared to the comparative thinness of the lower unit at the same localities, indicate a subsidence in those areas which may be related to the Late Devonian geosyncline which is well developed to the northeast. A generalized isopach map of the upper unit of the Dowelltown member is given in figure 8.

Figure 8. Generalized isopach map of upper unit of the Dowelltown member.

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*Missing.

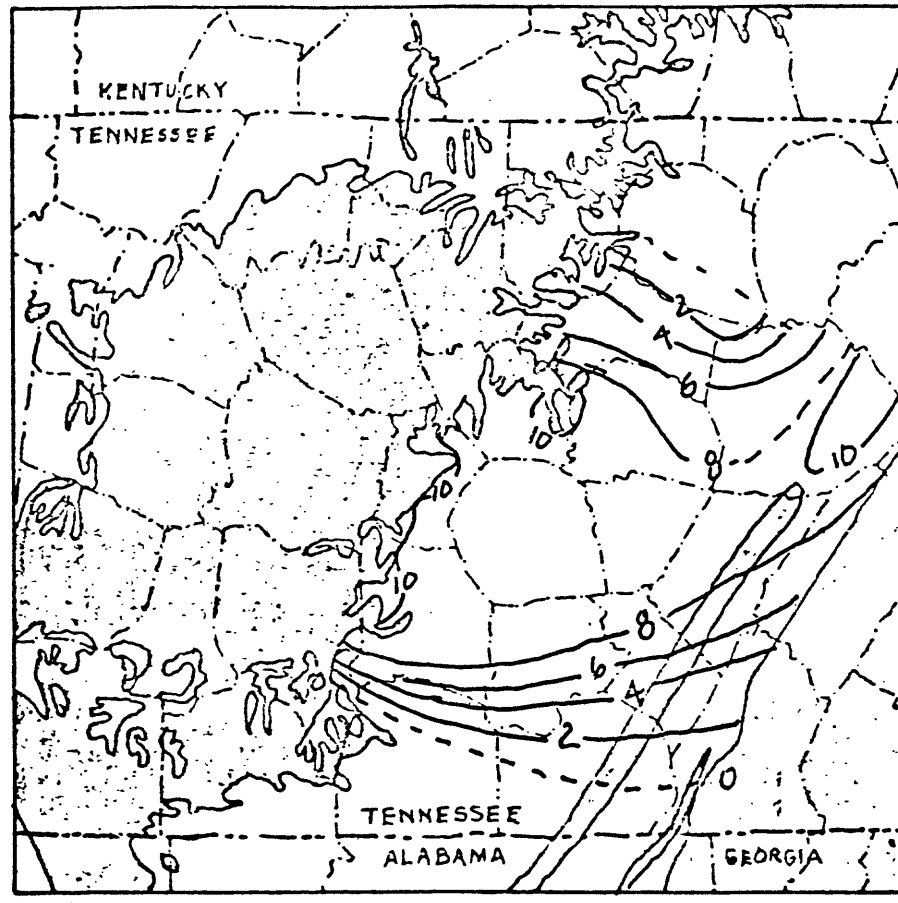

Fig. 4:—Generalized isopach map of the upper unit of the Dowelltown member of the Chattanooga shale

Isopach interval 2 feet

The gray claystones of the upper Dowelltown contain only about one-third to one-fourth as much organic matter as the underlying and overlying black beds. This difference could be attributed either to a much greater influx of detrital material into the sea during late Dowelltown time, or to a change from reducing to neutral or even oxidizing conditions in the sea. Available evidence, including analyses of the shale which are discussed in later sections of this report, support the statement of Glover (1959, p. 156) that the gray beds of the Chattanooga are primarily the result of larger amounts of detrital material in the sea rather than of a change in conditions. The gray beds thus represent much faster deposition than the black beds.

Throughout most of the Eastern Highland Rim, the Cumberland Plateau, and Walden Ridge the upper unit of the Dowelltown member contains, everywhere within 2 feet of the top of the unit, the Center Hill bentonite bed. This bed, which is only about 0.1 foot thick but which is easily distinguished in the field, represents a fall of volcanic ash from a source which probably was a considerable distance to the east or northeast (Conant and Swanson, 1961, p. 31-32). The discovery of the bed by Hass (1948) is strong evidence against the belief, widely held before 1947, that the Chattanooga shale is a time-transgressing unit. The bed is absent in approximately the northern half of Cannon County, including localities 99, 100, and 101 in the Eastern Highland Rim (see fig. 2*), and in much of the Northern Highland Rim.

*Missing.

Undivided member

Throughout the Northern Highland Rim as redefined for this report the Dowelltown member is a medium-dark-gray to dark-gray shale of much the same appearance and composition from bottom to top. At most outcrops it can be distinguished from the overlying Gassaway member by its thinner bedding and its tendency to be recessed slightly, but in drill cores the members can be differentiated only with difficulty except locally where the Bransford sandstone bed (Conant and Swanson, 1961, p. 35) is present at the base of the overlying Gassaway member.

The lower part of undivided Dowelltown member is the oldest part of the Chattanooga shale in Tennessee, as shown by the presence at the base of the member in northern Macon and adjacent counties of the Trousdale formation of Pohl (1930). This unit, only a few inches thick is here included in the undivided Dowelltown member. It is present close to but west of the late Devonian arch that extended northeastward from the Hohenwald Platform into Kentucky.

The thickness of the undivided Dowelltown member east of the Late Devonian arch and west of the Cumberland River is from 0 to 3 feet; east of the Cumberland River the thickness ranges from 3 to 6 feet in Tennessee and, on the basis of scattered conodont data (Hass, 1956) it is somewhat less in southern Kentucky. West of the arch the thickness of the member ranges from 7 to more than 15 feet and varies considerably within short distances, indicating that in that region the member was laid down on a comparatively uneven surface. South of Davidson County the member thins to extinction.

Data on the Dowelltown member in the Northern Highland Rim are relatively sparse as compared to those on the Gassaway member, because at many of the localities studied the Dowelltown member was neither measured nor sampled. The generalized isopach map of the member (fig. 9) reflects this lack of data.

Figure 9. Generalized isopach map of the undivided Dowelltown member

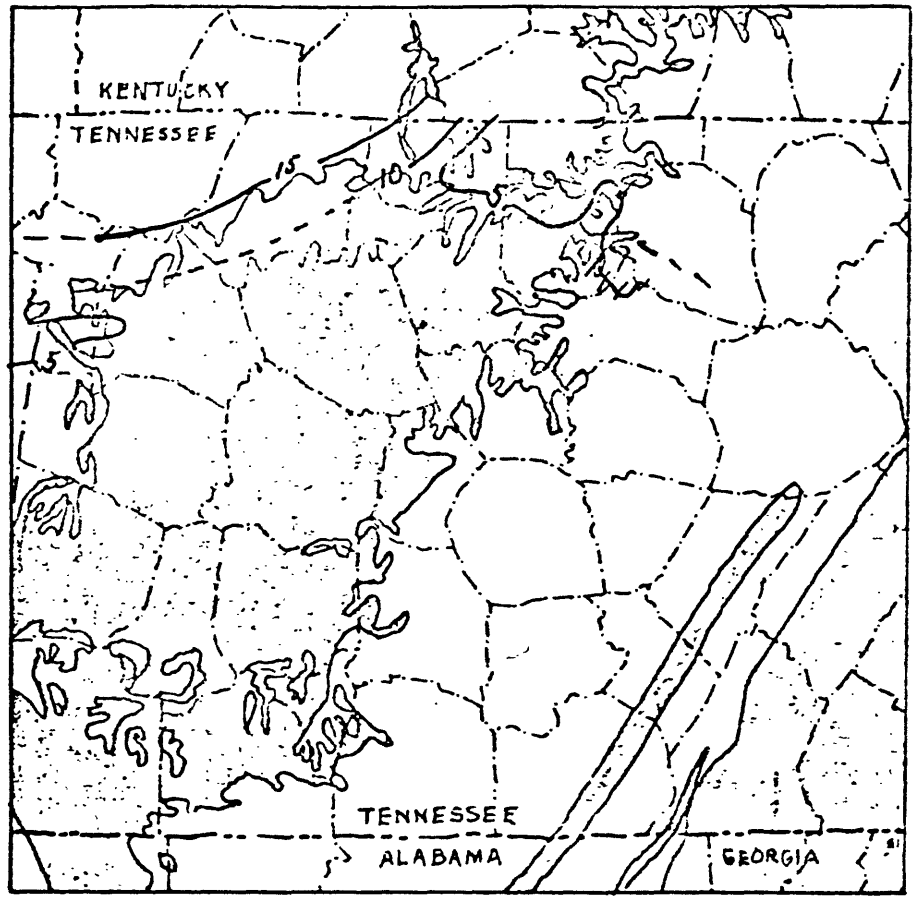

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Fig. 9:— Generalized isopach map of the undivided Dowelltown member of the Chattanooga shale

Isopach interval 5 feet

At several places in the western part of the Northern Highland Rim, among them localities 203B and C55, gray beds similar in appearance to the Upper Dowelltown of the Eastern Highland Rim occur between the black Dowelltown and the overlying Gassaway member. Although the distances are too great for positive correlations to be made, the presence of these gray beds, and the presence locally in other parts of the Northern Highland Rim of apparent angular unconformities between the Dowelltown and the Gassaway, are evidence that the black undivided Dowelltown of that region may be in large part correlative with the Lower Dowelltown of the Eastern Highband Rim, and that over much of the region beds equivalent to the Upper Dowelltown were never deposited or, if deposited, were removed later by erosion. If the Late Devonian Arch was a positive area during much of Dowelltown time, the absence of the gray beds is readily explained. The absence of the Center Hill bentonite in the Northern Highland Rim is of interest in this connection, although data on the source of the ash fall which the bentonite represents are too scanty to admit of a positive conclusion. There can be no doubt, however, that the Late Devonian Arch exerted a considerable influence upon Dowelltown deposition. Northwest of the arch the Dowelltown is sandy from bottom to top, whereas to the southeast it is sandy only at the base (Hass, 1956, p. 19). Also, holes drilled in 1962 in Logan and Simpson Counties, southern Kentucky, show that the entire Chattanooga shale section there differs widely from that at the closest Tennessee localities (T. M. Kehn, written communication, 1962).

The lower beds of the Chattanooga shale at localities C64, C65, and C66 in Alabama are considered in this report as being of questionable Dowelltown age. The distance of these drill holes from other localities, and the lack of paleontologic data, make any attempt at positive correlation impossible at this time.

Gassaway member

The Gassaway member has much greater potential as a source of uranium, oil, and other economic products than either unit of the Dowelltown member, and for that reason most investigations of the Chattanooga shale have been concentrated on the Gassaway. The best evidence is that except for the Northern Highland Rim and a small part of the Eastern Highland Rim deposition was continuous from Dowelltown into Gassaway time, and for the region as a whole there was no abrupt change in depositional conditions. There were, however, a number of differences as well as similarities between the two members that should be taken into consideration.

The first difference is that during Dowelltown time the Chattanooga sea in Alabama, Tennessee, and southern Kentucky was divided into embayments, separated from each other by the Hohenwald Platform and by arches or ridges extending northeast and east from the platform. The Tennessee embayment included the present Eastern Highland Rim, Cumberland Plateau, and Walden Ridge; this embayment was deepest in the western part of the Eastern Highland Rim, and progressively shallower northward; in southern Kentucky it may be considered as barred except northeast of Walden Ridge. The Alabama embayment was separated from that in Tennessee by the ridge that extended eastward from the Hohenwald Platform to approximately the present location of Chattanooga. In contrast to the separated embayments of Dowelltown time, the sea during Gassaway time covered the entire region and formed one great southern extension of the main Chattanooga sea.

A second difference, relating to Tennessee and southern Kentucky, is that the deepest part of the Gassaway sea was considerably east of the deepest part of the Dowelltown sea, and that near the Tennessee-Kentucky state line the Gassaway sea deepened northward, whereas the Dowelltown had become progressively shallower except where influenced by the geosyncline to the northeast.

A third and most important difference may be postulated from the much smaller proportion of gray beds in the Gassaway member as compared to those in the Dowelltown member, and from the higher percentage of carbonaceous material in the Gassaway member. If, as seems likely, the gray beds represent primarily an increase in the amount of detrital material brought into the sea rather than changes in bottom conditions, it follows that deposition during Gassaway time was much slower than it had been during late Dowelltown time.

Similarities between the two members include the absence, except locally, of gray beds in either member in the Northern Highland Rim and in Alabama. Also of interest, though its meaning is not known, is the fact that the gray beds of the Gassaway member are present in almost exactly the same area as those of the upper unit of the Dowelltown member.

In summary, the general picture of deposition of the Gassaway member in the area of this report is one of extremely slow deposition in a shallow sea (Conant, 1956), into which only a small amount of detrital material was introduced and in which bottom conditions were so strongly reducing that the great amount of carbonaceous material in the black muds could not be oxidized nor removed by scavengers.

The thickness of the Gassaway member in Tennessee ranges from about 4 feet in southern Tennessee, not far east of the Hohenwald Platform, to 20 feet at locality C50, northeast of Walden Ridge, and in the eastern part of the Northern Highland Rim. In the western part of the Northern Highland Rim the thickness of the Gassaway, like that of the underlying Dowelltown, is comparatively irregular but in general it thins westward to the vicinity of Nashville, and southward from that city it thins to extinction. An isopach map of the member is given in figure 10.

Figure 10. Isopach map of the Gassaway member.

In the Eastern Highland Rim as here redefined the Gassaway member is divisible into lower, middle, and upper units. These units can be distinguished also in cores from the northern localities in Walden Ridge, but can be identified with difficulty if at all at outcrops in the same area. In the Northern Highland Rim and Alabama the Gassaway, like the Dowelltown, cannot be subdivided. At the top of the upper unit in the northern part of the Eastern Highland Rim, and locally at the top of the undivided member in the Northern Highland Rim, is a phosphatic zone which, because of its influence on the concentration of uranium, is discussed separately in the text and shown separately in the tables.

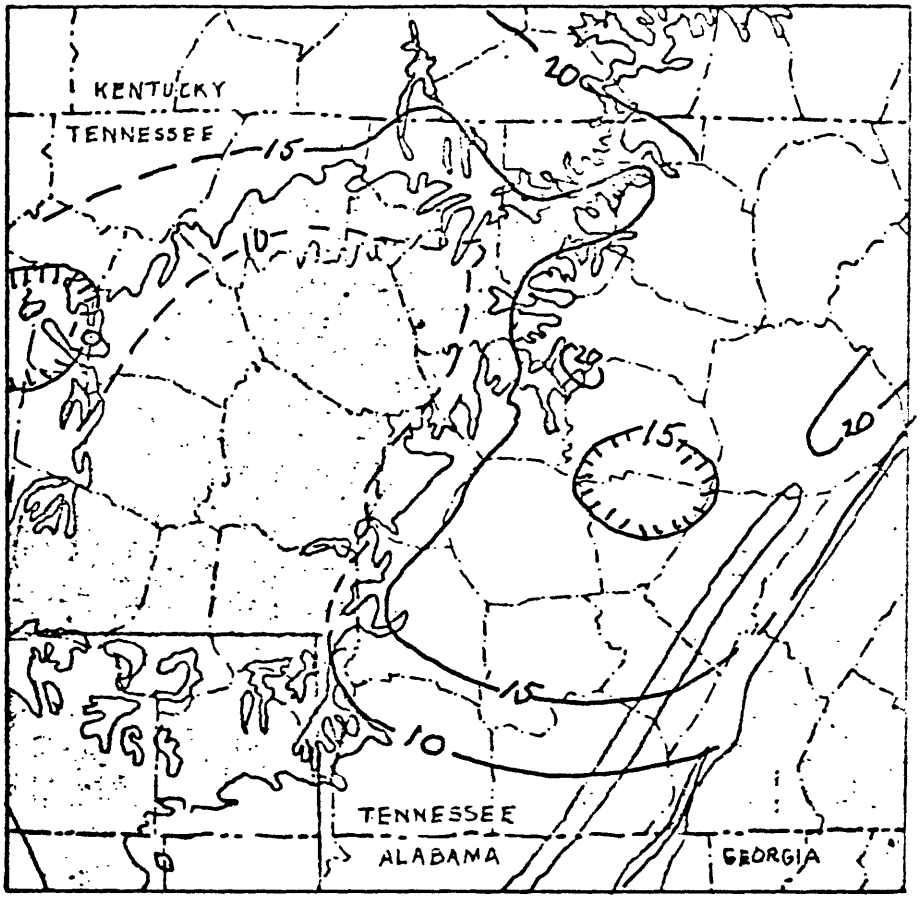

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Fig. 4:—Generalized isopach map of the Gassaway member of the Chattanooga shale

Isopach interval 5 feet

Lower unit

The lower unit of the Gassaway member is a tough, fine-grained, dark-gray to black shale; in appearance, general composition, and other characteristics it is much like the lower unit of the Dowelltown member except that it is somewhat thicker-bedded. In the Eastern Highland Rim and Walden Ridge it rests, conformably except locally, upon the upper unit of the Dowelltown member, the contact being sharp or distinguishable within one or two inches. It is thickest—8 to 10 feet—in Warren, eastern DeKalb, western White, and southern Putnam Counties, and thins in all directions from that area except for a thickening at locality C50 in the northern part of the Walden Ridge area. Northward, it disappears as an identifiable unit near the Roaring River line. A generalized isopach map of the lower unit of the Gassaway member is given in figure 11.

Figure 11. Generalized isopach map of the lower unit of the Gassaway member.

Middle unit

The middle unit of the Gassaway member consists of a sequence of alternating thin (1- to 2-inch) beds of black and gray shale. At most localities 3 to 5 gray beds can be distinguished (Conant and Swanson, 1961, p. 40), but individual beds cannot be traced for more than short distances and they probably are lenticular.

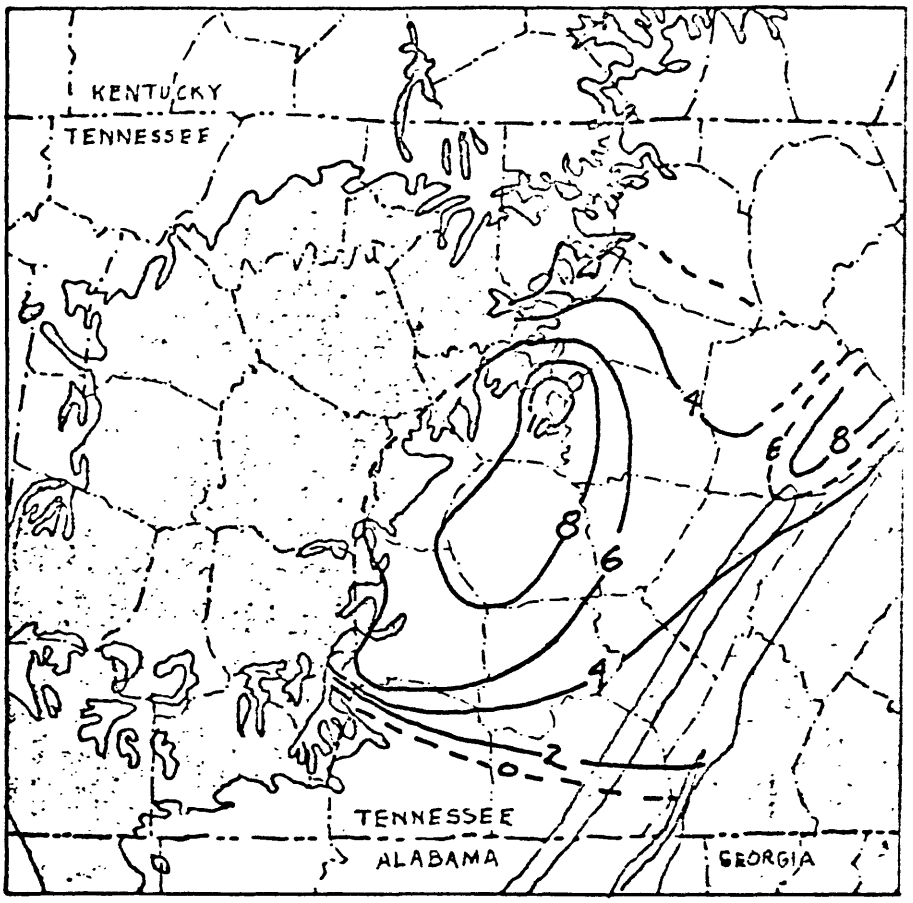

Fig. 11:—Generalized isopach map of the lower unit of the Gassaway member of the Chattanooga shale

Isopach interval 2 feet

The unit is thickest—about 3 feet—in northeastern Warren County, northwestern White County, and southern Putnam County (see fig. 2*). From this area it thins in all directions, being about 1 foot thick in the southern part of the Eastern Highland Rim, at locality C211 in the southeastern part of White County, and in the northern part of the Walden Ridge area. It cannot be identified north of the Roaring River line. A generalized isopach map of the unit is given in figure 12.

Figure 12. Generalized isopach map of the middle unit of the Gassaway member.

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*Missing.

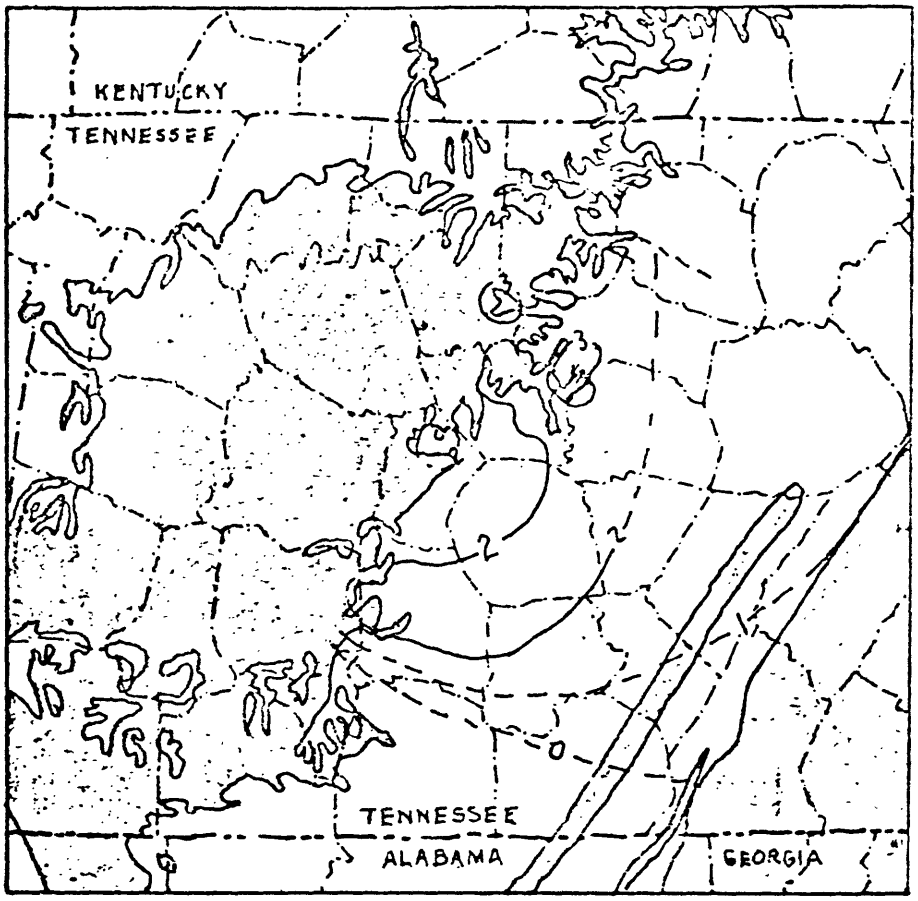

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Fig. 19:—Generalized isopach map of the middle unit of the Gassaway member of the Chattanooga shale

Isopach interval 1 foot

Upper unit, including the phosphatic zone

The upper unit of the Gassaway member is a tough, massive black shale that at most outcrops projects beyond the less resistant lower units of the member. Its thickness, including the phosphatic zone where it is present, ranges from 2 to 16 feet in the Eastern Highland Rim and from 6 to 10 feet in Walden Ridge. It is thinnest—3 to 4 feet—in the western part of the Smithville area and adjacent parts of Cannon and Coffee Counties, and averages about 6 feet in thickness over a large area extending east from the Smithville area to the vicinity of locality C211. From that area it thickens eastward and northward, especially where the phosphatic zone is present. At C50, the northernmost Walden Ridge locality, however, where the phosphatic zone is very thin—probably about 1 foot—the unit is 10 feet thick. A generalized isopach map of the upper unit of the Gassaway member is given in figure 13.

Figure 13. Generalized isopach map of the upper unit of the Gassaway member, including the phosphatic zone.

The thinning of the upper unit of the Gassaway member in the western part of the Smithville area is due to erosion of the uppermost beds toward the end of Gassaway time (Conant and Swanson, 1961, p. 36). This area is approximately the same which was uplifted toward the close of Dowelltown time and the upper beds of the Dowelltown, including the Center Hill bentonite, were removed.

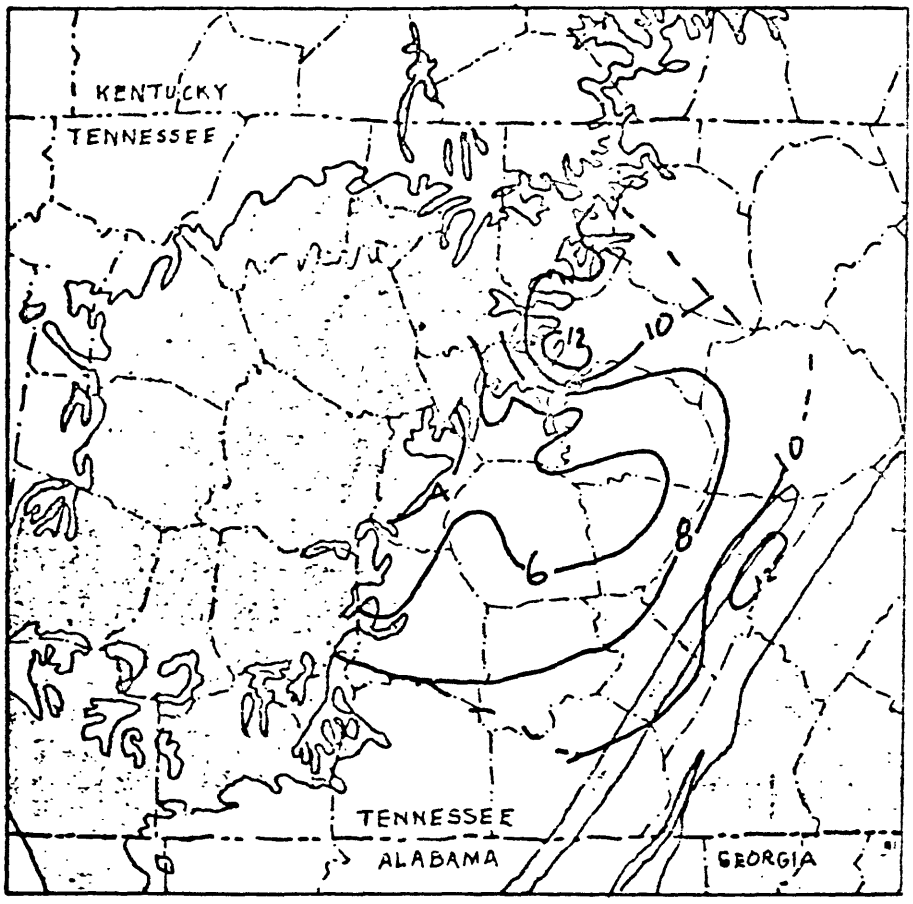

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Fig. 14:—Generalized isopach map of the upper unit of the Cassaway member of the Chattanooga shale, including the phosphatic zone

Isopach interval, 2 feet

Undivided member

In the Northern Highland Rim the Gassaway member is a black shale, essentially homogeneous from bottom to top, and considerably less massive than the upper unit of the member in the Eastern Highland Rim. It is from 10 to 18 feet thick in Macon, Clay, and Jackson Counties, and ranges considerably in thickness within short distances.. In general it thins westward, but over a large area in Sumner and Davidson Counties it has a remarkably uniform thickness of 10 to 12 feet. Like the Dowelltown member, it thins to extinction south of Nashville. A generalized isopach map of the member is given in figure 14.

Figure 14. Generalized isopach map of the undivided Gassaway member.

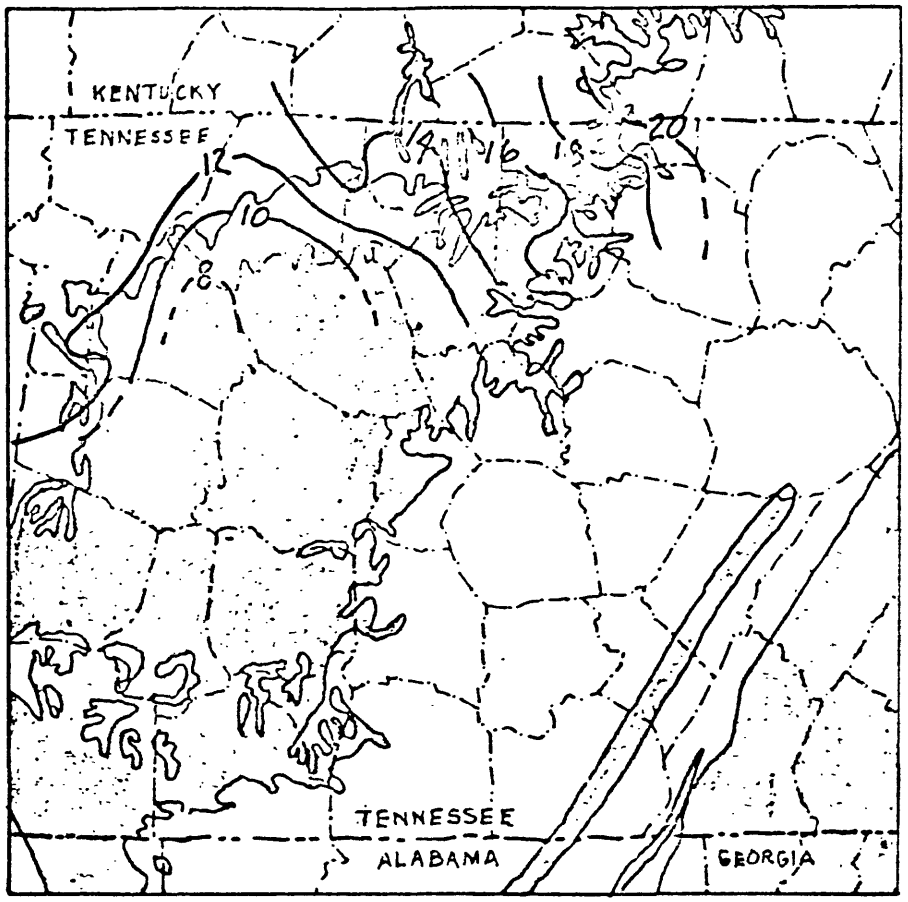

Fig. 14:—Generalized isopach map of the undivided Gassaway member of the Chattanooga shale

Isopach interval, 2 feet.

Phosphatic zone

In the northern parts of the Eastern Highland Rim and Walden Ridge, and locally in the Northern Highland Rim, the uppermost beds of the Gassaway member contain phosphatic nodules, usually less than an inch in diameter, that occur either in distinct layers or disseminated throughout the shale. Everywhere the change from the typical upper Gassaway beds to the beds containing nodules is gradational, and for that reason the thickness of the zone as shown in figure 15 is not as

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Figure 15. Generalized isopach map of the phosphatic zone of the Gassaway member.

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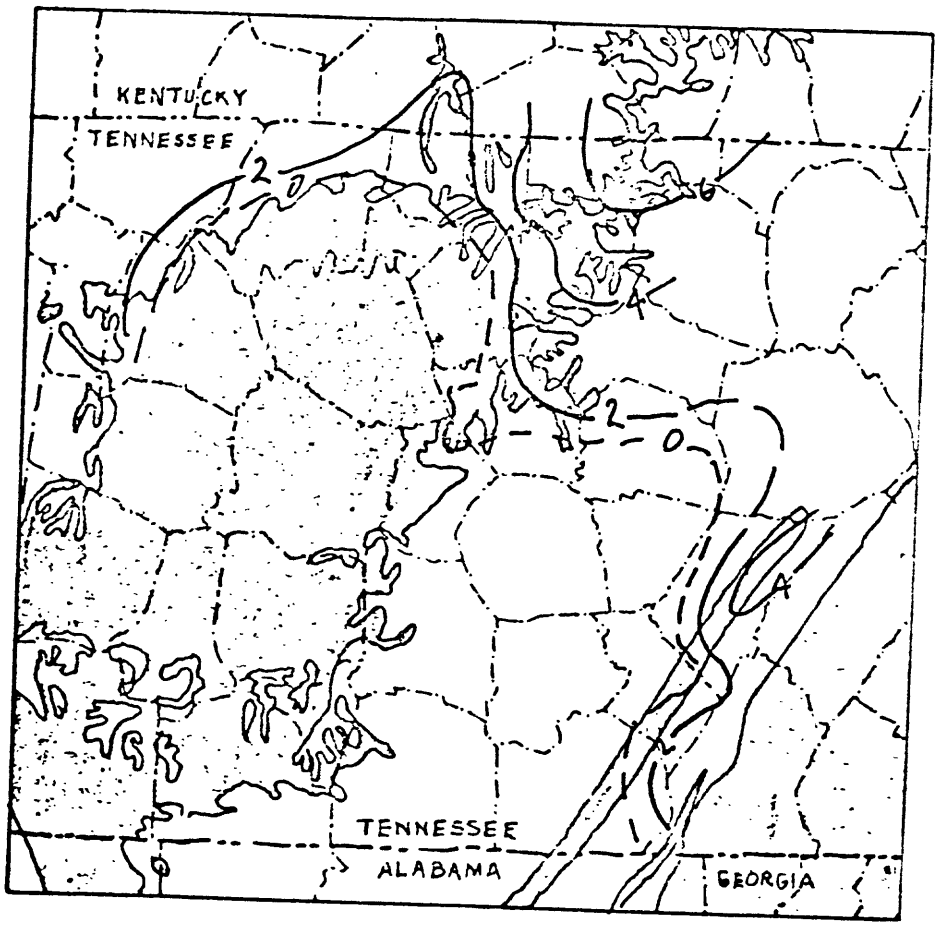
precise as the mapped thicknesses of the units of the member. With that qualification, it may be said that the thickness of the zone ranges generally from 0 to 4 feet, although it reaches 6 feet in Jackson County near the Cumberland River and at locality 4 in Pulaski County, Kentucky.

Conditions under which the phosphatic zone was deposited have been discussed by Swanson (1961, p. 96-97). The zone is of economic interest because its uranium content is invariably lower than that of the Gassaway beds below the zone.



15

Figl 15:—Generalized map of the phosphatic zone, Gassaway member of the Chattanooga shale

Isopach interval, 2 feet.

Anomalous unit at locality C49

In drill hole C49 in the northern part of Walden Ridge (see fig. 2)* the upper 4 feet of the Gassaway member is so anomalous, both in appearance and composition, as to require an attempt at explanation. The interval is above the phosphatic zone, which here is 4 feet thick, and its phosphate content is lower than that of the zone, being about the same as that of the underlying beds. The core is lighter in color and somewhat more shattered than that of the lower units. One of several possible explanations is that this upper 4 feet at locality C49 is reworked material, deposited in a shallow depression or a small embayment. There are no signs of comparable conditions at any other locality studied.

*Missing.

Formations overlying the Chattanooga shale

The formation immediately overlying the Chattanooga shale throughout the area covered by this report is the Maury shale, which is present at all localities examined, including those in areas such as the Hohenwald Platform where the Chattanooga shale is absent. The Maury consists mostly of claystone that in cores is a light bluish-gray in color, but which at all outcrops has a greenish tinge due to limonitic staining. This color is so distinctive that the Maury is generally referred to as a green shale. In the western parts of Tennessee beds of sandstone occur in the Maury, and in the Eastern Highland Rim thin beds of black shale and a zone of phosphatic nodules are found locally at the base. The nodules in the black parts of the Maury, unlike those in the Chattanooga, are as much as 2 feet long and 1 to 2 inches thick, flattened into kidney shapes; nodules in the green shale itself are much smaller and are of both flattened and spherical types. The total thickness of the Maury shale ranges from 1 to 4 feet in the Eastern Highland Rim, 1 to 3 feet in the Northern Highland Rim, 2 to 3 feet in Walden Ridge, and 2 to 6 feet in Alabama.

The Maury is usually interpreted as a transitional unit marking a regional change from the reducing conditions of the Late Devonian sea to the oxidizing conditions of the succeeding Mississippian sea. Paleontologic evidence cited by Hass (1956, p. 23) indicates that some of the uppermost beds of the Chattanooga shale were removed by erosion over large areas before deposition of the Maury, but, except locally as in the western part of the Smithville area, field evidence of an unconformity between the Chattanooga and the Maury is scanty, and the preponderance of evidence is that with local exceptions deposition was continuous from Chattanooga time into Maury time and later.

The Maury shale is overlain, apparently conformably, by the cliff-forming Fort Payne chert of Mississippian age or its lateral equivalent, the New Providence shale, the sequence being about 200 to 250 feet thick. In the Northern Highland Rim and the northern part of the Eastern Highland Rim there is considerable interfingering between the Fort Payne and its shaly lateral equivalents; this is well shown, among other localities, at locality 16, at the Dale Hollow dam in Clay County.

After deposition of the Fort Payne chert and its equivalents deposition was apparently continuous throughout the remainder of Mississippian time and well into Pennsylvanian time; the presence of Pennsylvanian rocks over practically the entire area underlain by the Chattanooga is shown by their capping Short Mountain, an outlier of the Cumberland Plateau just south of the western end of the Smithville area. Although the rocks above the Fort Payne have been removed by erosion from much of the area covered by this report, their great original thickness was an important factor in the compaction of the Chattanooga shale.

Structure

The Chattanooga shale was deposited over a tremendously long period—all or nearly all of Late Devonian time—on an essentially stable, slowly subsiding sea floor, in which tectonic changes were confined to minor and local uplifts and subsidences of the sea floor. The area remained stable throughout Mississippian and Pennsylvanian times, during which the black muds were covered and compacted. This long period of relative quiescence was ended by the post-Carboniferous Appalachian orogeny.

The geosynclinal axis was shifting continuously during Late Devonian time (Conant and Swanson, 1961, p. 50), and it is possible that these shifts may be in part responsible for the thinning of the Dowelltown member northeastward from Tennessee into Kentucky, and the thickening of the Gassaway member in the same direction. Data in the northern part of the Cumberland Plateau in Tennessee are so scant that this hypothesis cannot now be proved, but it is supported by the thickening of the shale northward in the Walden Ridge area, and particularly by the comparatively thickness of both members of the Chattanooga at locality C50, the northernmost Walden Ridge locality. If, as seems likely, the northernmost Walden Ridge localities are in a trough which is related to the geosynclinal axis to the northeast, it is logical to assume some compensatory movements in the areas northwest of the trough.

The greatest tectonic changes of the Appalachian orogeny were southeast of the report area. In the Appalachian Valley-and-Ridge province the rocks have been so folded and faulted that reconstruction of the original conditions is impossible. The same pressures from the southeast that were responsible for the folding east of the Cumberland Front produced, west of the Front, the almost horizontal Sequatchie thrust fault of many miles displacement, along the trace of which the Sequatchie Valley later was cut. Walden Ridge, between the Sequatchie Valley and the Cumberland Front, was folded into a shallow syncline; along the western flank the Chattanooga shale dips into the ridge at angles of 10° to 15° and because of its incompetent nature is nearly everywhere shattered to a greater or less extent. The few exposures of the shale in the eastern flank of the ridge are too poor to be of much value. It seems clear that the Chattanooga is continuous beneath the ridge, but all data used in this report are based necessarily on outcrops and drill holes in the western flank. Much valuable information could be obtained from drill holes in the trough of the syncline, but such holes would have to be 1,000 feet or more deep to penetrate the Chattanooga.

West of the Sequatchie Valley tectonic changes accompanying the Appalachian orogeny were less violent than those to the east. Over a long period of time the Cincinnati Arch rose, the greatest uplifts being in the present Nashville Basin in Tennessee and the Lexington Basin in Kentucky. The movement was so gentle that the incompetent Chattanooga shale was little disturbed, although some minor movements have been noted. As a result of the doming and subsequent erosion of the Nashville dome the originally level Chattanooga now dips away from the center of the basin in all directions. The rates of dip vary from place to place, but in the Eastern Highland Rim the average is about 30 feet to the mile. Thus the shale is under as much as 2,000 feet of cover in the Cumberland Plateau west of the Sequatchie Valley.

Mention should be made of two unusual features in the Eastern Highland Rim, though they have no economic significance. These structures are the Howell disturbance in northern Lincoln County, and the Flynn Creek disturbance in Jackson County, about 5 miles south of Gainsboro (see fig. 2)*. Several theories as to the origin of the disturbances have been proposed, the earliest being that they are the result of cryptovolcanic explosions. Other hypotheses are that they are craters formed by meteorites, or that they overlie salt-dome types of intrusions. Both disturbances are pre-Chattanooga in age, and have been discussed by Washburne (1937), Bucher (1936), Boon and Albritton (1938), Wilson and Born (1936), Luck (1927), Conrad, Elmore, and Maher (1934, 1957), and Conant and Swanson (1961).

*Missing.

Another feature comparable to the Howell and Flynn Creek disturbances is the Wells Creek disturbance in Stewart County, Tennessee, not far west of the area of this report. This feature, which is of post-Chattanooga age, is discussed by Bucher (1936, p. 1066-1070).

Composition of the shale

Chemical composition

Complete chemical analyses by the so-called "rapid-rock" method have been made of samples of the Chattanooga shale from 7 localities in Tennessee and 1 locality in Alabama, and of the New Albany shale, which is correlative with the Chattanooga, in Kentucky. These analyses are given in table 1, which includes also analyses for sulfur

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Table 1. Chemical analyses of samples of Chattanooga shale.

(included in loss on ignition in the chemical analyses) and uranium. Localities from which the samples were taken are shown on figures 1*, 2*, and 3*. They include 1 drill hole (C64) in Blount County, Alabama; 3 drill holes (C48, C49, and C50) in Walden Ridge, Tennessee; 2 drill holes (C37 and C42) in the Eastern Highland Rim, Tennessee; 1 drill hole (C56) and 1 outcrop (16) in the Northern Highland Rim, Tennessee; and 1 outcrop (323) in Marion County, Kentucky. Locality 323, which as stated above is in the New Albany rather than the Chattanooga shale, was selected because it is the northernmost locality for which good samples were available; as the formations are correlatives, the formation name is not referred to again, except incidentally, in the text. Of the samples of the Chattanooga, those of the Gassaway member at all localities were analyzed, as were samples of the upper unit of the Dowelltown member from localities C37 and C49 and of the lower unit of the Dowelltown from locality C59. Samples of the undivided Dowelltown member from locality C56 and of the questionable Dowelltown beds

*Figures are missing. So

at locality C64 were also analyzed. In the discussion the shale at locality 323 is considered to be the Gassaway member.

Table 1. -- Chemical analyses of samples of the Chattanooga Shale.

Includes analyses for sulfur and uranium. Analyses by P.L. Elmore, S.D. Botts, and M.D. Mack, 1957.

Table is split into 4 pages--parts A B C D

Gz Gassaway member undivided
Gu? Gassaway member, upper unit, uncertain correlation
Gu Gassaway member, upper unit
Gup Gassaway member, upper unit, phosphatic zone
Gm, Gassaway member, middle unit
Gl, Gassaway member, lower unit
Du, Dowelltown member, upper unit
Dl, Dowelltown member, lower unit
Dz, Dowelltown member undivided

Sample No.	Lab. No.	Thickness test	Unit	SiO_2	Al_2O_3	Fe_2O_3 1/	MgO	CaO
C04-12	120217	3.75	Gz	55.1	12.2	8.5	1.4	1.2
-13	120218	3.76	Gz	57.4	12.4	6.0	1.6	1.5
-14	120219	4.44	Gz	57.2	11.5	6.2	1.4	2.0
(Total and average)		11.95	G	56.6	12.0	6.9	1.5	1.6
C04-15	120220	5.08	Dz	63.3	12.6	4.4	1.8	2.1
-16	120221	2.32	Dz	50.7	14.4	5.6	1.8	1.1
(Total and average)		7.40	D	61.9	13.2	4.8	1.8	1.8
C48-2	115061	5.00	Gz	43.6	9.3	14.0	0.70	0.83
-3	115062	5.00	Gz	46.5	10.8	10.6	1.4	1.1
-4	115063	5.07	Gz	55.6	12.5	7.6	1.2	.86
(Total and average)		15.07	G	47.4	20.8	20.7	1.1	0.86
C49-11	115059	4.00	Gu?	54.9	14.2	6.0	1.6	0.44
-21	115060	4.00	Gup	45.6	20.7	12.7	1.2	3.2
-31	115064	5.40	Gu	45.8	11.4	10.4	1.1	.61
-32	115065	1.72	Gu	56.0	13.0	7.5	1.2	.46
-33	115066	2.85	Gl	52.4	13.9	6.7	1.4	.49
(Total and average)		17.97	G	50.7	12.4	8.8	1.3	0.88
C49-41	115055	6.46	Du	59.0	17.2	5.5	1.9	1.0

1/ Total iron as Fe_2O_3.

A	B
51A	51B
C	D
51C	51D

INDEX TO PARTS OF TABLE 1 WITH PAGE NUMBERS

Table 1.--Part B.

Constituents, percent									
Na_2O	K_2O	TiO_2	P_2O_5	MnO	LOI	Sum	CO_2	S	U, ppm
0.21	3.4	0.82	0.17	0.04	16.5	100	1.2	5.57	40
0.31	3.6	.87	.20	.07	15.3	99	1.7	3.77	46
0.30	3.4	.86	.18	.05	15.9	99	1.9	4.20	45
0.27	3.5	0.85	0.19	0.06	15.9	---	1.6	4.50	44
0.74	3.7	0.97	0.15	0.08	9.6	99	2.9	2.14	17
.62	4.3	.89	.24	.04	11.5	99	1.3	2.69	24
0.70	3.9	0.94	0.18	0.07	10.2	---	2.4	2.31	19
0.43	2.7	0.60	0.26	0.03	27.2	99	0.30	9.9	59
.56	3.2	.66	.13	.03	25.0	100	1.0	7.1	91
.68	4.1	.73	.16	.04	18.1	99	.52	4.3	58
0.56	3.3	0.66	0.18	0.03	23.4	---	0.53	7.4	69
0.41	4.5	0.75	0.25	0.04	16.2	99	0.80	0.38	29
.42	3.5	.04	1.2	.04	39.4	100	1.0	14.92	38
.53	5.5	.07	.27	.05	24.2	99	.31	8.82	92
.63	4.2	.80	.14	.04	15.9	100	.04	6.80	61
.66	4.5	.78	.14	.04	18.6	99	.72	5.84	62
0.53	4.0	0.71	0.43	0.04	19.7	---	0.69	9.41	58
0.61	4.8	0.90	0.16	0.04	8.3	99	1.2	3.80	11

Table 1.--Part C.

C90-12	115773	5.20	Gu	45.2	9.7	15.0	0.9	1.2
-13	115771	5.21	Gu	49.8	11.2	9.2	1.2	.64
-21	115772	1.81	Gu	57.0	13.0	6.6	1.2	.68
-31	115775	4.38	Gl	54.0	12.8	7.2	1.2	1.0
-32	115774	4.38	Gl	51.0	14.5	7.7	1.4	.54
(total and average)		21.04	G	50.4	12.0	9.2	1.2	0.80
C92-2	114068	6.50	Gu	46.9	10.8	11.0	0.94	0.54
-3	114069	1.86	Gu	58.0	12.6	6.3	1.1	1.6
-4	114070	9.99	Gl	52.9	13.4	6.4	1.4	.78
(total and average)		18.35	G	51.5	12.2	8.0	1.2	0.77
C97-2	114102	6.80	Gu	45.8	10.3	10.1	1.0	1.6
-3	114103	5.01	Gu	50.7	13.2	6.5	1.2	1.8
-4	114104	7.62	Gl	50.6	12.8	8.3	1.1	.60
(total and average)		17.43	G	50.1	11.9	8.7	1.1	1.2
C97-5	114125	11.50	Du	56.9	16.7	5.0	2.5	2.0
C97-6	114126	5.11	Dl	52.6	15.3	6.1	2.0	1.0
16-11A	2269	2.00	Gu	55.7	12.2	4.8	1.2	2.2
-11B	2270	2.00	Gu	55.6	12.4	5.3	1.4	.20
16-11C	2271	2.00	Gu	54.5	10.4	6.5	1.2	.16
-11D	2272	2.00	Gu	56.6	12.7	6.5	1.2	.22
-11E	2273	2.00	Gu	55.9	11.9	7.3	1.0	.20
-11F	2274	1.50	Gu	52.8	12.5	8.3	1.2	.12
-11G	2275	1.51	Gu	48.8	12.5	10.8	1.4	.36
-12	2276	1.82	Gu	48.5	11.1	11.9	1.1	.84
-13	2277	1.82	Gu	56.1	11.8	9.0	1.0	.46
(total and average)		16.65	G	53.0	12.1	7.7	1.2	0.58
C96-2	115095	6.00	Gu	47.0	11.2	11.0	1.2	0.52
-3	115096	3.67	Gu	46.9	10.9	10.6	1.1	.30
(total and average)		9.67	G	47.4	11.1	10.6	1.1	0.43
C96-4	115097	5.00	Du	56.0	14.6	5.6	2.7	2.3
-5	115098	5.00	Du	57.3	15.4	4.2	2.8	2.0
-6	115099	3.15	Du	53.6	13.6	4.2	3.6	3.3
(total and average)		13.15	Du	55.9	14.0	4.6	2.8	2.7
32-A	90008-D	5.00	Gu	51.6	12.0	4.7	0.95	0.16
-B	90011-C	12.00	Gu	55.8	13.2	5.8	.97	.08
-C	90013-C	16.00	Gu	54.4	11.5	8.2	.84	.21
(total and average)		33.00	G	54.5	12.3	6.7	0.91	0.15

Analyses by P. L. Moore, S. D. Botts, and H. D. Buck, 1957.

Table 1.--Part D.

0.55	3.1	0.62	0.70	0.02	24.2	99	0.42	11.64	75
.62	3.6	.71	.13	.03	21.6	99	0.66	6.56	82
.72	4.9	.82	.13	.03	15.0	99	.46	4.64	57
.73	3.7	.79	.14	.04	17.5	99	1.1	4.88	56
.67	4.0	.80	.12	.04	19.2	100	.38	4.60	64
0.65	3.6	0.73	0.37	0.03	20.3	---	0.62	6.86	69
0.50	3.3	0.67	0.13	0.02	25.3	100	0.43	5.29	80
.54	4.1	.82	.14	.02	13.6	99	1.2	3.87	49
.55	4.1	.74	.14	.03	19.2	100	.73	3.91	52
0.54	3.8	0.72	0.15	0.03	20.8	---	0.68	4.39	62
0.50	3.3	0.80	1.0	0.02	25.4	100	0.34	7.1	86
0.61	4.2	.84	.15	.02	11.9	99	1.6	4.0	33
.51	4.0	.80	.15	.03	21.2	100	.48	5.6	57
0.52	3.7	0.81	0.48	0.02	21.2	---	0.62	5.0	64
0.60	4.7	0.89	0.14	0.05	10.2	100	1.7	1.3	12
0.55	5.4	0.86	0.19	0.04	16.2	100	1.2	2.8	34
0.31	2.7	0.50	3.33	0.02	18.4	100	0.06	1.03	28
.34	3.6	.93	.12	.01	22.0	101	.18	2.52	54
.44	3.7	.90	.11	.02	20.6	100	.13	3.67	55
.39	3.8	.94	.14	.02	17.8	100	.15	3.44	60
.41	3.6	.82	.11	.02	19.1	100	.20	4.18	43
.40	3.7	.90	.13	.01	20.6	100	.36	5.19	54
.47	3.7	.78	.14	.02	21.4	100	.28	7.37	73
.42	3.4	.80	.14	.02	22.2	100	.10	8.43	60
.51	3.7	.76	.37	.01	16.4	100	.33	5.45	43
0.41	3.5	0.82	0.32	0.02	29.3	---	0.17	4.53	52
0.34	3.5	0.80	0.19	0.01	21.0	100	0.11	5.05	58
.40	3.4	.69	.27	.02	25.4	100	.12	9.51	55
0.55	3.5	0.76	0.22	0.03	19.3	---	0.14	6.78	56
0.49	4.5	0.70	0.13	0.04	14.3	99	0.28	1.49	12
.40	4.2	.79	.19	.02	11.8	100	.50	1.96	8
.42	4.2	.76	.31	.02	24.2	99	.46	1.82	7
0.47	4.3	0.73	0.21	0.03	15.3	---	0.39	1.75	9
0.35	3.5	0.70	0.37	0.01	25.7	100	0.20	2.39	34
.38	3.9	.79	.12	.01	18.8	100	.10	2.87	39
.46	3.4	.64	.00	.02	19.8	100	.12	4.75	37
0.41	3.6	0.67	0.17	0.02	20.4	---	0.11	3.44	38

OLD (p. 58 follows)

The "rapid rock" method of analysis has been described by Shapiro and Brannock (1956), who checked the results obtained by this method against standard chemical analyses made by the Geological Survey and the U. S. Bureau of Standards. For most constituents the accuracy of the "rapid rock" analyses is well within $\pm$ 5 percent, and thus sufficiently accurate for the purposes of this report. Exceptions are K_2O and Ca, which are accurate within about 10 percent, and P_2O_5, which varies somewhat more widely.

The content of trace elements in the shale was determined by semiquantitative spectrographic methods. Determinations were made on all the samples listed in table 1, and in addition on samples of the Gassaway member from 6 drill holes (C16, C26, C36, C44, C46, and C51) in the Eastern Highland Rim and 1 outcrop (22) in the Northern Highland Rim. Samples of the Dowelltown member from localities 22, C16, and C44 were analyzed also. These localities are shown in figure 1*.

* Missing.

Major constituents

The major constituents of the Chattanooga shale are SiO_2, Al_2O_3, Fe (total Fe as Fe_2O_3), K_2O, MgO, CaO, and carbonaceous matter as represented by loss on ignition (LOI). These constituents combined comprise about 98 percent of both members and units of the Chattanooga. Weighted averages for the constituents at each locality from which samples were analyzed, and unweighted averages for the Walden Ridge and Eastern Highland Rim areas, are given in table 2. Data from other areas

Table 2. Major constituents of the Chattanooga shale by members, units, and areas. Data summarized from table 1.

are too scattered for averages to have any meaning.

Silica (SiO_2)

Silica comprises about half of the Gassaway member and of the lower unit of the Dowelltown member, and a somewhat higher percentage of the upper unit of the Dowelltown. The silica content is highest at the Alabama locality, next highest at the northernmost localities, outcrop localities 16 in Clay County, Alabama, and 323 in Marion County, Kentucky; at these last localities the composition of the shale could have been affected by weathering processes. The lowest silica contents are in Walden Ridge and at locality C56 in the Northern Highland Rim.

Table 2.--Major constituents of Chattanooga shale by members, units, and areas. Data summarized from Table 1.

Member	Locality	Area [1]	Constituents, percent							
			SiO_2	Al_2O_3	Fe_2O_3	K_2O	MgO	CaO	LOI	Sum
Gassaway	C64	AL	56.6	12.0	6.9	3.5	1.5	1.6	15.9	98.0
	C48	WR	47.4	10.8	10.7	3.3	1.1	.9	23.4	97.6
	C49	WR	49.7	12.9	8.8	4.0	1.3	.9	19.7	97.3
	C50	WR	50.4	12.0	9.2	3.6	1.2	.8	20.3	97.5
	Average	WR	49.2	11.9	9.5	3.6	1.2	.9	21.1	97.4
	C37	EHR	50.1	11.9	8.7	3.7	1.1	1.2	21.1	97.8
	C42	EHR	51.3	12.2	8.0	3.8	1.2	.8	20.8	98.1
	Average	EHR	50.7	12.1	8.3	3.7	1.2	1.0	21.0	98.0
	16	NHR	54.0	12.1	7.7	3.5	.5	.4	19.3	97.5
	C56	NHR	47.4	11.1	11.6	3.5	1.1	.3	23.8	98.8
	Average	NHR	50.7	11.6	9.1	3.5	.8	.4	22.0	98.1
	323	KY	54.5	12.3	6.7	3.6	.9	.2	20.4	98.6
Undivided Dowelltown	C64	AL	61.9	13.2	4.8	3.9	1.8	1.8	10.2	97.6
Undivided Dowelltown	C56	NHR	55.9	14.0	4.0	4.3	2.8	2.7	13.3	97.0
Lower unit Dowelltown	C37	EHR	52.6	15.3	6.1	5.4	2.0	1.0	16.2	98.6
Upper unit Dowelltown	C37	EHR	56.9	16.7	5.0	4.7	2.5	2.0	10.2	98.0
	C49	WR	59.0	17.2	5.5	4.8	1.9	1.0	8.3	97.7

[1] AL, Alabama; WR, Walden Ridge, Tennessee; EHR, Eastern Highland Rim, Tennessee; NHR, Northern Highland Rim, Tennessee; KY, Kentucky.

Where the Gassaway member is not divisible into units the silica content is highest at the base of the member and decreases slightly toward the top. Where the units can be distinguished, the content is highest in the middle unit, lowest in the upper unit. At locality C49 in Walden Ridge the anomalous upper 4 feet contains the abnormally high silica content for the area of 54.9 percent, but the member below that unit contains only 45.9 percent silica.

The silica in the Chattanooga is in the form of finely divided quartz and in the clay minerals and micas. In Alabama quartz accounts for about half the silica content, but the quartz content decreases northward, with a corresponding increase in the content of clay minerals.

Alumina (Fe_2O_3)

The alumina content of the Gassaway member of the Chattanooga shale is fairly consistent at all localities, the range being 10.8 to 12.3 percent except at locality C49, where the anomalous upper 4 feet contains 14.2 percent alumina, bringing the average for the locality up to 12.9 percent.

Except in Walden Ridge, where the distribution is distinctly bottom-preferential, the distribution of alumina is fairly uniform vertically throughout the Gassaway member, and there is little variation between the alumina contents of the units. Both units of the Dowelltown member contain more alumina than the Gassaway; the lower unit at locality C37 contains 15.3 percent alumina, and the content of the upper unit ranges from 12.3 percent at the Alabama locality to 17.3 percent at locality C49 in Walden Ridge.

The alumina in the Chattanooga is mostly in the feldspars and clay minerals. The silica-alumina ratio ranges from 3.4 to 4.7, the highest ratio being for both members at locality C64 in Alabama, the lowest for the Dowelltown member at localities C37 and C49. For all other localities the range for both members is from 3.9 to 4.5.

Potash (K_2O)

The potash in the Chattanooga shale, which occurs in the feldspars and micas and is distributed rather uniformly regionally, the range for the Gassaway member (excluding the upper 4 feet of locality C49 which contains 4.5 percent K_2O), being from 3.3 to 3.8 percent. At all localities except C64 the potash content is highest at the bottom of the member, and there is little difference between the units.

The potash content of the Dowelltown member is higher than that of the Gassaway; the lower unit at locality C37 contains 5.4 percent K_2O, and the range for other Dowelltown samples is from 3.9 to 4.8 percent. Thus the decrease in potash content from bottom to top applies not only to the Gassaway member, but to the Chattanooga shale as a whole.

Iron (total iron as Fe_2O_3)

The iron content of the Gassaway member of the Chattanooga shale ranges considerably both regionally and vertically. Where the units of the member can be distinguished the iron content is highest (10.1 to 14.0 percent) in the upper unit, the content of the other units ranging from 6.3 to 10.6 percent. Regionally, the lowest content (6.9 percent) is for the undivided member at locality C64 in Alabama, the highest (11.6 percent) at locality C56 in the Northern Highland Rim. The low iron content of the shale from localities 16 and 323 (7.7 and 6.7 percent respectively) probably represents in part loss through weathering.

The shale of the lower unit of the Dowelltown member at locality C37 contains 6.1 percent iron; the content of the upper unit or the undivided member ranges from 3.6 to 5.5 percent. The iron content of the shale shows a good positive correlation with the total organic matter, reflecting the reducing conditions in the Chattanooga sea which furthered the concentration of the element, mostly in pyrite or marcasite. At all localities 90 percent or more of the iron in the shale is in those minerals; Bates (1956) and Strahl (1958) report "free iron" or "iron oxides" as about 1 percent of the total shale.

The wide differences in iron (as well as sulfur) content from one sample to another are explained by the fact that pyrite, unlike many constituents of the shale, tends to be concentrated in distinct aggregates. For this reason analyses of different quarters from the same core can show noticeable differences in iron and sulfur contents.

Magnesia (MgO)

The magnesia content of the Gassaway member of the Chattanooga shale averages about 1 percent, being highest (1.5 percent) at locality C64 in Alabama and lowest (0.91 percent, or locality 323, the Kentucky outcrop. The vertical distribution is fairly uniform except in Walden Ridge. There it is distinctly bottom-preferential except for a relatively high content in the anomalous upper 4 feet of locality C49.

The magnesia content of the Dowelltown member, on the basis of relatively few analyses, appears to increase from south to north, from 1.8 percent at locality C64 to 2.8 percent at locality C56 in the Northern Highland Rim. Semiquantitative spectrographic analyses of samples from localities other than those for which chemical analyses were made fall within the X. and .X ranges, confirming in a general way the pattern described above.

Most of the magnesium in the shale is in the micas and clay minerals, on the basis of available evidence.

Lime (CaO)

The lime content of the Cassaway member varies widely both regionally and vertically within the member, the highest contents being in the phosphatic zone. For the member as a whole, the lime content is highest in Alabama, and lowest at localities 323, 16, and C56. Localities 323 and 16 are outcrops from which lime possibly has been removed by leaching, and some lime may have been lost from drill hole C56, which entered the Chattanooga at a depth of only 14 feet and the core of which shows weathering at the top of the Cassaway. Most of the relatively high lime content of the phosphatic zone is in the apatite nodules, which are resistant to weathering; this is exemplified by the situation at locality 16, an outcrop in which the phosphatic zone, 3 feet thick, contains 2.2 percent CaO, the remainder of the section only 0.25 percent, lower than the content at most other localities. The phosphatic zone at locality C49 contains 3.2 percent CaO.

The relatively high lime contents of samples from localities C37, C42, and C50, where the phosphatic zone is absent or very thin (about 1 foot at locality C50), does not have a ready explanation.

The lime content of the Dowelltown member is somewhat higher than that of the Cassaway member, being highest (2.7 percent) in the undivided member at locality C56, and lowest (1.0 percent) in the lower unit at locality C37.

Carbonaceous material

The loss on ignition included in chemical analyses represents mostly carbonaceous material, sulfur and water and thus gives a rough measurement of the amount of carbonaceous material in the rock. A more precise measurement of that constituent, however, is organic isolates segregated from the samples. These organic isolates are defined as the organic matter, plus mineral matter insoluble in hydrochloric and hydrofluoric acid.

Loss on ignition.—The average percentage of ignition loss for samples of the Cassaway member ranges from 15.9 percent at locality C64, to 23.8 percent at locality C56 in the Northern Highland Rim. Where the three units of the Cassaway can be distinguished the ignition loss is highest in the upper unit, lowest in the middle unit. Somewhat surprisingly, the highest ignition loss in all of the samples analyzed is in the upper 5 feet of shale from locality 323 in Kentucky, where the percentage is 25.7 percent. For the lower 25 feet of shale from that locality the ignition loss is 19.3 percent, still a higher percentage than would have been expected.

For the Dowelltown member the ignition loss ranges from 8.3 to 13.3 percent, the latter figure being from locality C56, where the Cassaway member also has the highest percentage of all the samples analyzed.

Organic isolate.—Analyses of the Chattanooga shale for organic isolate are given in table 3, which includes for comparison the percent of loss on ignition for those samples on which that determination was made. The percent of organic isolate is generally higher than the ignition loss in the black parts of the shale, but lower in the gray parts, particularly the upper unit of the Gassaway member. Although other factors probably enter into the difference, much of it apparently is due to the larger proportion of clay minerals in the gray units. These minerals contain considerable water which is included in the loss on ignition but not in the organic isolate.

As the uranium content and oil yield are related directly to the carbonaceous material in the shale, the organic isolates are discussed more fully in the sections on those subjects. At this point, however, the carbon content of the shale is of interest.

Table 3.—Comparison of loss on ignition with organic isolate content of Chattanooga shale samples

Sample no.	Unit	LOI (percent)	Organic isolate (percent)	Sample no.	Unit	LOI (percent)	Organic isolate (percent)
C64-12	Gz	16.5	18.2	C37-2	Gu	25.4	29.3
-13	Gz	15.3	15.7	-3	Gm	11.9	13.0
-14	Gz	15.9	16.4	-4	Gl	21.2	23.8
Average	Gz	15.9	16.7	Average	G	21.2	24.1
C64-15	Dz?	9.6	7.2	C37-5	Du	10.2	5.9
-16	Dz?	11.5	11.0	-6	Dl	16.2	17.3
Average	Dz?	10.2	8.4	16-11A	Gz	18.4	16.1
C48-2	Gz	27.2	24.2	-11B	Gz	21.0	20.2
-3	Gz	25.0	25.3	-11C	Gz	20.6	19.6
-4	Gz	18.1	20.4	-11D	Gz	17.8	16.7
Average	G	23.4	23.3	-11E	Gz	19.1	17.0
C49-11	G?	16.2	16.1	-11F	Gz	20.6	22.1
-21	Gup	19.4	23.4	-11G	Gz	21.4	25.8
-31	Gu	24.2	26.0	-12	Gz	22.2	27.3
-32	Gm	15.9	17.7	-13	Gz	16.4	19.2
-33	Gl	18.6	20.0	Average	G	19.3	20.2
Average	G	19.7	21.4	C56-2	Gz	24.0	25.8
C49-41	Du	8.3	6.9	-3	Gz	23.4	27.1
				Average	Gz	23.8	26.3

Table 3.—Comparison of loss on ignition with organic isolate content of Chattanooga shale samples—Continued

C50-12	Gu	24.2	28.7	C56-4	Dz	14.3	10.0
-13	Gu	21.6	24.3	-5	Dz	11.8	9.5
-21	Gm	15.0	16.8	-6	Dz	14.2	11.6
-31	Gl	17.5	20.0	Average	Dz	13.3	10.2
-32	Gl	19.2	21.3	323-A	Gz	25.7	21.6
Average	G	20.3	23.2	-B	Gz	18.8	16.7
C42-2	Gu	25.3	28.6	-C	Gz	19.8	15.3
-3	Gm	13.6	15.9	Average	Gz	20.4	16.9
-4	Gl	19.2	20.4				
Average	G	20.8	22.3				

1/ Gz, Undivided Gassaway; Gu, upper unit, Gassaway; Gup, Phosphatic zone of upper unit, Gassaway; Gu?, anomalous unit, upper Gassaway; Gm, middle unit, Gassaway; Gl, lower unit, Gassaway; Dz, undivided Dowelltown; Du, upper unit, Dowelltown; Dl, lower unit, Dowelltown.

Organic isolate determinations by S. M. Berthold, U. S. Geological Survey

Deul (1957) made an exhaustive analysis of a sample 1.35 feet thick from the upper unit of the Gassaway member at locality 99 in the Eastern Highland Rim, finding a total carbon content of 13.6 percent. Later, as part of a study of the oil yield of the shale (Breger and Brown, 1962), the carbon content of a number of samples was calculated from the percentage of carbon in the organic isolates; these figures are given in table 4. Analyses of cores of the Gassaway member for total carbon, made by the Pennsylvania State University and reported by Bates (1956) and Strahl (1958), are in line with the carbon content of the Gassaway member as given in the table. As would be expected, the carbon content of the Dowelltown member, particularly the upper unit, is lower than that of the Gassaway member.

Sulfur

Determinations for total sulfur, which is included in the loss on ignition in the chemical analyses, were made of all samples of which complete chemical analyses were made; these additional determinations are shown in table 1. In addition sulfur was determined on samples from drill holes C46 and C51 in the Eastern Highland Rim and outcrops 22 and 25 in the eastern part of the Northern Highland Rim; these analyses are given in table 5.

Table 4.--Total carbon content of samples of Chattanooga shale

Locality and sample no.	Unit[1]	Thickness (feet)	Organic isolate (percent)	Carbon in isolate (percent)	Carbon in shale (percent)
C64-A	Gz	11.95	17.0	47.2	8.0
-D	Dz?	7.40	8.4	47.7	4.0
C48-A	Gz	15.07	23.3	41.2	9.6
C49-31[2]	Gu	5.40	26.0	46.8	12.2
-33	Gl	2.85	20.0	52.2	10.4
-41	Du	6.46	6.9	39.8	2.7
C42-2	Gu	6.50	28.6	46.3	13.2
-3	Gm	1.86	15.9	48.0	7.6
-4	Gl	9.99	20.4	55.4	11.3
Average	G				11.6
C37-2	Gu	6.80	29.3	45.7	13.4
-3	Gm	3.01	13.0	36.8	4.8
-4	Gl	7.62	23.8	49.4	11.8
Average	G				11.2
16-A	Gz	8.00	18.1	61.8	11.2
-B	Gz	3.50	18.6	52.7	9.8
-C	Gz	5.15	24.0	41.7	10.0
Average					10.5
C56-A	Gz	9.67	26.1	40.5	10.6
-B	Dz	13.15	10.2	60.9	6.2

Table 4.--Total carbon content of samples of Chattanooga shale--Continued

323-A	Gz	5.00	21.6	70.5	15.2
-B	Gz	12.00	16.7	57.2	9.6
-C	Gz	13.00	15.3	46.8	7.0
Average					9.4

1/ Unit symbols: Gu, upper unit, Gassaway member; Gm, middle unit, Gassaway member; Gl, lower unit, Gassaway member; Gz, Gassaway member undivided; G, total Gassaway member; Du, upper unit, Dowelltown member; Dl, lower unit, Dowelltown member; Dz, Dowelltown member undivided.

2/ Only part of section analyzed.

Table 5.—Analyses for sulfur, in addition to those shown in table 1

Sample no.	Lab. no.	Thickness (feet)	Unit	S (percent)
C46-2	115049	5.18	Cu	8.1
-3	115050	2.27	Cm	7.5
-3	115051	8.95	Cl	8.1
Total and average		16.40	C	8.0
C46-5	115052	9.63	Du	4.9
-6	115053	6.16	Dl	6.7
25-11	2201	2.09	Czp	7.8
-12	2202	2.09	Cz	9.0
-13	2203	2.09	Cz	9.9
-14	2204	2.09	Cz	12.1
-15	2205	2.09	Cz	13.1
-21	2206	2.17	Cz	10.1
Total and average		12.62	C	10.3
C51-12	117624	5.06	Cu	12.2
-13	117625	5.07	Cu	12.1
-21	117626	2.74	Cm	9.3
-31	117627	4.02	Cl	11.2
Total and average		16.89	C	11.8

Table 5.--Analyses for sulfur, in addition to those shown in table 1--Continued

22-11A	2191	2.00	Gzp	7.1
-11B	2192	2.00	Gzp	8.5
-11C	2193	2.00	Gz	8.4
-11D	2194	1.50	Gz	10.5
-11E	2195	1.43	Gz	9.3
-12	2196	2.15	Gz	11.4
-13	2197	2.15	Gz	11.9
Total and average		13.23	G	9.6

Analyses by R. Moore and W. Tucker, 1957.

1/ Unit symbols: Gu, upper unit, Gassaway member; Gm, middle unit, Gassaway member; Gl, lower unit, Gassaway member; Gz, undivided Gassaway member; Gzp, phosphatic unit, undivided Gassaway member; G, total, Gassaway member; Du, upper unit, Dowelltown member; Dl, lower unit, ~~Gassaway~~ Dowelltown member.

Most of the sulfur in the shale is combined with iron to form pyrite or marcasite. Few analyses of the types of sulfur in the shale have been made. A bulk sample of the upper unit of the Gassaway member at the adit (locality 79) contains 0.87 percent organic sulfur, 0.23 percent sulfur as sulfate, and 6.1 percent sulfur as sulfide (Deul, 1956).

Minor constituents

Soda (Na_2O)

The average soda content of the Gassaway member ranges from 0.27 to 0.65 percent for localities from which samples were analyzed, being lowest in Alabama, the Northern Highland Rim, and Kentucky, and highest in Walden Ridge. Vertically the soda content decreases from the bottom to the top of the member. The soda content of the Dowelltown is approximately the same or slightly more than that of the Gassaway.

The potash-soda ratio, a useful clue to mineralogic composition, is highest in the Gassaway member at locality C64, where it is 13.0. In Walden Ridge the range is 5.5 to 7.5, and in the Eastern and Northern Highland Rims, 7.0 to 8.5. For the lower unit of the Dowelltown member at locality C37 the ratio is 10.2; and for the undivided Dowelltown member, 5.6 at locality C64 and 8.9 at locality C56. Thus, except for the Gassaway member at locality C64, the potash-soda ratio in the shale increases from south to north.

Carbon dioxide (CO_2)

As is to be expected, the carbon dioxide content of the Chattanooga shale shows a positive correlation with the lime content. It is highest—1.6 percent—at locality C64, and lowest—0.11 to 0.17 percent—in the Northern Highland Rim and Kentucky. An apparent exception to the rule of correlation between lime and CO_2 is the upper 3 feet of outcrop locality 16, which contains 2.2 percent CaO but only 0.06 percent CO_2. This apparently represents loss of CO_2 by weathering of calcite from an old outcrop.

Phosphate (P_2O_5)

Phosphate, apparently mostly in the form of finely divided apatite, is disseminated throughout both members of the Chattanooga shale in concentrations ranging from 0.11 to 0.37 percent except in the phosphatic zone, in which the concentration is everywhere more than 1.0 percent. In addition to the localities for which complete chemical analyses were made, P_2O_5 was also determined from 6 other localities—outcrops 22, 25, and 29 in the Northern Highland Rim, and outcrop 91 and drill holes C46 and C51 in the Eastern Highland Rim. Analytical data on these localities are given in table 6.

Table 6.—Analyses of Chattanooga shale for P_2O_5 in addition to those given in table 1.

Sample no.	Laboratory no.	Unit[1]	Thickness (feet)	P_2O_5 (percent)
22-11A	2191	Gz	2.00	5.9
-11B	2192	Gz	2.00	.2
-11C	2193	Gz	2.00	.1
-11D	2194	Gz	1.50	.3
-11E	2195	Gz	1.43	.2
-12	2196	Gz	2.15	.3
-13	2197	Gz	2.15	.3
25-11	2201	Gz	2.09	1.2
-12	2202	Gz	2.09	.5
-13	2203	Gz	2.09	.2
-14	2204	Gz	2.09	.5
-15	2205	Gz	2.09	.2
-21	2206	Gz	2.17	.2
C51-12	117624	Gu	5.06	.8
-13	117625	Gu	5.07	.4
-21	117626	Gm	2.74	.2
-31	117627	Gl	4.02	.3
C29-12[2]	113243	Gup	1.00	1.15
-13	113244	Gu	1.00	.24
-14	113245	Gu	1.00	.24

Table 6.—Analyses of Chattanooga shale for P_2O_5 in addition to those given in table 1—Continued.

91-12[1]	81	Gu	2.00	0.6
-13	82	Gu	2.00	.2
-14	83	Gu	1.70	.2
C46-2	115049	Gu	5.18	.3
-3	115050	Gm	2.27	.4
-4	115051	Gl	8.95	.2
-5	115052	Du	9.63	.6
-6	115053	Dl	6.63	.3

[1] Unit symbols: Gz, undivided Gassaway member; Gup, phosphatic zone, upper unit, Gassaway member; Gu, upper unit, Gassaway member; Gm, middle unit, Gassaway member; Gl, lower unit, Gassaway member; Du, upper unit, Dowelltown member; Dl, lower unit, Dowelltown member.

[2] Analyses by R. Moore and W. P. Tucker, U. S. Geological Survey, 1957.

Of the localities for which analyses were made, the phosphatic zone is present and was sampled separately at localities 16, 22, 25, C29, and C49. It is present, but is thin and was not sampled separately, at localities 91, C37, and C50. Most of the phosphate in the phosphatic zone is in the nodules, which are composed of hydroxylapatite (Mary Mrose, personal communication, 1957), and the P_2O_5 content of samples from the zone varies considerably according to the number of nodules that happen to be in the sample. Nodules collected from locality 95A by the author contain 33.2 and 32.5 percent P_2O_5 respectively, and other samples from the same general area are reported to contain from 20.8 to 32.5 percent P_2O_5. As an indication of the extent to which phosphate is concentrated in the nodules, a sample of the shale in the phosphatic zone at locality 95A from which the nodules had been removed contains only 0.8 percent P_2O_5. (Analyses by J. Budinsky and W. P. Tucker, 1957, lab. nos. 151698-151700.)

Titanium oxide (TiO_2)

The titanium oxide content of the Chattanooga shale ranges in individual samples from 0.60 to 0.98 percent. The concentration is somewhat higher in the gray units than in the black units of the shale but the differences are not great. Regionally, the concentration is highest at locality C64 in Alabama, lowest at locality C56 in the Northern Highland Rim and locality 323 in Kentucky; this distribution could reflect the greater distance from the shore line in the northern localities.

Most of the TiO_2 in the Chattanooga shale probably is in the form of rutile or ilmenite, which is disseminated through the shale in minute grains. Semiquantitative spectrographic analyses of samples from localities other than those for which chemical analyses were made show titanium contents within the .1-.5 or .X ranges, which is in line with the chemical analyses for TiO_2.

Manganese oxide (MnO)

The manganese oxide content of the Gassaway member of the Chattanooga shale ranges from 0.01 percent at locality 323 to 0.06 percent at locality C64. In Waldon Ridge the concentration is 0.03 to 0.04 percent, in the Northern and Eastern Highland Rims about 0.02 percent. The lower unit of the Dowelltown member at locality C37 contains 0.04 percent MnO; the range for the upper unit of the Dowelltown is from 0.03 to 0.05 percent. Semiquantitative spectrographic analyses for manganese from localities other than those for which chemical analyses were made have proved somewhat difficult to interpret because some of the results indicate lower manganese contents than the MnO analyses show. Re-examination of the plates, however, showed that in the questionable samples the manganese content was near the top of the range, and differences therefore were minimal.

The average MnO content of 36 Paleozoic shales is given by Goldschmidt (1954, p. 639) as 0.08 percent. Little is known of the manganese content of black shales such as the Chattanooga, but, as Goldschmidt points out, in such sediments the proportion of manganese to iron is likely to be considerably less than the average for the lithosphere because the preferential leaching of manganese under reducing conditions apparently prevails over its concentration. This is true of the Chattanooga shale, in which the Mn/Fe ratio in analyzed samples ranges from about 0.003 to 0.008, far below Goldschmidt's figure of 0.13 for Paleozoic shales.

Trace elements

The trace elements content of the Chattanooga shale was determined by semiquantitative spectrographic methods on samples from 16 localities, which are shown in figure 1*. The contents are shown by histograms in figure 16. As the data used were obtained over a considerable period of time, they are reported to different sensitivities. Analyses of samples from localities C16, C26, C36, C37, C44, and C49 were reported in the X., .X, OX, etc. ranges. Those of samples from C42, C46, C48, C50, C51, and C64 were reported in 5-10 percent, 1-5 percent, 0.5-1.0 percent, etc., ranges; and the last samples on which determinations were made were reported in figures - 0.1, 0.3, 1, 3, etc. All of the samples reported in this manner were from localities 16, 22, C56, and 323; all of these localities are in the Northern Highland Rim and in Kentucky. For purposes of comparison with other ranges, the figures represent the following ranges:

1 = 0.56 to 1.7 percent

3 = 1.7 to 5.6 percent

etc.

Samples of the Gasaway member from all localities listed above were analyzed. Samples of the Dowelltown member from 6 localities were also analyzed; these are localities C64, C49, C16, C37, C44, and C56.

*Missing.

Exclusive of manganese and titanium, which are discussed under the chemical composition of the shale, the following 21 elements were detected by the spectrographic analyses:

Ag	B	Ba	Be	Co	Cr	Cu
Ga	La	Mo	Nb	Ni	Pb	Sc
Sn	Sr	V	Y	Yb	Zn	Zr

All of these elements except Ag, La, Nb, Sn, and Zn were detected in all or practically all samples analyzed. Of the elements detected at all localities eight—B, Be, Cu, Ga, Pb, Zr, Y, and Yb—are distributed fairly evenly through all units and members of the shale at each locality. Three elements—Co, Mo, and Ni—have heavier concentrations in the black beds of the shale than in the gray beds. Three elements—Ba, Sc, and Sr—show vertical patterns of distribution at each locality but without regard to the units; and the distribution of two elements—Cr and V—is best described as irregular.

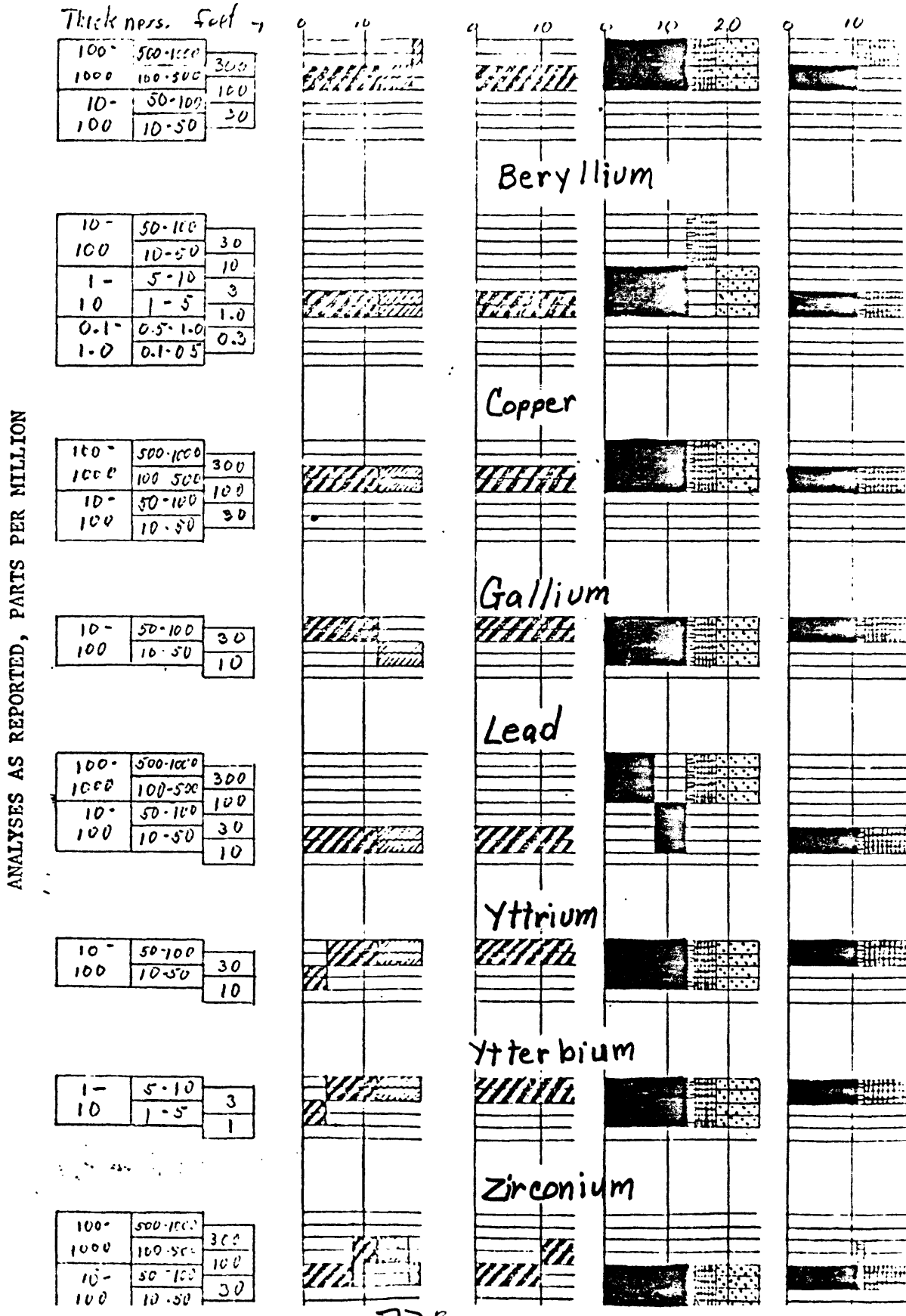
Distribution of the 16 elements listed above is shown by histograms in figure 16, in which the ranges are given in parts per million.

Figure 16. Histograms showing distribution of some trace elements in the Chattanooga shale.

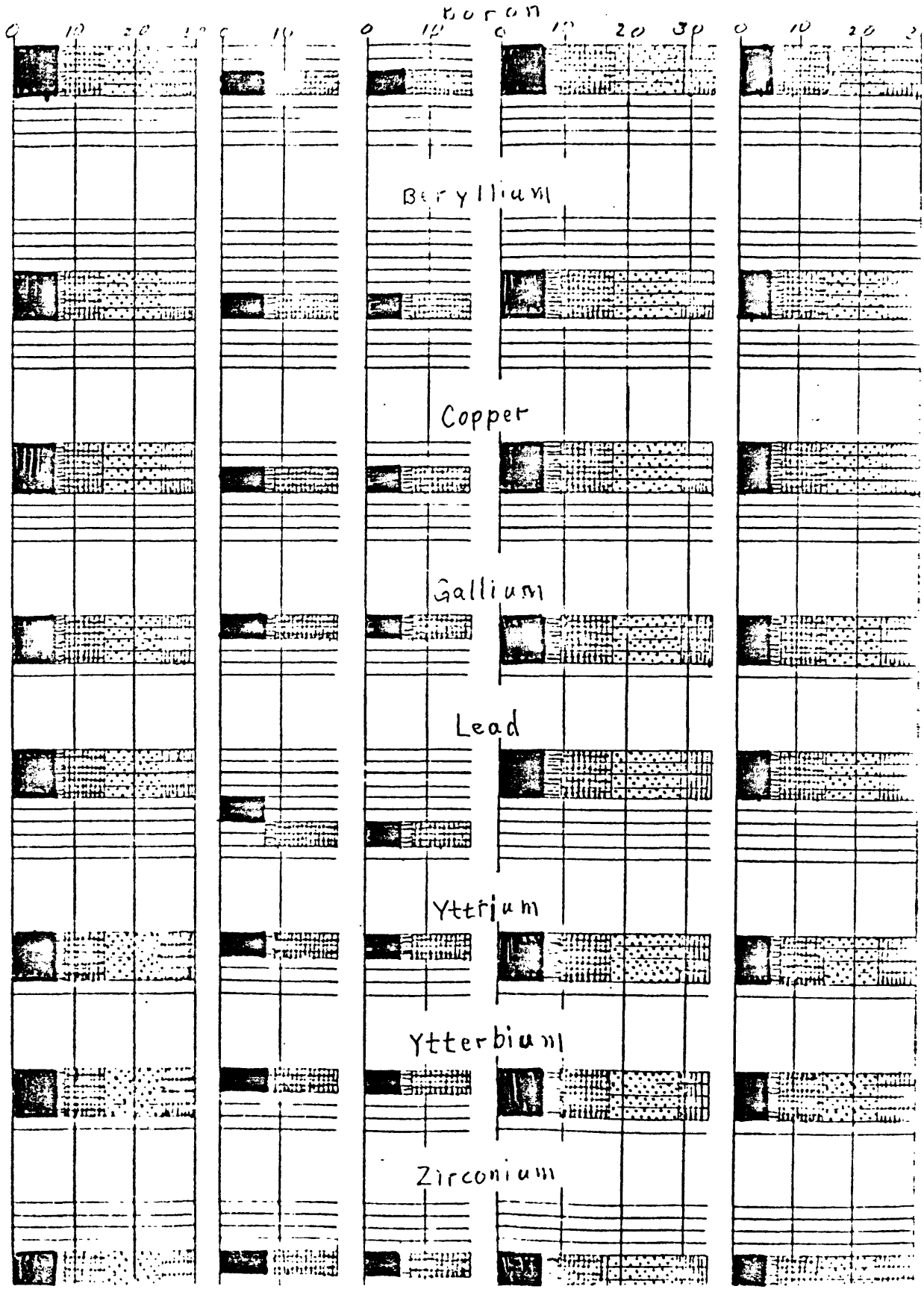
On the basis of the ranges, the actual concentration of certain elements has been estimated, but because of the semiquantitative nature of the data such estimates should be considered as only rough approximations, introduced for comparing concentrations in the Chattanooga with those in other rocks.

Figure 16. Histograms showing distribution of some trace elements in the Chattanooga shale. Ranges are given in parts per million. 9 pages of histograms follow. The explanation of the symbols is on pages 77H-77J.

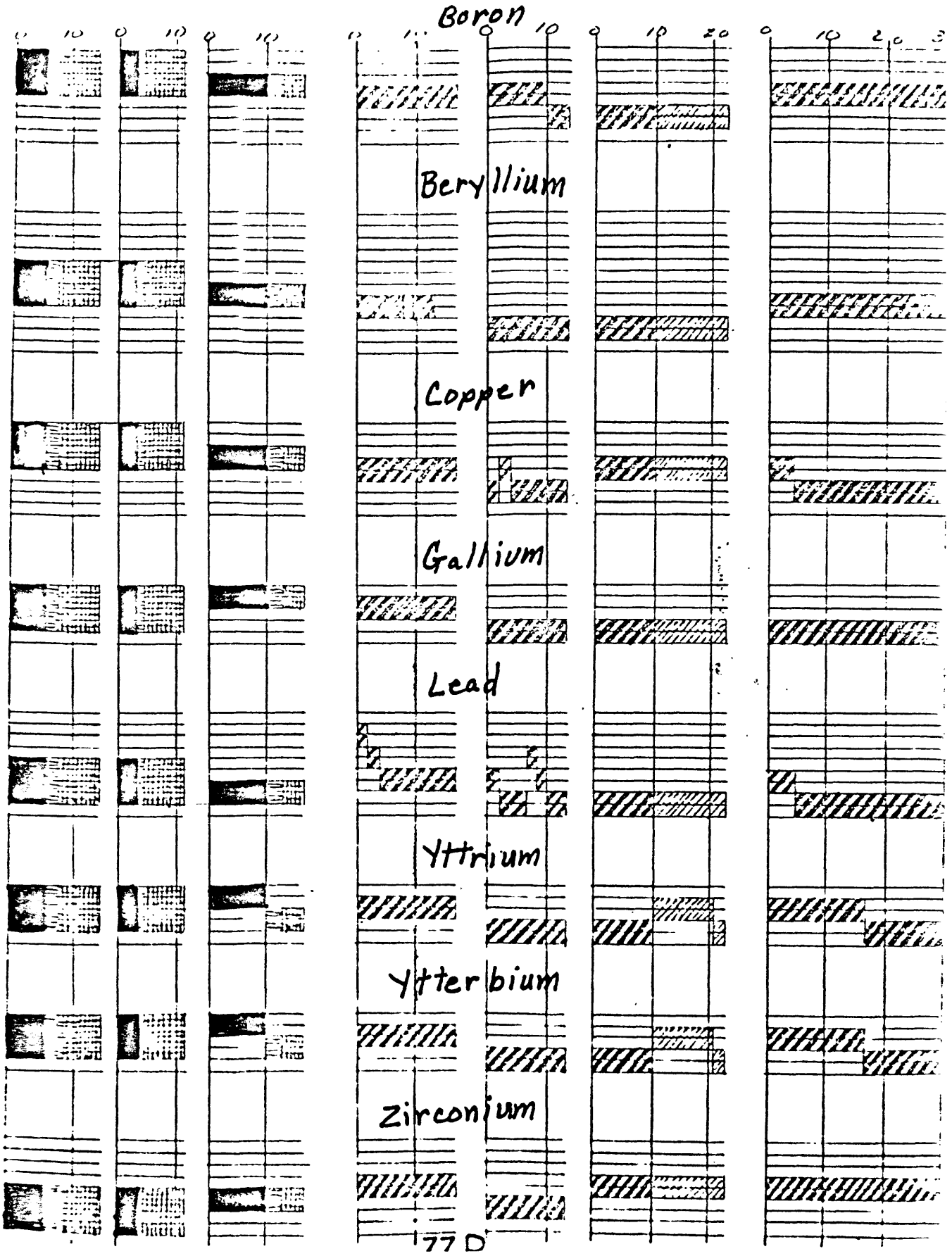
Elements distributed fairly evenly throughout the shale



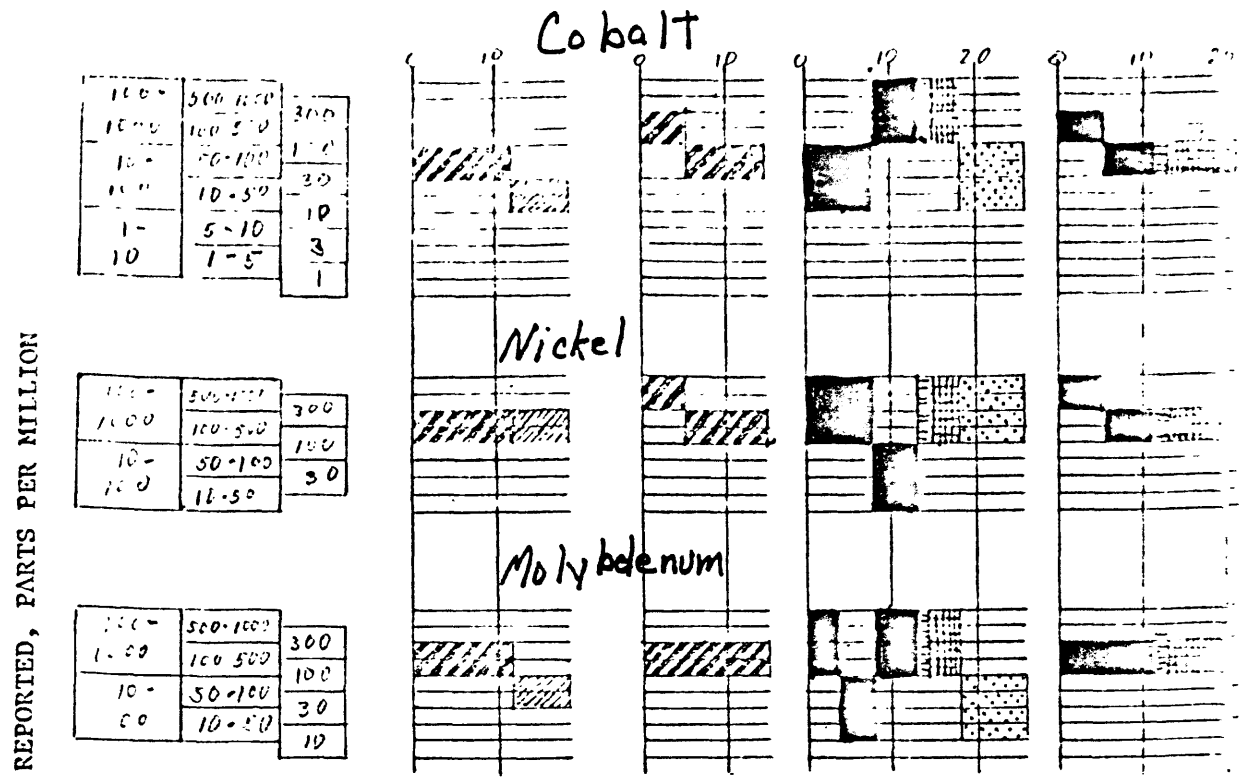
Elements distributed fairly evenly throughout the chalc



Elements distributed fairly evenly throughout the shale

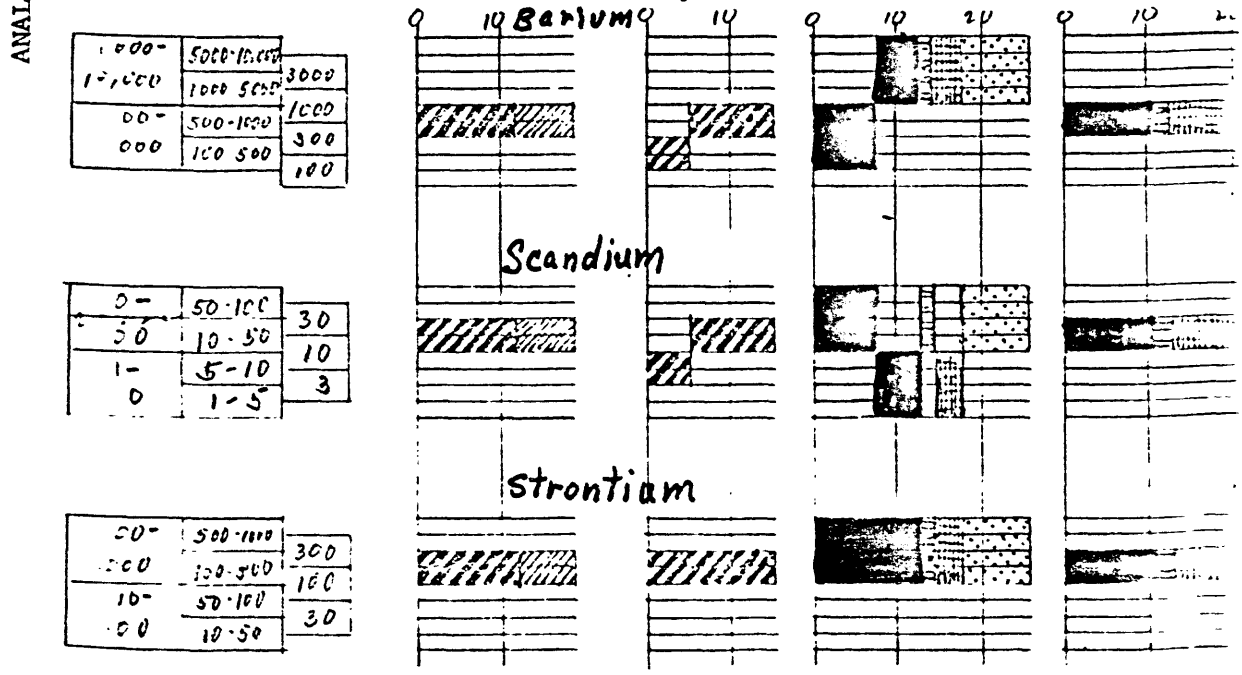


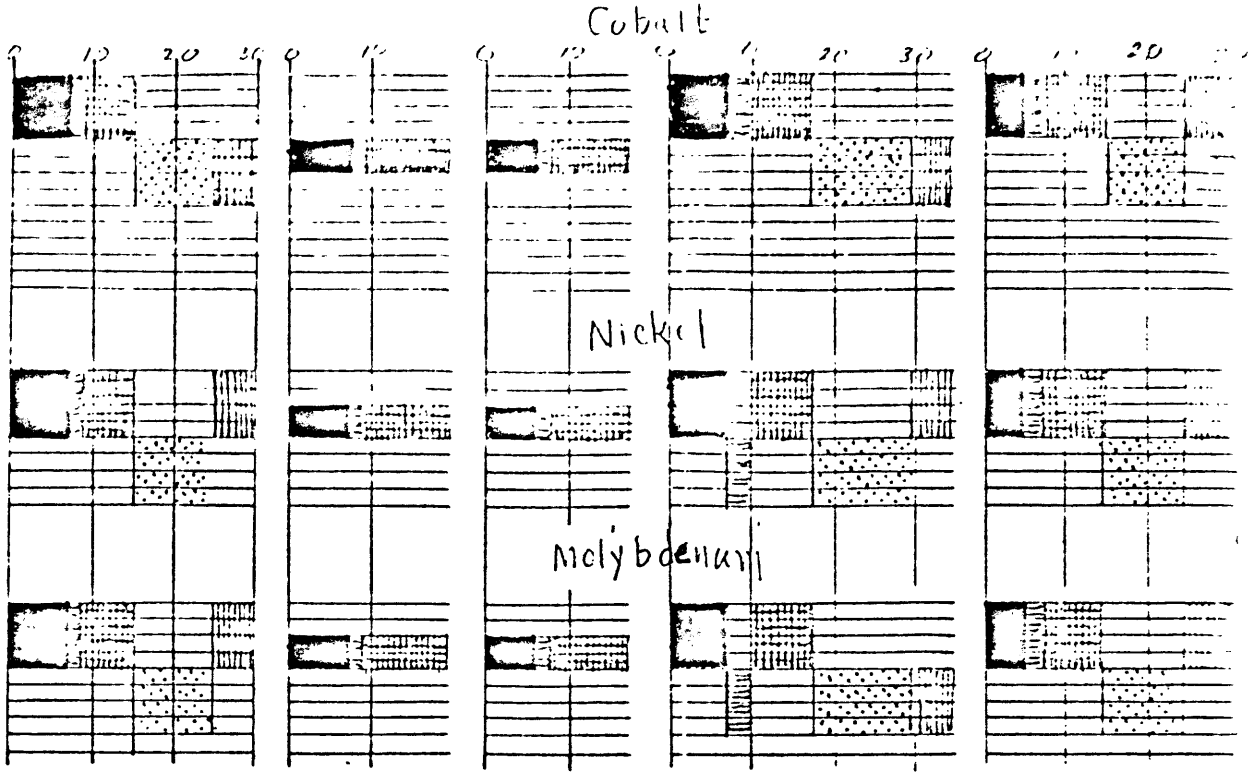
Elements distributed largely by units of the shale



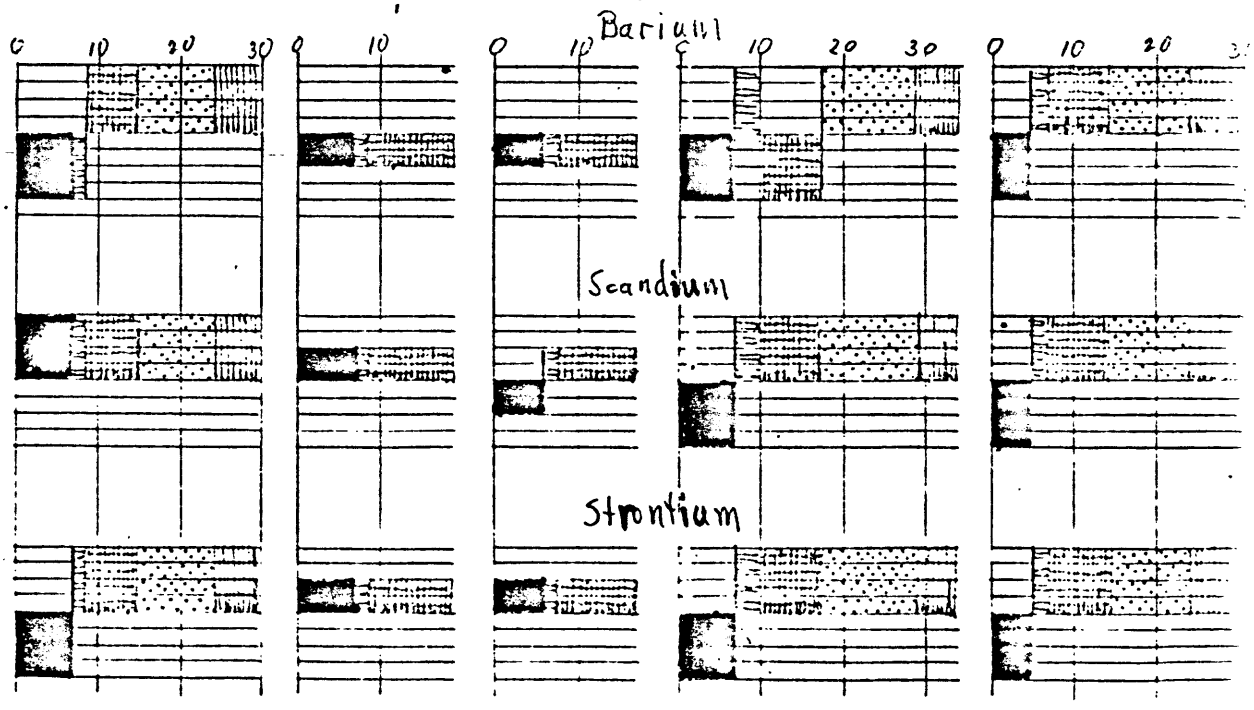
ANALYSES AS REPORTED, PARTS PER MILLION

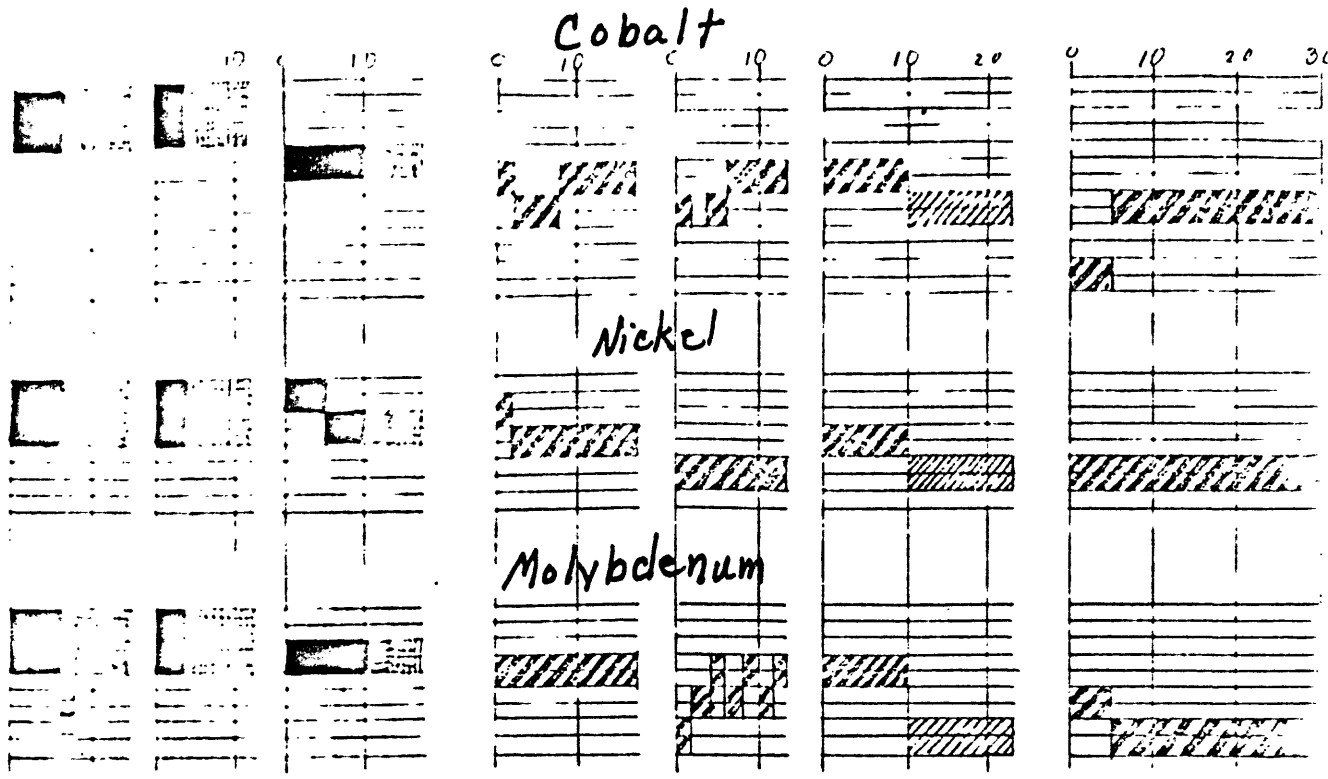
Elements showing vertical patterns of distribution



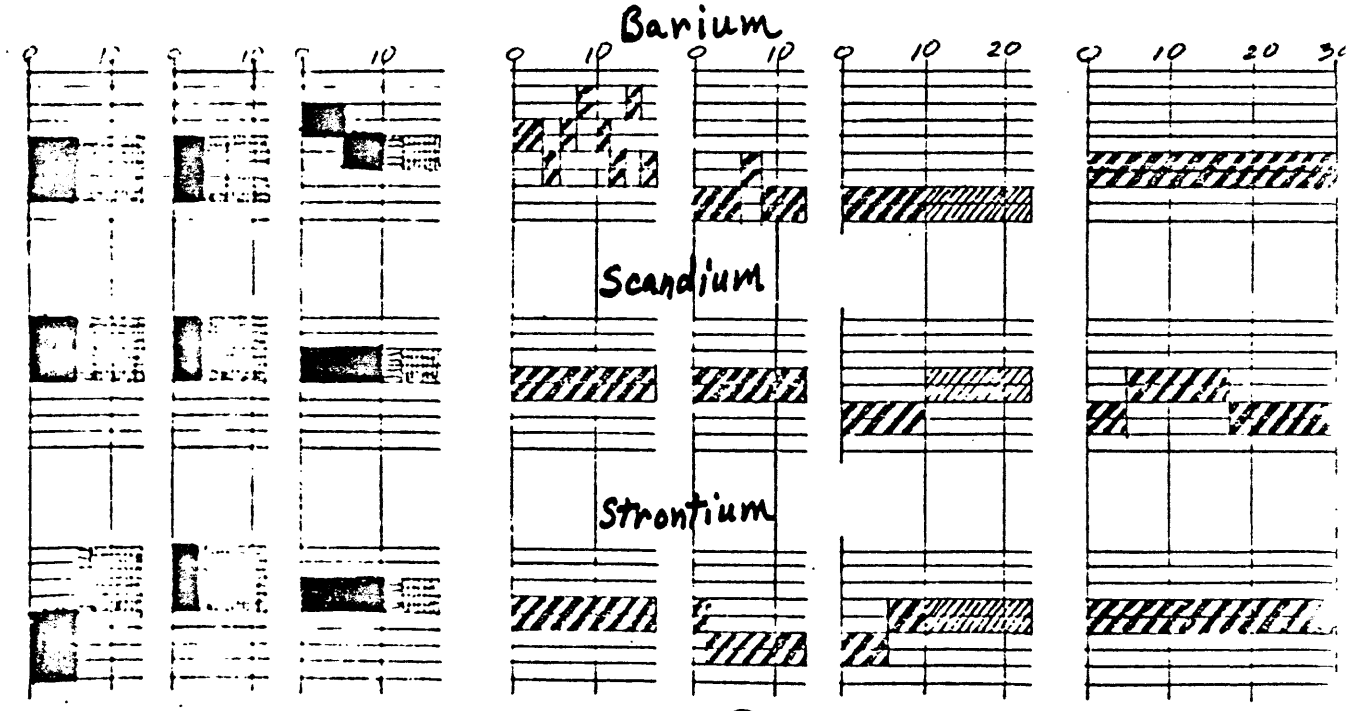


Elements showing vertical patterns of distribution



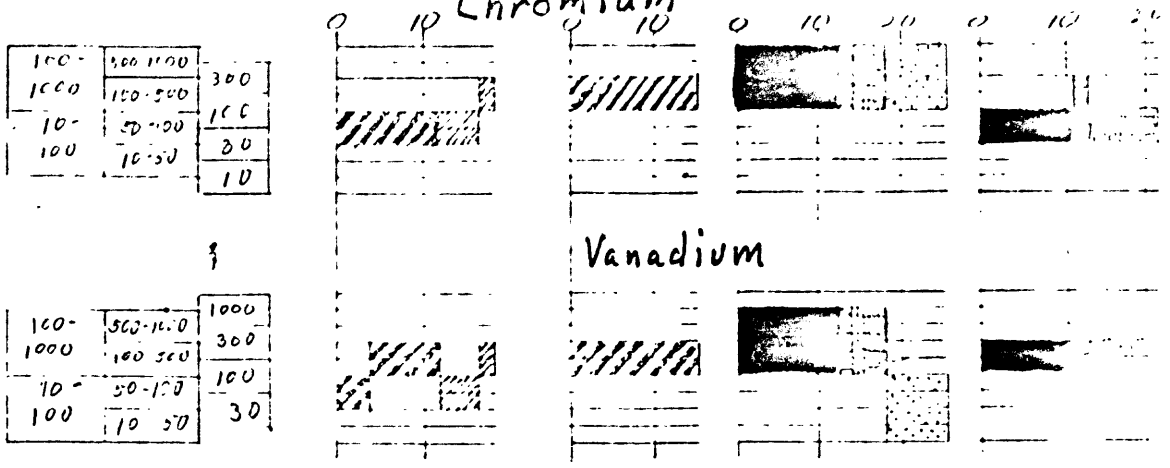


Elements showing vertical patterns of distribution



ANALYSES AS REPORTED, PARTS PER MILLION

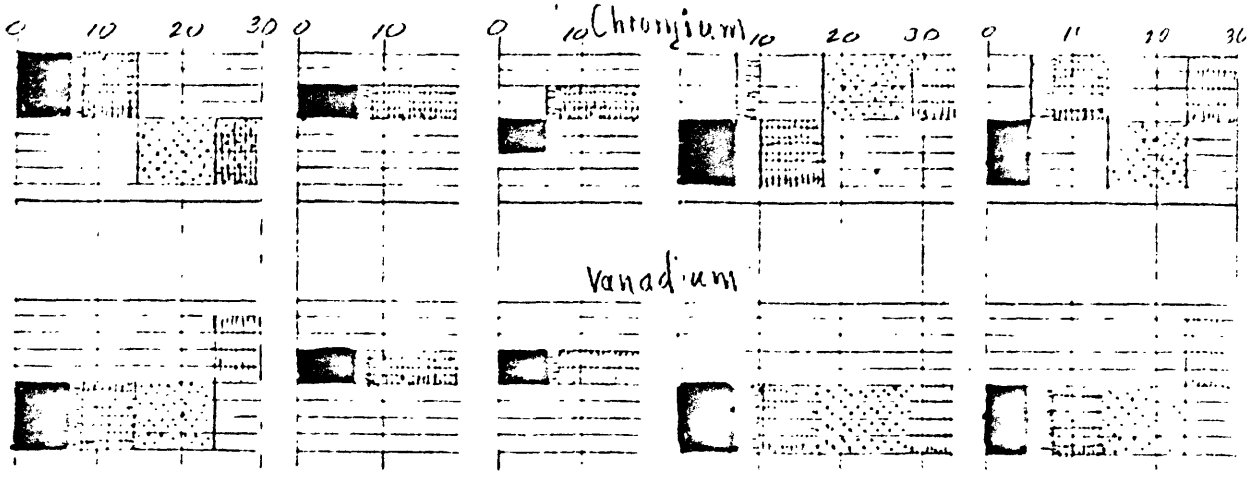
Elements showing irregular distribution



Grassaway member

Upper unit

Elements showing irregular distribution



Explanation of member and unit symbols

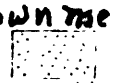
Gassaway member

Middle Unit

Lower unit

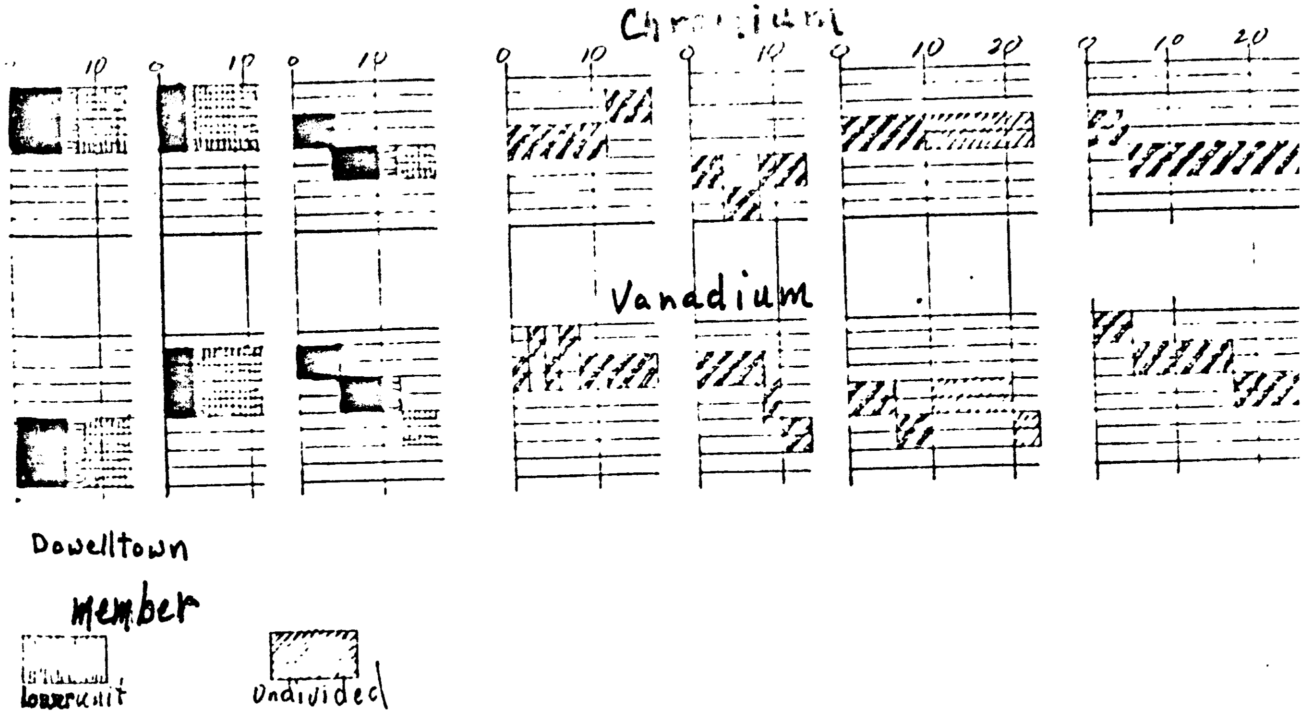
Undivided

Dowelltown member



Upper unit

Elements showing [illegible] distribution



In the following discussion figures for the crustal abundance of the elements in the lithosphere are from Goldschmidt (1954); those for concentrations in black shales from Krauskopf (1955); and those for the concentration in the Sharon Springs member of the Pierre shale (a carbonaceous slate of Cretaceous age which has been studied in detail by the Geological Survey) are from Tourtelot (1956).

Elements distributed fairly evenly throughout the shale

Boron.—The boron content of both members of the Chattanooga shale in Alabama, Walden Ridge, and the Eastern Highland Rim, probably is about 200 to 300 ppm; exceptions are the lower samples from localities C50 and C64, which contain more than 500 ppm. In the Northern Highland Rim and Kentucky, however, the content drops to about 100 ppm except at locality C56, where it drops still lower to about 30 ppm. The low concentration at locality C56, the only locality west of the late Devonian arch that extended northeast from the Hohenwald Platform, is of interest in connection with the theory of Landergren (1945) that the boron content of some sediments is directly proportional to the salinity of the water in which the sediments were deposited. If the arch had the effect of partially barring the Tennessee embayment from the main Chattanooga sea to the north, the salinity of the water in the embayment would have been increased.

The crustal abundance of boron is only about 10 ppm, and the estimate for black shales is 310 ppm; the Sharon Springs member of the Pierre shale contains 30 to 150 ppm boron, about half the concentration in the Chattanooga. As some of the carbonaceous material in the Chattanooga has much the same composition as coal, it is of interest that certain coals in the Northern Great Basin contain 15 to 356 ppm boron, the average being 116 ppm (Zubovic and others, 1961, p. 30).

Beryllium.—In Alabama, Walden Ridge, and the Eastern Highland Rim the beryllium content of the Chattanooga shale may be estimated at about 3 ppm. In the Northern Highland Rim and Kentucky the beryllium content decreases like that of boron, particularly at localities 22 and C56 where the concentration is only 0.3 ppm. For purposes of comparison, the beryllium content of the Sharon Springs member of the Pierre shale is about 1.5 ppm, the average for black shales about 3.5 ppm, which is also the average for coal beds (Stadnichenko, Zubovic, and Sheffey, 1961). In coal beds the highest beryllium content is near the edge of the basin of deposition, and the northward drop in the content of the Chattanooga shale lends some support to the hypothesis that this might be the case with the Chattanooga. The facts, however, are too few and scattered for tenable conclusions to be drawn.

So far as is known the beryllium in the Chattanooga shale is not in beryllium minerals, but it may substitute for other elements in the lattices of the alkali feldspars, tourmaline, and the micas (Sahama, 1950, p. 444; Goldschmidt, 1954, p. 209).

Copper.--The copper content of both members of the Chattanooga shale is probably 100 to 200 ppm throughout the area covered by this report. The two localities for which lower contents (30 to 100 ppm) are reported are 22 in the Northern Highland Rim and 323 in Kentucky. Both of these localities are old outcrops from which considerable copper could have been removed by weathering; this conclusion is strengthened by the approximately normal copper content at drill hole C56 and locality 16, a fairly new outcrop which has not been subjected to as much weathering as localities 22 and 323.

The copper content of the Chattanooga shale, which as stated above is remarkably uniform over large areas, is in fair agreement with Krauskopf's estimate of 100 to 500 ppm for black shales, and is considerably higher than the concentration of 30 to 70 ppm for the Sharon Springs member of the Pierre shale. Tourtelot (personal communication, 1957) states that Paleozoic shales commonly contain more copper than Mesozoic shales. On the other hand, the copper content of the Chattanooga is much less than that of some European shales. The Permian "copper shale" of central Europe contains as much as 2.9 percent copper, and in the black Ordovician shales of Norway and Sweden concentrations of as much as 1,000 ppm are common.

Copper can be concentrated readily from sea water under reducing conditions, particularly if deposition is extremely slow as was the case with the Chattanooga shale. It therefore is not necessary to postulate any source area containing large amounts of copper-bearing rocks.

Gallium.--Except in the Northern Highland Rim and Kentucky, the gallium content of the Chattanooga shale is probably about 75 ppm. At locality 16 in the Northern Highland Rim it is reported as 30 ppm, and at the other northern localities, 10 ppm, which is near the lower limit of detection of the element by spectrographic methods. As the crustal abundance of gallium is 15 ppm, the element is enriched in the Chattanooga. It is not enriched, however, in the Sharon Springs member of the Pierre shale, which contains 7 to 15 ppm gallium.

The manner of occurrence of gallium in the Chattanooga shale is not known. Its enrichment apparently is due to the affinity of the element for sulfur which was abundant in the reducing conditions of the Chattanooga sea. The gallium content decreases to the north in a manner similar to that of a number of other trace elements in the shale.

Lead.—The vertical distribution of lead is fairly uniform at all localities except for higher contents in the top parts of the section at localities C42, 16, and 323. The concentration ranges considerably, however, from one locality to another within relatively short distances. In Walden Ridge the central locality (C49) contains lead in the 100-1,000 ppm range in all but one sample, whereas the other two localities (C48 and C50) contain only 10-50 ppm lead. As locality C49 is unusual in several other respects, this difference would not be so striking were it not for the fact that in the Eastern Highland Rim localities C44, C37, and C16 contain lead in the 100-1,000 ppm range, whereas the other localities contain only 10 to 50 ppm of the element. Even if it be considered that the 100-1,000 ppm range represents an actual concentration of not much more than 100 ppm, the difference is still striking. There are faint suggestions of a regional pattern; for example, the lead content in the Smithville area (localities C37, C16, C26, and C36) clearly decreases from east to west, but more data would be required for the pattern to be mapped. It can only be said, from the data at hand, that the lead content of the shale varies from about 30 to more than 100 ppm in Alabama, the Eastern Highland Rim, and Walden Ridge, but drops to about 10 ppm at localities C56 in the Northern Highland Rim and 323 in Kentucky.

The crustal abundance of lead is about 16 ppm and the element is thus enriched in the Chattanooga shale except possibly in parts of the Northern Highland Rim. In the Sharon Springs member of the Pierre shale the concentration is 15 ppm, about the same as the crustal abundance.

In reducing environments such as prevailed in the Chattanooga sea appreciable amounts of lead sulfide are precipitated with other insoluble sulfides, and such enrichment probably accounts for the enrichment of lead in the Chattanooga shale. This enrichment, however, is far less than that in the copper shale of Germany, where lead concentrations of as much as 5,000 ppm have been reported (Goldschmidt, 1954, p. 403).

Single crystals of galena, 1 to 2 mm in diameter, have been recovered from the shale at locality 54 in the northern part of the Eastern Highland Rim, and from the Smithville area.

Yttrium.—The estimated concentration of yttrium in the Chattanooga shale is about 60 to 70 ppm throughout the area of this report except at localities C56 and 22 in the Eastern Highland Rim and 323 in Kentucky, where it is somewhat lower. This concentration compares with an estimated average of 30 ppm for shales, and 15 to 30 ppm in the Sharon Springs member of the Pierre shale.

Yttrium commonly is present in many minerals in granitic rocks, which could have been the source of the yttrium and many other trace elements in the Chattanooga shale.

Ytterbium.—Ytterbium is present in all samples of the Chattanooga shale that have been analyzed, in concentrations consistently one range lower than the yttrium content.

Zirconium.—The zirconium content of the Chattanooga shale is probably about 75 ppm at all localities except locality C64 in Alabama, where it is somewhat higher, and locality 22 in the Northern Highland Rim, an outcrop where it is somewhat lower. Unlike many trace elements, zirconium does not show a regional pattern and is present in the shale in much the same concentration throughout the area of this report.

The crustal abundance of zirconium is about 220 ppm, several times the concentration in the Chattanooga shale. The Pierre shale contains more zirconium than the Chattanooga, the range being 70 to 150 ppm. Most of the zirconium in the Chattanooga apparently is in the resistant mineral zircon, which has been identified as fine grains in a number of samples.

Elements concentrated according to units of the shale

Cobalt.—In the Eastern Highland Rim the cobalt content of the Gassaway member is in the 50-100 ppm and 100-1,000 ppm ranges, and it is likely that the actual content ranges from not much below to not much above 100 ppm. The concentration h Walden Ridge is about the same, but at localities C48 and C50 the upper unit contains more cobalt than the other units; at locality C49, however, the cobalt concentration in the anomalous top 4 feet and the 4-foot phosphatic zone beneath it is less than 100 ppm. In Alabama, the Northern Highland Rim, and Kentucky the cobalt content of the Gassaway is somewhat lower than in other areas. The bottom-preferential distribution of the element at the three outcrops —localities 16, 22, and 323—may represent the effect of weathering.

The cobalt content of the Dowelltown member at most localities is one range lower than that of the Gassaway. Throughout the entire Chattanooga shale the black beds contain more cobalt than the gray beds, but the differences are not great.

The crustal abundance of cobalt is about 40 ppm, and the element is thus enriched in the gray beds of the Chattanooga and to a greater extent in the black beds. The concentration in the Chattanooga is greater than that of black shales in general, which is estimated at 5 to 50 ppm, the maximum figure being 180 ppm. The Sharon Springs member of the Pierre shale contains 3 to 30 ppm cobalt, the average being about 15 ppm.

Under the reducing conditions that prevailed in the Chattanooga sea cobalt commonly is concentrated in muds rich in organic matter; it is an "inherent element" in the organic matter itself, and additional amounts may be absorbed from the sea water or precipitated as sulfides (Rankama and Sahama, 1950, p. 685).

Nickel.--The distribution of nickel in the Chattanooga shale is much the same as that of cobalt, but the concentration is somewhat higher. In Alabama, the Eastern Highland Rim, and Walden Ridge the Gassaway member contains 200 to 300 ppm nickel, the content in the Northern Highland Rim and Kentucky being from 30 to 100 ppm. The highest reported content is in the upper part of the member in Walden Ridge, where the nickel content is more than 500 ppm.

Except for the lower unit at localities C16 and C44, the nickel content of the Dowelltown member is less than 100 ppm.

The crustal abundance of nickel is about 100 ppm, and the element is thus enriched in the black units of the Chattanooga shale, but not in the gray beds. The nickel content of black shales in general varies widely, the estimates ranging from 20 to 300 ppm. The Sharon Springs member of the Pierre shale contains from 30 to 70 ppm nickel.

Nickel is a common constituent of organic matter. It has a high affinity for sulfur and under reducing conditions is concentrated in organic-rich muds.

Molybdenum.—The concentration of molybdenum in the Chattanooga shale in Alabama and in the Eastern Highland Rim and Walden Ridge in Tennessee is much the same as that of nickel; 200 to 300 ppm in the black beds and less than 100 ppm in the gray beds. At localities 12, 22, and C56 in the Northern Highland Rim the molybdenum content of the Gassaway member is about the same or slightly lower than that in the Eastern Highland Rim, but the Dowelltown member at locality C56—the only locality in that area for which determinations on the Dowelltown were made—is only about 10 ppm. At locality 323 in Kentucky, which contains the Gassaway member only, the content is also about 10 ppm, much lower than that of the Gassaway at any other locality.

The crustal abundance of molybdenum is 2 to 3 ppm and black shales commonly contain from 10 to 300 ppm; the element is thus enriched in the black parts of the Chattanooga. In the Sharon Springs member of the Pierre shale, however, it was detected in a very low concentration in only one of the 60 samples analyzed.

Molybdenum solutions, when brought in contact with carbonaceous sediments under reducing conditions, can precipitate the element in sulfides (Sahama, 1950, p. 629-639). Molybdenum probably was concentrated in the Chattanooga shale by this process.

Molybdenum is recovered as a by-product from the Permian copper shale of Europe (Goldschmidt, 1954, p. 560). As the molybdenum content of the Gassaway member of the Chattanooga shale (200 to 300 ppm) is somewhat higher than that of the copper shale (100 to 200 ppm), the element might be recovered on a by-product basis should the Chattanooga ever be mined on a large scale.

Elements showing vertical patterns of distribution

Barium.--The barium content of both members of the Chattanooga shale in the Eastern Highland Rim and Walden Ridge falls within the 100-1,000 ppm and 1,000-10,000 ppm ranges, and probably averages not far from 1,000 ppm. Where vertical differences exist the upper parts of the Gassaway member contain less barium than the remainder of the section except at locality C51 in the northern part of the Eastern Highland Rim, where the upper unit of the Gassaway has the highest content. Locality C64 in Alabama and locality 16 in the eastern part of the Northern Highland Rim also contain about 1,000 ppm barium, but at locality 16 different samples range from about 300 to as much as 3,000 ppm. At localities 22 and C56 in the Northern Highland Rim, however, the barium content of the shale is only about 100 ppm, and at locality 323 in Kentucky, 300 ppm.

The crustal abundance of barium is about 430 ppm, and the concentration in black shales is 450 to 750 ppm with a maximum of 2,400 ppm; the element is thus somewhat enriched in the Chattanooga shale. The barium content of the Sharon Springs member of the Pierre shale, 300 to 700 ppm, is lower than that of the Chattanooga.

Most of the barium in the Chattanooga shale probably is in the feldspars, the clay minerals, and the micas, where barium commonly substitutes for potassium. The relatively high concentration in the Dowelltown member and the lower part of the Gassaway member, as compared to the upper Gassaway, probably reflects in part the larger proportion of those minerals in the lower part of the shale.

Scandium.—All analyses of the Chattanooga shale for scandium fall within the 1 to 100 ppm range, the actual content probably is not much more than 10 ppm; the content of the Gassaway member at locality C56, however, is only about 3 ppm, and at locality 323 the average content probably is about 7 ppm. Distribution of the element generally is bottom-preferential, but at locality C49 in the Walden Ridge area can best be classed as irregular.

The crustal abundance of scandium is about 5 ppm and no figures on the concentration in black shales are available. The content of the Sharon Springs member of the Pierre shale is 10 ppm, about the same as that of the Chattanooga. The geochemistry of scandium is related more to that of magnesium and ferrous iron than to that of the rare earths as formerly was supposed (Goldschmidt and Peters, 1931) and at least part of the scandium in the Chattanooga probably is present as a replacement of magnesium and other elements.

Scandium metal has special properties that may make it technologically useful even at its present high price, although no specific uses have been discovered. Lash and Ross (1961) state that small amounts of scandium are recovered with uranium from some ores mined in the Colorado Plateau. Whether the element could be recovered similarly from the Chattanooga shale is not known, but if uses are developed it might be possible to recover it as a by-product in any future mining of the shale.

Strontium.—The pattern of distribution of strontium in the Chattanooga shale is about the same as that of scandium, but strontium is about 10 times as abundant as scandium, the average content being on the order of 100 ppm.

The crustal abundance of strontium is about 150 ppm, about the same as the concentration in the Chattanooga shale. The geochemistry of strontium is generally similar to that of calcium and barium, but valid comparisons cannot be made because of lack of data. The distribution pattern of strontium in the Chattanooga is much like that of barium.

Elements distributed irregularly in the shale

Chromium.—The chromium content of the Chattanooga shale in the area of this report is in the 10-100 and 100-1,000 ppm ranges, and the average is probably not much more nor less than 100 ppm; the only apparent exceptions are localities 22 and 323, both outcrops, in which the concentration is about 30 ppm. As a rule the concentration is higher in the gray beds than in the black beds, but there are exceptions, such as locality C16 in the Smithville area where the upper gray Dowelltown contains chromium in the same range as the black upper Gassaway. On the whole, neither the vertical distribution nor the regional pattern is distinct.

The crustal abundance of chromium is about 200 ppm and the element thus appears to be depleted, but not greatly so, in the Chattanooga shale. The content of the Pierre shale, 50 to 150 ppm, is about the same as that of the Chattanooga, and both formations contain about the same concentration as black shales in general.

Chromium distribution is complex; the element is "inherent" in organic matter, but also is distributed widely through minerals. Unlike most trace elements in the Chattanooga shale, chromium does not form sulfides, and thus is not greatly affected by the reducing conditions under which the shale was formed.

Vanadium.—The vanadium content of both members of the Chattanooga shale in the area of this report is on the order of 100 ppm except for localities 16, 22, and 323, in the Northern Highland Rim and Kentucky, where the concentration is about 300 ppm; the highest content apparently is at locality 16, where two of the upper samples are reported as containing 1,000 ppm. The vanadium content of the upper or gray unit of the Dowelltown is low, but at two localities (C16 and C44 in the Eastern Highland Rim) the black lower unit of the Dowelltown contains more vanadium than the Gassaway member.

The crustal abundance of vanadium is 150 ppm, and the element is thus not enriched in the Chattanooga shale except in the northern part of the region under discussion. The concentration is not far from that in the Sharon Springs member of the Pierre shale, which contains 70 to 300 ppm vanadium.

Vanadium is characteristically associated with carbonaceous shale, but the concentration of the element in the Chattanooga shale reflects to only a slight degree the percentages of carbonaceous matter in the different units. It may be that vanadium is concentrated by only one of the several types of carbonaceous material, and its apparently erratic distribution reflects this limitation.

Elements detected only locally in the shale

Lanthanum.—Lanthanum, in a concentration of about 30 ppm, was detected in one sample from near the middle of locality 16; in the middle and lower units of the Gassaway member at locality C42; and in the lower unit of the Gassaway member and the upper unit of the Dowelltown member at locality C49. These localities are shown in figure 17.

Figure 17. Sketch map showing localities at which lanthanum and niobium were detected in the Chattanooga shale.

The lower limit of detection of lanthanum by semiquantitative spectrographic methods is 10 ppm and it is possible that the element is present in other localities, those in which it is present representing areas of slight enrichment. Although lanthanum, where detected, appears to be concentrated near the middle of the formation vertically, too little data are available for any safe conclusions to be drawn.

Niobium.—The threshold of detection of niobium when the determinations were made was 10 ppm, and the element was detected, in approximately that concentration, at localities 22, C56, and 323 (see fig. 17). At all of these localities the element is distributed evenly throughout the entire section of the shale.

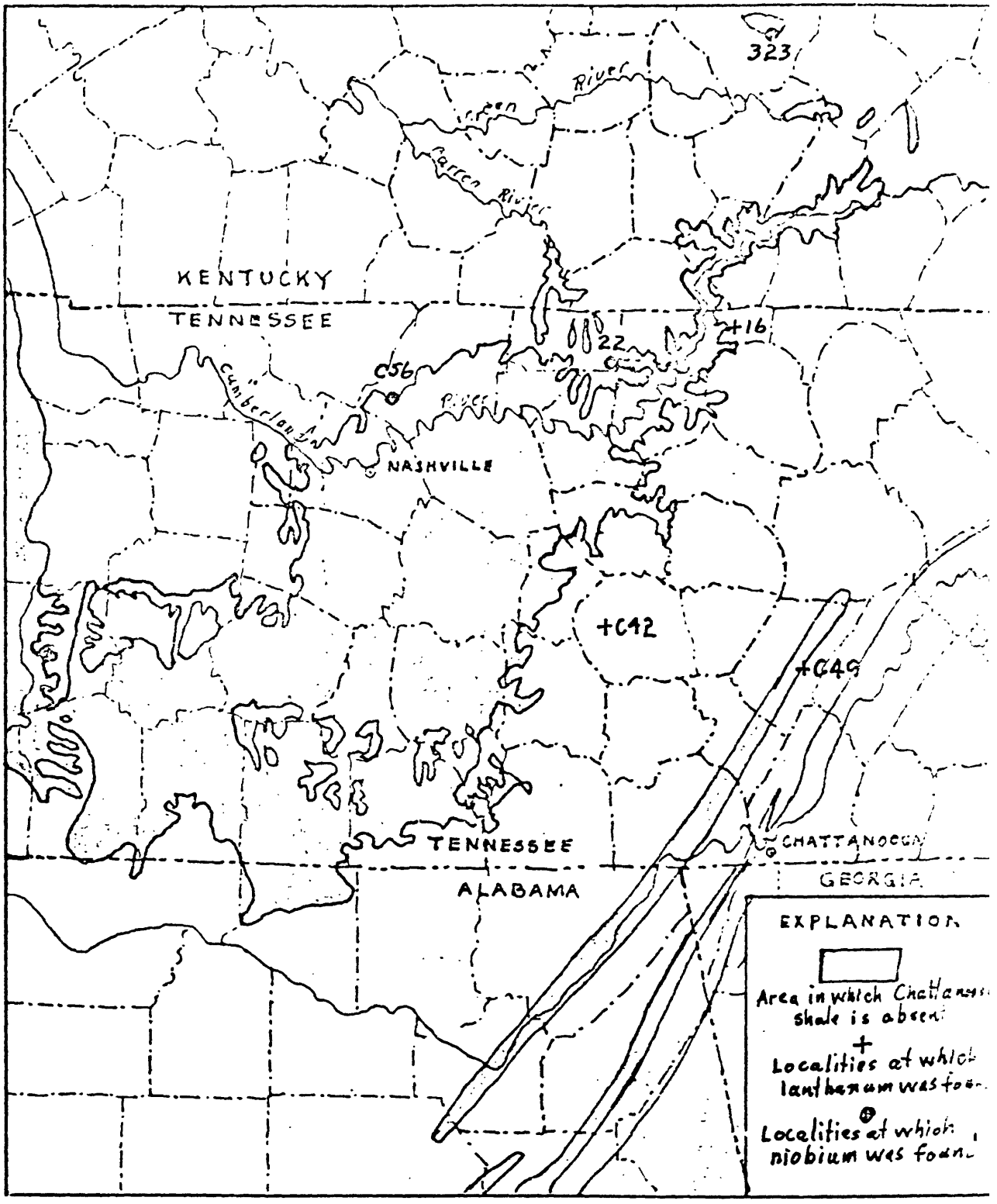


Fig. 17—Sketch map showing localities at which lanthanum and niobium were found in the Chattanooga shale.

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The three localities in which niobium was found are in the northwestern part of the area discussed in this report, a long distance from the shore of the Chattanooga sea. This fact suggests a regional pattern of distribution; but the data are too sparse for this to be more than a suggestion. It should be said, also, that the samples from localities 22, C56, and 323 were in the last group analyzed, and the determinations possibly were more precise than those made earlier.

Silver and gold.—Over the period in which spectrographic analyses of the shale were made the lower limit of detection for silver decreased from 1 ppm to 0.1 ppm, and about half the samples showed the element just above the threshold. Therefore it can only be said that the Chattanooga shale in the area covered by this report contains 1 ppm or less of silver. Gold was not detected in any of the spectrographic analyses.

About 1920 samples of Devonian shales from 22 counties in Kentucky were selected for fire assays of gold and silver content, and the results reported by Crouse (1925a). The assays were made on hand samples which may or may not be representative of the shale in large areas, and the exact locations of the sampled localities are not given. Also, the assays were made on roasted samples, which had lost an estimated 20 percent of their original weight. The average silver content of the 22 samples is given as 0.09 ounce per ton, the average gold content as 0.009 ounce per ton.

Of more possible value than the assays from 22 scattered counties are those from 6 counties—Boyle, Casey, Cumberland, Lincoln, Marion, and Taylor (locality 323 of this report is in Marion County and Cumberland County is between localities 12 and 16). In these counties the average silver content is 0.063 ounce per ton, the average gold content 0.009 ounce per ton. As 1 ounce per ton is equivalent to 30 ppm, it follows that the roasted shale in those areas has an average silver content of about 2 ppm and a gold content of about 0.27 ppm, and that the shale before roasting contains about 1.5 ppm silver and 0.2 ppm gold. These values, though extremely low, are not so low as to prohibit possible recovery on a by-product basis should the shale be mined for other purposes.

Tin.—Tin, in concentrations of 10 to 30 ppm, was detected in the shale from localities C49, C16, C26, C36, C44, C56, 22, and 323 (see fig. 18). The highest concentration is in a 1.72-foot sample 2.85 feet

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Figure 18. Sketch map showing localities at which tin was detected in the Chattanooga shale.

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above the base of the Cassaway member at locality C49, where tin in the 100-1,000 ppm range was reported; the remainder of the section contains the element in the 10-100 ppm range. Except for this locality, the vertical distribution of tin is virtually even vertically, throughout both members of the Chattanooga shale, at each locality.

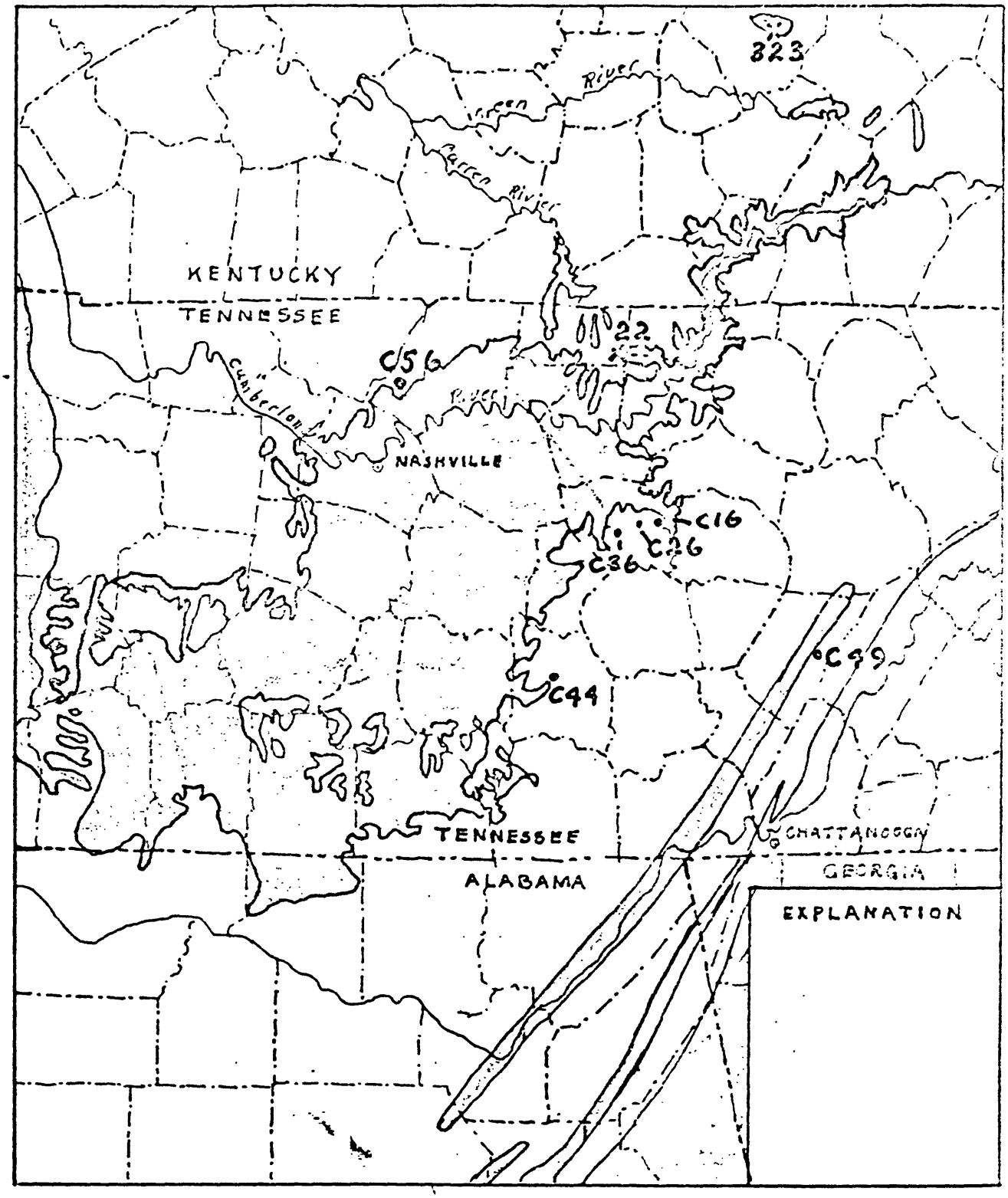

Fig. 18:—Sketch map showing localities in which tin was detected in the Chattanooga shale

The threshold of detectability for tin by semiquantitative spectrographic methods is 10 ppm, and the element possibly is present at localities other than those in which it was detected. It appears, however, that the highest tin content is in a belt extending northwest from locality C49 through the Smithville area and into the Northern Highland Rim and Kentucky. The occurrence at locality C44 may be an isolated one, or may represent a southern continuation of the relatively high tin area in the Smithville area.

Some of the tin in the Chattanooga shale may be in galena, and some possibly is in detrital cassiterite, which is common in granitic rocks such as those from which much of the detrital material in the Chattanooga was derived. Cassiterite has not been identified, however, in samples of the shale.

Zinc.—Zinc in quantities above the lower limit of detection, which was 30 ppm when all samples were analyzed, was detected in samples from the upper part of the Gassaway member from 6 localities—C26 and C96 in the western part of the Smithville, C51 in the northern part of the Eastern Highland Rim, 16 and 22 in the Northern Highland Rim, and 323 in Kentucky. In the Smithville area the element is reported in the 10-100 ppm and 100-1,000 ppm ranges; the actual content probably is not far from 100 ppm. At locality C51 it is reported in the 50-100 ppm range, and at the more northerly localities the content ranges from about 100 ppm at locality 323 to more than 300 ppm at locality 16, the top 2 feet of which contains about 1,000 ppm. No zinc was detected in the Dowelltown member except at locality C64 in Alabama, which contains 50 to 100 ppm zinc.

Except for the Alabama locality, the vertical and regional distribution of zinc makes clear patterns, as shown in figure 19. A general

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Figure 19. Sketch map showing localities at which zinc was detected in the Chattanooga shale.

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correlation of zinc content with the phosphatic zone of the Gassaway member can be distinguished, although the zone was not detected in the Smithville localities analyzed but is known to be present at other nearby localities.

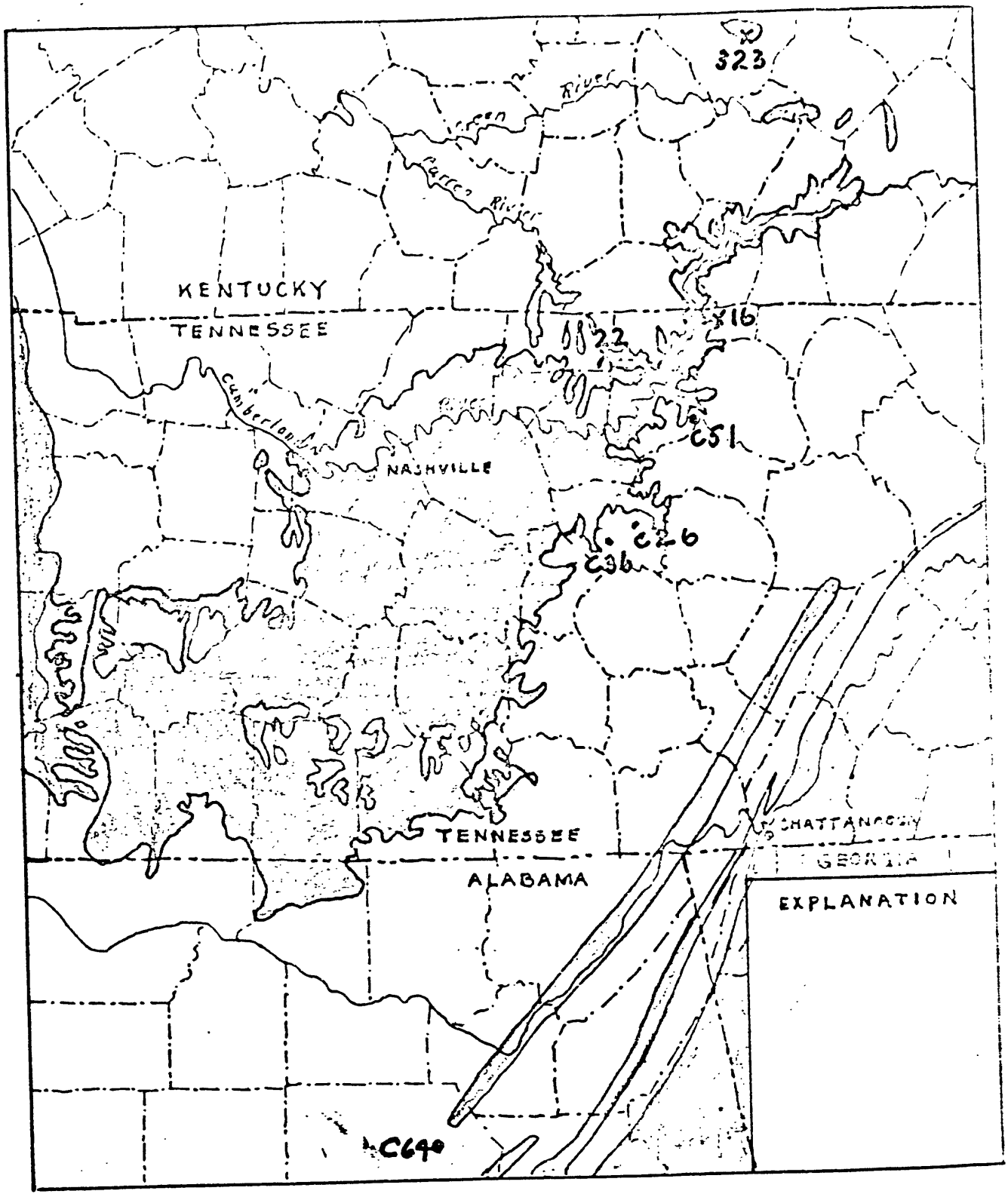

Fig. 19:—Sketch map showing localities at which zinc was detected in the Chattanooga shale

Shales containing organic remains, such as the Gassaway member, are commonly rich in zinc, and the highest concentrations occur in places where the production of hydrogen sulfide from decaying organisms is comparatively weak (Krauskopf and Sahama, 1949, p. 713). As the phosphatic zone was deposited in better aerated water than the underlying parts of the Gassaway member, this condition might explain the distribution of zinc in the member.

Germanium.--In the middle 1950's there was considerable interest in finding germanium for use in transistors, a need that dropped off when methods of using silicon for that purpose were developed. Germanium was not found in any samples of the Chattanooga shale on which spectrographic determinations were made; if present, it was below the threshold of detectability, 3 ppm. As the association of germanium with certain parts of coal beds was well known (Stadnichenko and others, 1953), samples of thin (half an inch or less) coaly stringers in the Gassaway member of the Chattanooga shale at locality 2038 in Davidson County, Tennessee were collected by L. C. Conant and T. M. Kehn of the Survey and analyzed chemically for germanium and other elements. The results, reported by Breger and Schopf (1955) show that the coaly material, which in composition is practically the same as high volatile A bituminous coal, contains from 250 to 510 ppm germanium, whereas the unweathered shale between the woody stringers contains only 0.8 ppm germanium, far below the limit of detection by semiquantitative spectrographic methods.

On the basis of geochemical considerations, it seems probable that the coaly material originally was logs or woody fragments.floated into the basin of deposition, and was germanium-bearing when it entered the sea.

Rare earths.—Glover (1959, p. 153) reports an unusual assemblage of rare earths in a grab sample of highly weathered coal material from the Maury-Fort Payne content at his locality 8M-2 in Dade County, Georgia. The coal probably represents burial of one or two isolated logs and hence would be of no commercial importance, but the occurrence is of considerable scientific interest and is here mentioned even though it is not in the Chattanooga shale itself. The coal burns to 10 percent ash that contains all the rare earths except promethium. In the 1 to 5 percent range as determined spectrographically are yttrium, manganese, gadolinium, and neodymium, and the ash also contains 0.16 percent uranium by chemical analysis (Breger and Deul, 1955, p. 186).

Observations on the chemical composition of the shale

Observations on the composition of the Chattanooga shale must be evaluated in the light of the conditions under which the data were obtained, and the resultant gaps in the information. As stated in the Introduction, the Geological Survey's investigations were primarily geologic field studies, and routine analyses for radioactivity and uranium. Additional studies made later, mostly after 1955, did not constitute a comprehensive study of the geochemistry, mineralogy, and petrography of the shale, but were directed toward obtaining answers to specific questions. Investigations by The Pennsylvania State University, which have been drawn upon in the preparation of this report, were limited to the chemistry, mineralogy, and petrography of the Gassaway member of the shale from cores supplied by the Bureau of Mines and the Geological Survey, and included no field work.

The uniformity of the Chattanooga shale in appearance and general characteristics over large areas, which has been commented upon by practically every student of the formation, is substantiated by the data obtained during the Survey's investigations. There are, however, regional differences, and differences between the members and units of the shale, that have important bearings on the economic potential of the formation.

Two of the localities for which chemical analyses were made—064 in Blount County, Alabama, and 323 in Marion County, Kentucky—are long distances from the area of intensive investigations in Tennessee, having been selected to obtain an idea of regional changes north and south of the Tennessee area. Locality 064 has particular importance because throughout Dowelltown time and early Gassaway time the Alabama embayment in which it occurs was separated from the Tennessee embayment, and even after the two embayments coalesced depositional conditions in the two areas were somewhat different. On the other hand, the shale at locality 323, which is New Albany rather than Chattanooga shale, does not differ materially from that in the Tennessee areas except for changes related to its greater distance from the shore line of the Chattanooga sea.

The shales of the Gassaway member and of the beds of questionable Dovelltown age in Alabama are coarser-grained than the Chattanooga shale of Tennessee, and the formation contains much disseminated quartz sand, scattered chert beds, and intraformational conglomerate; these conditions are more pronounced east and northeast of locality C64 than at the locality itself (Glover, 1959, p. 139-149). The quartz content of the shale of the Gassaway member at locality C64 (33.1 percent) is higher than that of any other locality from which samples were analyzed, and decreases with fair regularity northward, being about 22 percent at locality C56 in the Northern Highland Rim of Tennessee; no data are available north of that locality. No data on the quartz content of the shale in Walden Ridge has been obtained, but Glover (1959, p. 156) states that the shale in that area is sandier than that to the west; comparison of the silica content of the shale from Walden Ridge with that from Alabama, however, suggests that quartz is not as plentiful there as in Alabama. As the Walden Ridge and Alabama localities probably were about the same distance from the Late Devonian shoreline, the higher quartz content in Alabama could reflect differences in source areas about which too little is known for conclusions to be drawn.

The only locality which does not fit into a regional pattern on the basis of the chemical analyses is locality C49 in Walden Ridge. There the upper 4 feet is distinctly anomalous in several respects, and throughout the entire section the distribution of some elements is unusual.

At all localities and for all units of the shale silica, alumina, potassia, magnesia, lime, iron, and loss on ignition comprise about 98 percent of the rock. The principal variables are silica and alumina on the one hand, iron and ignition loss on the other. As most of the iron is in pyrite or marcasite, the iron content and that of sulfur and carbonaceous material are closely related. These constituents combined comprise about 23 percent of the Cassaway member from locality C64, 24 to 30 percent in Walden Ridge, and 27 to 35 percent in the Northern and Eastern Highland Rims and in Kentucky. The range of these same constituents in the upper unit of the Dowelltown member and the undivided Dowelltown is 14 to 17 percent, and for the one locality (C37) from which samples of the lower Dowelltown were analyzed, the content is 22 percent.

The high contents of iron and organic matter in the Chattanooga shale reflects the strongly reducing conditions of the Chattanooga sea. The fact that the combined content is about half as much in the gray beds of the upper unit of the Dowelltown member as in the black beds of the Gassaway member supports strongly the statement of Glover (1959), which has been mentioned previously, that the change from black to gray beds in the Chattanooga shale reflects primarily an increase in detrital material introduced into the sea, rather than a change from reducing to oxidizing conditions. Had oxidizing conditions prevailed for the long period of time over which the gray beds were deposited, it is hard to believe that enough of the pyrite and carbonaceous matter would have been preserved to make up about one-seventh of the total shale. Another evidence is the relatively large size of the quartz grains in the middle unit of the Gassaway member (27 microns as against 18 microns in the lower and upper units) at two localities in the Smithville area; no measurements of the Dowelltown member were made, but the differences between the black and gray units of the Gassaway are instructive.

Like that of the major constituents, the distribution of trace elements in the Chattanooga shale is remarkably uniform when the large area covered by the investigations is considered; this is particularly true in the Western Highland Rim and Walden Ridge, which are southeast of the late Devonian arch extending northeast from the Nashville Platform. Because of the semiquantitative nature of the data interpretations must be made cautiously; but generally speaking, for most elements and at most localities the concentration falls within two adjacent orders of magnitude, leading to the conclusion that the actual content over the region is not much above nor below the dividing line between the ranges in which it is reported.

Regionally, the concentrations of copper and zirconium are fairly uniform vertically at each locality and over the region as a whole, though there is some depletion of copper at the two old outcrop localities, 22 and 323. Of the other elements that show little change vertically at each locality, boron, beryllium, and gallium have a fairly uniform regional distribution except that the content is somewhat lower in the Northern Highland Rim and Kentucky than elsewhere; to a less extent this is true of yttrium and ytterbium. The concentration of lead ranges considerably between nearby localities, but no pattern can be discerned from the scattered data at hand.

The concentrations of cobalt, nickel, and molybdenum show positive correlations with the content of organic matter. Barium, scandium, and strontium are distributed top-preferentially in the shale, the lowest content usually being in the upper unit of the Dowelltown member. Of elements that were not detected at all localities, too little data on niobium, lanthanum, and silver are available for conclusions to be drawn. Tin and zinc were detected only in samples from the Northern Highland Rim and Kentucky, and these elements thus show a regional pattern of distribution opposite that of most of the trace elements, which appear to increase from north to south.

The only localities for which the content of trace elements does not fit reasonably well into regional or vertical patterns are localities C49 and 22. The conditions at locality C49 have been discussed previously. At locality 22, an old outcrop, weathering unquestionably has had some effect on the present concentration of certain elements; in addition, the locality is near the crest of the Late Devonian arch, and the shale in that area partakes of some characteristics of the rock in both the Eastern and Northern Highland Rims.

Petrology and mineralogy

The petrographic data and in part the mineralogic data in this section are summarized from Conant and Swanson (1961, p. 42-48), who point out that the most obvious characteristic of the black beds of the Chattanooga shale is the extremely fine grain size of most of the constituents and the high degree of sorting which results in very fine laminae. Most of the minerals observed range downward from silt-size particles to the limit of visibility with a light microscope. Among the minerals visible microscopically are quartz, feldspar (mostly orthoclase according to Bates and Strahl,1958), pyrite, mica in flakes locally large enough to be seen with the naked eye, microscopic masses of phosphate, and calcite which commonly occurs as scattered single crystals. In general, the black beds of the shale are extremely fine-grained argillaceous quartz siltstones, rich in organic matter and pyrite. The black shale of the lower unit of the Dowelltown member is less well sorted than the Gassaway.

The gray beds of the Dowelltown member and to a less extent those of the middle unit of the Gassaway member are finer-grained and contain more clay, and less organic matter, than the black beds. Thin-section study shows that clay, or some equally fine-grained material, constitutes about 65 percent of the rock. Recognizable quartz, pyrite, and organic matter are next in importance. These clay-rich beds show less parallelism than the black beds and the lamination is poor; they are properly referred to as claystones.

Only one complete mineralogical analysis of the Chattanooga shale has been made by the Survey, this being by Deul (1957) with the objective of determining the relationship between organic material and uranium content. The sample analyzed was from the upper 1.36 feet of the upper unit of the Gassaway member at locality 99, just southwest of the Smithville area in the Eastern Highland Rim. The uranium content of the sample was 91 ppm, somewhat higher than the average content of the upper unit of the Gassaway. The content of organic matter was 17.5 percent (13.7 percent carbon, 1.2 percent hydrogen, 0.5 percent sulfur, 0.4 percent nitrogen, and 1.7 percent oxygen). The constituents of the mineral matter which make up 82.5 percent of the shale are given below:

Mineral	Content, percent
Pyrite and marcasite	12.0
"Hydromica" (illite?)	30.8
Feldspar	5.9
Kaolin minerals	2.1
Gypsum	.3
Calcite	.2
Biotite	1.0
Quartz	23.3
Other minerals, including hematite, limonite, and sulfates.	6.5 1/
Total	82.1

1/ The summation of 82.1 is increased to 82.5 when the elements not analyzed for, but known to be present from semiquantitative spectrographic analyses, are included.

The Pennsylvania State University analyzed cores of the Gassaway member from 13 drill holes for pyrite, carbon, and silicates. Four of the cores were from the Northern Highland Rim, 6 from the Eastern Highland Rim, 1 from Walden Ridge, and 2 from Alabama. The sample units were small—1 to 2 inches—and no effort was made to subdivide the Gassaway into units. In some cores the entire section was not analyzed, thus making a certain amount of extrapolation necessary; this, however, is not considered serious, although the averages, given in table 7, should be considered general rather than precise.

As table 7 shows, the pyrite and carbon contents are lowest—6 and 8 percent respectively—and the silicates highest—75 percent—at the Alabama localities. The pyrite content is highest—about 12 percent—in the Northern Highland Rim; it is 8 to 9 percent in the Eastern Highland Rim and Walden Ridge. In all areas except Alabama the carbon content is about 12 percent, the silicate content 65 to 68 percent.

Strahl (1958) analyzed cores from 5 localities for quartz, kaolinite, and illite; his figures are summarized in table 8.

Table 7.—Mineral content of the Conasauga member of the Chattanooga shale, summarized from Bates and others (1956) and Strahl (1958)

Locality	Pyrite (percent)	Carbon (percent)	Silicates (percent)
Northern Highland Rim			
C54	16.1	11.5	61.7
C59	10.8	12.3	65.0
C60	9.1	12.4	70.2
C62	12.8	11.5	64.4
Eastern Highland Rim			
C4	9.8	11.9	65.6
C11	9.1	12.3	65.9
C14	8.3	11.1	70.9
C19	9.0	11.8	70.0
C44	9.2	11.4	71.9
C45	6.6	12.2	73.9
Walden Ridge			
C47	8.4	12.0	65.3
Alabama			
C64	5.8	7.6	76.4
C66	6.6	8.4	74.4

Table 8.—Quartz, kaolinite, and illite content of the Gassaway member of the Chattanooga shale, summarized from Strahl (1958).

Locality	Quartz (percent)	Kaolinite (percent)	Illite (percent)
		Northern Highland Rim	
C59	21.7	3.3	25.3
C60	21.9	3.1	29.0
		Western Highland Rim	
C11	28.1	2.9	22.0
C14	26.0	2.9	22.2
		Alabama	
C64	33.1	3.3	18.9

The size of the quartz grains in the shale from different localities is reported by Strahl (1958). At the Alabama locality, 064, the range in the Gassaway member is 26 to 43 microns, the average 31 microns. In the Smithville area the average (from localities C11 and C14) is 19 and 17 microns respectively, but for the middle gray unit the sizes are 26 microns and 28 microns respectively. In the undivided Gassaway member in the Northern Highland Rim the average size is 16 microns and there is little difference from top to bottom of the member. Thus the grain size of the quartz, like the quartz content, decreases from south to north.

Uranium content of the shale

General features

Uranium analyses of samples of the Chattanooga shale are given in table 9, which includes data from all localities for which analyses within a precision of $\pm$ 5 ppm were made, as well as a few localities for which the analyses are precise within $\pm$ 10 ppm; these are included to complete the regional picture for certain areas, and to include all localities for which oil-yield data have been obtained. In addition to the chemical analyses for uranium, determinations of total radioactivity, expressed in terms of equivalent uranium (eU) are also given for most of the samples.

Both members and all units of the Chattanooga shale are enriched in uranium to some degree. The crustal abundance of the element is 2 to 3 ppm, and the enrichment in the Chattanooga ranges from about four-fold in the upper unit of the Dowelltown member to as much as forty-fold locally in the upper unit of the Gassaway member. Over large areas the Gassaway member contains about 60 ppm uranium, and over a smaller area the lower unit of the Dowelltown member contains 25 to 35 ppm. The uranium content of the upper unit of the Dowelltown member is much lower, about 10 ppm.

The uranium in the Chattanooga shale is in a metallo-organic complex (Deul, 1957) and no uranium minerals have been identified in the rock in Tennessee. In DeKalb County, Alabama, however, at locality 74-2 of Glover (1959), Swingle and Hardeman of the Geological Survey of Tennessee found identifiable uranium minerals (R. A. Laurence, personal communication, 1962). There is general agreement that the uranium was concentrated syngenetically with the formation of the shale (Conant and Swanson, 1961, p. 70-77), and that the total radioactivity of the rock is in secular equilibrium with its uranium content (Breger, 1955), the few apparent exceptions to the latter rule being traceable to weathering. Examples of secondary enrichment that have been noted may be explained also by weathering processes. One locality that shows both radioactive disequilibrium and secondary enrichment is locality 74-2 in Alabama, at which, as mentioned above, uranium minerals were found. In this faulted and weathered section a 6-foot interval near the middle of a thick (about 70 feet, which possibly includes some duplication of beds) section, the uranium content of the shale ranges from 65 to 90 ppm, compared to about 40 ppm for the remainder of the section. The equivalent uranium for the same interval measured 0.009 to 0.016 percent, whereas the measurements for most localities containing comparable amounts of uranium are on the order of 0.008 to 0.012 percent.

At nearly all outcrop localities and drill holes the distribution of uranium in each unit of the Chattanooga shale follows a fairly regular pattern. In the upper unit of the Cassaway member the concentration is highest about the middle, or slightly above the middle, of the unit. In the middle unit the content varies according to the number and thickness of gray beds present; and in the lower unit the distribution is bottom-preferential but not markedly so. At three localities along the Eastern Highland Rim, however, the distribution is sufficiently anomalous to justify discussion. These localities are outcrops 99, 103, and 106, which are in a line about 18 miles long along the strike of the formation (see fig. 2*). Locality 99 is in the bed of an intermittent stream alongside a gravel road; localities 103 and 106 are road cuts. At locality 99 a 1.5-foot sample, 2.35 to 4.35 feet below the top of an 8-foot section of the lower unit of the Cassaway member, contains 130 ppm as against an average for the entire unit of 68 ppm; this high content of one sample is not an analytical error, but the possibility of contamination cannot be ruled out. At locality 103 the middle 4 feet of a 7.1 foot section contains 63 ppm uranium as against an average for the unit of 55 ppm; and at locality 106 the middle 1.31 feet of a 4.42-foot section of the unit contains 72 ppm as against 55 ppm for the entire unit. Locality 104, which is between localities 103 and 106, does not show comparable enrichment in the lower unit of the Cassaway. The reason for the enrichment at localities 99, 103, and 106 is not known. The fact that the localities are in the area in

* Missing.

which the bentonite bed near the top of the Dovelltown member is absent suggests that when the area subsided after the late Dovelltown uplift more than normal amounts of carbonaceous material may have been brought into the sea, providing conditions favorable for enrichment in uranium; this is evidenced by the characteristics of the highly uraniferous interval at locality 99, which is much more massive than the more normal lower Cassaway. This, however, is only a suggestion.

At localities 99 and 106 the upper unit of the Cassaway member is comparatively thin—4.12 and 2.8 feet respectively—and the top samples are very high in uranium—100 ppm and 92 ppm respectively. At locality 103, where the upper Cassaway is 3.94 feet thick, the uranium content of the unit is 79 ppm and the vertical distribution is almost uniform. The high uranium content of the top beds at localities 99 and 106 may be related to the fact that in this area the topmost beds of the Cassaway apparently have been removed by erosion (Conant and Swanson, p. 36), and there could have been some enrichment of the remaining beds. At locality 99 the upper Cassaway is even more massive than the unit at most localities. A number of large samples taken from the upper part of the unit confirm the high uranium content shown by the routine analyses given in table 10.

The uranium content of the shale shows a good positive correlation with the content of organic isolate, and to a less extent with that of pyrite. No causal relationship between the uranium and pyrite contents has been proved, however, though it may exist. It is likely that the concentrations of the mineral and the element reflect nothing more than the reducing conditions in the Chattanooga sea that were favorable to the concentration of both. The studies made to date do not show that the uranium is intimately associated with the pyrite, but more data are needed before definite conclusions can be drawn.

As a rule, those parts of the Chattanooga shale that contain as much as 50 ppm uranium also contain 20 percent or more of organic material as measured either by loss on ignition or by the percent of organic isolate (see tables 1 and 9†). Basically, the organic matter comprises two main types, woody or humic matter, and sapropelic material composed of spores, cuticles, and related materials. Of the samples that have been analyzed, the highest uranium content has been found in thin (a quarter to half an inch) beds of woody material from the upper part of the undivided Gassaway member at locality 203B in Davidson County, in which germanium was also found (see p. ?). Six samples of this material contained from 140 to 250 ppm uranium, as reported by Breger and Schopf (1955, p. 290) and Swanson (1961, p. 35). For this locality the uranium content of eight 1-foot samples of the shale, including the beds of woody material, ranges from 52 to 61 ppm and averages 56 ppm. Although coaly material such as that analyzed from locality 203B is fairly abundant—cores of the shale show an average of 3 to 5 such bands (Breger and Schopf, 1955), no analyses of the material except that from locality 203B have been made. At any locality, however, it comprises only a very small part of the total shale.

† Table 9 starts on page 304.

It has been suggested (Swanson, 1960, 1961) that uranium is concentrated primarily in the humic fraction of the organic matter in the Chattanooga shale. Only indirect evidence of the proportions of humic and sapropelic matter in the rock are available, and at present it is not possible to prove or disprove that hypothesis. However, both humic and sapropelic substances are acidic and are able to fix uranium as the uranyl ion (Stadnikoff, 1930), and in the area covered by this report the uranium content of the shale shows a good correlation with the total amount of organic matter; this is shown by the diagram (fig. 20) on which the uranium content of the shale, in parts per million, is

Figure 20. Diagram showing relation of uranium in the Chattanooga shale to percent of organic isolate.

plotted against the percent of organic isolate. The problem is discussed further in the section on the oil yield of the shale.

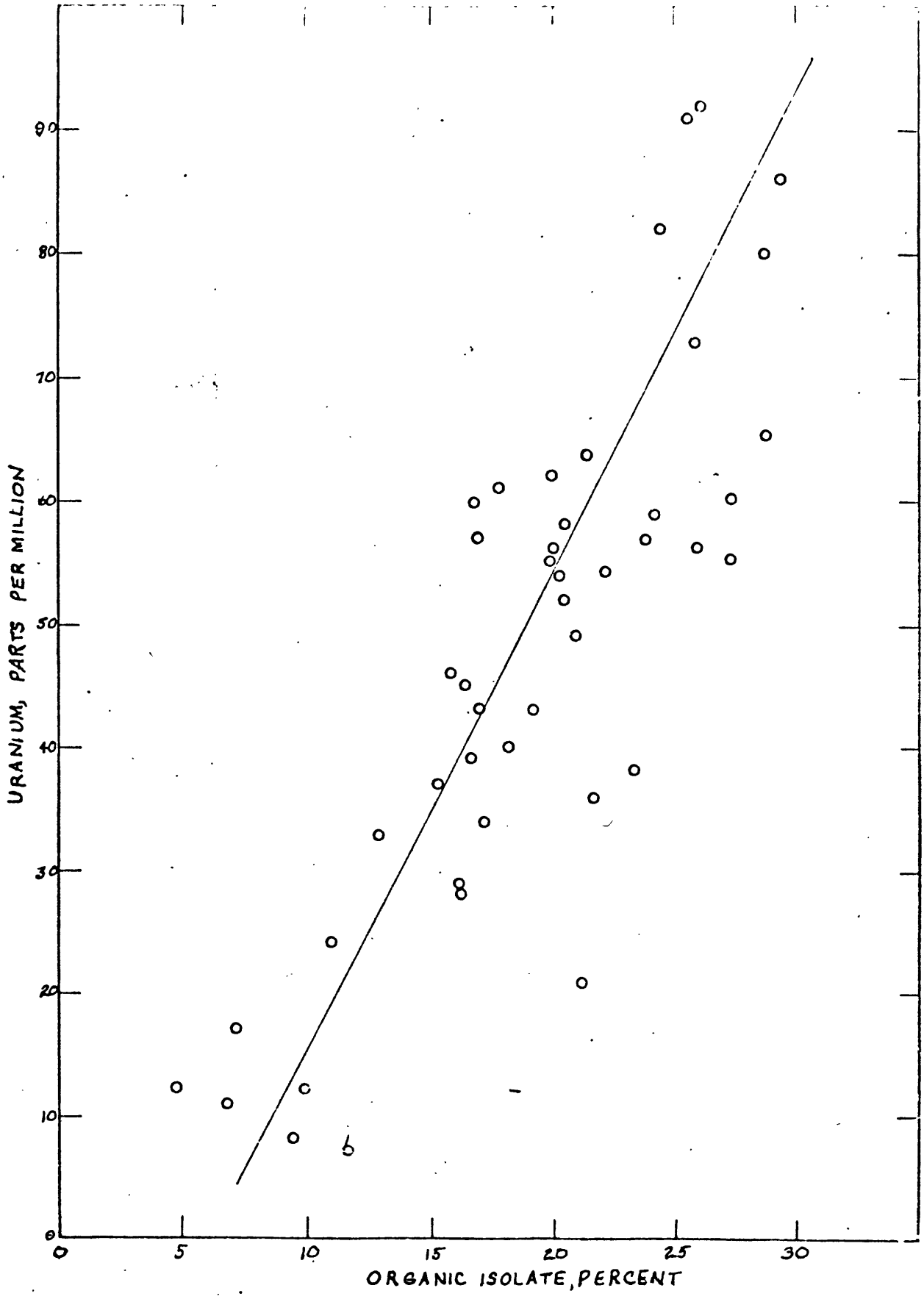

Fig. 20:—Diagram showing relation of uranium content to percent of organic isolate in the Chattanooga shale.

The concentration of uranium in the Chattanooga shale has been interpreted as the result of fixation by carbonaceous material over a tremendously long period of the uranium normally present in sea water, or to the presence of an unusually uraniferous area, which in this case would be the granitic landmass that bounded the Chattanooga sea on the southeast and south. Conant and Swanson (1961, p. 75) and Swanson (1961, p. 84) consider that no particularly uraniferous source was necessary. They attribute the lower uranium content of the shale in Kentucky and other states north of Tennessee, which are farther from the shore line than the Tennessee areas, to the fact that the formation is thicker in those areas than in Tennessee, because larger amounts of clastic material were introduced into the sea. This clastic material acted as a diluent and thus reduced the content of uranium in the present shale, even though the reducing conditions of the Tennessee area prevailed also in the more northern parts of the sea.

Arguments for a uraniferous source area to the southeast of the Tennessee area are afforded by analyses of the black beds of the Dowelltown member and those of the Gassaway member. The highest uranium content of the Dowelltown member at any Tennessee locality is 43 ppm at locality C50, the northernmost locality in the Walden Ridge and the only one in that area at which the lower or black Dowelltown is present; this locality was fairly close to the shoreline. The lower Dowelltown in the Eastern Highland Rim contains, generally, 25 to 35 ppm uranium; but the undivided Dowelltown of the Northern Highland Rim, which is a black shale, contains only about 10 ppm. As during early Dowelltown time the western part of the Northern Highland Rim was partly separated from the more eastern areas by the Late Devonian arch that has been referred to previously; the low uranium content of the shale could represent not only distance from the shoreline, but a cutting off of the uranium supply by the arch. On the other hand, the black shale of the questionable Dowelltown at locality C64 in Alabama contains 19 ppm uranium, and the other Alabama localities, nearby drill holes C65 and C66, contain 24 and 16 ppm respectively. As the direct correlation between organic material and uranium is well established, it is of interest that the low-uranium Dowelltown at locality C56 in the Northern Highland Rim contains 10.2 percent organic isolate, whereas that at locality C64 in Alabama contains only 8.4 percent. At locality C37 near the eastern edge of the Smithville area in the Eastern Highland Rim, the uranium content of the lower Dowelltown is 34 ppm, the percent of organic isolate, 17.3 percent. The organic isolate of

the unit at locality C50 which, as stated previously, contains 43 ppm uranium, has not been determined. It will be noted that at the Alabama localities the uranium content, while low as compared to that of the shale in Tennessee, is comparatively high when compared to the one determination of the organic isolate. The evidence from the black beds of the Lowelltown member seems to show that the presence of a uraniferous source area had an important bearing on the concentration and distribution of uranium in those beds.

Although during Gassaway time the embayments of Dowelltown time had coalesced and the barriers to movement of uranium were almost or entirely eliminated, the evidence is that the uraniferous source area still had some influence. In Walden Ridge the actual uranium content of the Gassaway member is taken conservatively to be about 70 ppm, although the condition of the drill-hole cores makes accurate estimates difficult. In the Eastern Highland Rim the content of the member is about 60 ppm, in the richer parts of the Northern Highland Rim about 55 ppm. The organic isolate content of three localities in Walden Ridge averages 22.6 percent, of two localities in the Eastern Highland Rim 23.2 percent, and the content at locality C56 in the Northern Highland Rim is 26.3 percent. For comparison, the Gassaway member at locality C64 in Alabama contains only 16.7 percent organic isolate, but has 44 ppm uranium; and the northernmost locality, 323 in Kentucky, contains from 36 to 39 ppm uranium, and 15.3 to 21.6 percent organic isolate.

The uranium concentrations by areas may be questioned because the differences are hardly more than the precision of the analyses. This objection is hardly valid, however, because errors in the analyses are compensatory rather than cumulative. Individual analyses may be questioned, but the average of a large number may be considered reliable.

From the evidence presented above it seems safe to say that the comparatively high uranium content of the Chattanooga shale in Tennessee is due at least in part to the presence of a uraniferous source area to the southeast. Although the importance of fixation of quantities of the element normally present in sea water over a long period of time is not questioned, the distribution of uranium in the Chattanooga sea seems to require a uraniferous source area also. Had no such source been present, the uranium content of the shale would have been highest in the Northern Highland Rim where the Chattanooga sea began to spread over the Tennessee embayment, and would have been least in Walden Ridge, which was near the farthest extent of the sea. The opposite is the case (Breger and Brown, 1962).

Because of their possible bearing on a hydrothermal source of some of the uranium in the Chattanooga shale, mention should be made of veins or fracture fillings containing barite, fluorite, galena, and sphalerite, in the Ordovician rocks of the Nashville Basin which at one time were overlain by the shale. Only one such feature in the Chattanooga is known; it penetrated about 3.5 feet into the lower part of the shale (V. E. Swanson, personal communication, 1962). A study of the veins or fracture fillings was made by Jewell (1947), who considered them true veins cutting through the sediments from the Precambrian basement which, at the one locality in Tennessee (in northern Giles County) where it has been penetrated, is about 5,700 feet below the surface. Jewell points out that although he considers the features true veins, the mineral assemblages are common to both veins and fracture fillings. In any event, the features are so small and scattered that it is impossible to believe that they had any material influence on the concentration of uranium in the Chattanooga shale.

Effect of weathering on uranium content of outcrop samples

The mobility of uranium in water has long been recognized. An example of this mobility as affecting the Chattanooga shale is analyses of two water samples taken from the adit (locality 79), which was driven into the upper unit of the Gassaway member early in 1949. The last round shot down, from 95 to 100 feet, was left on the floor of the adit; the shale was well broken, the largest pieces being about the size of a man's head. The floor was practically level, so that some water ran out during wet seasons, but the water accumulated in pools during dry seasons. On November 11, 1951—about 22 months after the adit was completed—water samples were taken from a pool at the entrance, and from one at the face. The entrance sample contained 71 parts per billion uranium, the face sample, 690 parts per billion (analyses by R. Meyrowitz, U. S. Geological Survey, Report no. TEC-1902). Although evaporation was undoubtedly a factor in the high uranium content of the water, it is not sufficient to explain the great enrichment of the sample taken from near the face where the broken shale had been left.

The water samples focused attention on a problem encountered during the early field work, before any drilling had been done; that of evaluating the uranium content of outcrop samples, which showed a wider range than had been anticipated. The drilling programs later showed that over considerable areas cores from holes which penetrated the Chattanooga shale below the water table were remarkably uniform in uranium content, this fact providing a basis for rough estimates of the effects of weathering on the content of outcrop samples.

The Gassaway member of the Chattanooga shale is the only member or unit for which sufficient data are available for comparisons to be made. The shale of this member is tough and difficult to sample, and few samples from outcrops in the Eastern Highland Rim and Walden Ridge contain rock from more than 3 or 4 inches behind the original surface. In the Northern Highland Rim jackhammers were used in sampling, and therefore the samples are of rock somewhat farther behind the original surface. In all areas, however, the samples are from a zone in which weathering might be expected to have some effect.

During field work notes were made of the apparent degree of weathering of the shale sampled, the most detailed descriptions being those of Swanson and his coworkers who worked mostly but not entirely in the Northern Highland Rim. Swanson (personal communication, 1957) described as "unweathered" not only the blocky shale of fairly new road cuts, but also exposures at which the shale showed distinct but not prominent surface corrugations. The descriptions ranged through "slightly weathered" and "moderately weathered" to "weathered," the distinctive characteristic of "weathered" exposures being the presence of paper-thin laminae which could be detached easily from the surface. In sampling practice these laminae, which do not extend more than an inch or so into the rock, were discarded and the harder rock behind sampled. Exposures described as "badly weathered" are those in which the original structure of the rock has disappeared, leaving either a mass of small flakes or a soft, amorphous mass of brownish material. Few of these badly weathered exposures were sampled.

A very general idea of the effect of weathering on the uranium content of outcrop samples as opposed to drill cores can be gained from the average contents by regions; the usefulness of these averages, however, is lessened by the fact that no distinction is made between the different types of outcrop exposures. The differences in all regions except Walden Ridge are less than the precision of the analyses, 5 ppm; but because of the large number of samples, and the fact that analytical errors are compensatory rather than cumulative, the averages are perhaps more reliable than analyses from single localities. The averages are given in table 10.

Table 14.—Average uranium content of the Gassaway member of the Chattanooga shale from outcrop and drill-hole samples, by regions.

Region	Outcrops		Drill holes	
	No.	Av. U, ppm	No.	Av. U, ppm
Western part, Northern Highland Rim	2	53.5	5	58.0
Eastern part, Northern Highland Rim	3	47.3	6	49.3
Northern part, Eastern Highland Rim	16	48.4	2	52.5
Smithville area, Eastern Highland Rim	8	58.2	45	59.9
Southern part, Eastern Highland Rim	10	58.7	6	62.5
Walden Ridge	5	55.8	4	69.2
Total and average	44	53.8	68	58.6

Evaluation of the figures for the eastern part of the Northern Highland Rim and the northern part of the Eastern Highland Rim must take into consideration facies changes in the shale in those areas. More reliable conclusions can be drawn in the western part of the Northern Highland Rim, the southern part of the Eastern Highland Rim, and particularly the Smithville area and an area immediately surrounding it, which covers an area of about 250 square miles in which the most intensive investigations were carried on. The Walden Ridge area, because of the broken condition of the rock in some drill cores and at all outcrops, presents particular problems.

In the Smithville area the uranium content of the Gassaway member at 45 drill holes ranges from 54 to 66 ppm, the lowest content being in 3 cores which contain the relatively low-uranium phosphatic zone. The outcrop localities in the same area for which uranium analyses within a precision of 5 ppm have been made include 1 bluff exposure (locality 64) which is somewhat sheltered by an overhanging ledge of Fort Payne chert and which contains 53 ppm uranium; 2 deep highway cuts which were new when sampled (localities 68 and 70) and which contain 61 and 66 ppm uranium respectively; 6 older road cuts (localities 67, 91, 92, 97, 100, and 101), which have uranium contents ranging from 51 to 64 ppm; 3 large waterfalls (localities 73, 74, and 89), in which the uranium content is 35, 45, and 48 ppm respectively; and 3 stream-bed exposures (localities 83, 86, and 99) at which the uranium contents are 59, 63, and 73 ppm respectively. Locality 99, which has the anomalously high uranium content of 73 ppm, has been discussed in the preceding section.

The uranium contents given above indicate that new, deep highway cuts have approximately the same content as that of the shale at depth, but that older, shallow road cuts locally, but not in all cases, have lost some of their uranium. The loss of uranium from road cuts is more pronounced outside of than in the Smithville area, because of 35 outcrop localities in that area that were sampled, only about half of the better ones were reanalyzed to a precision of 5 ppm and used in this report. The one bluff exposure in the Smithville area has lost some but not a great deal of its uranium, and no loss is apparent at the stream-bed localities.

In the Northern Highland Rim, outcrop localities 22 and 306 show some loss of uranium, but the most marked characteristic is redistribution of the element toward the bottom of the exposures. Locality 22 is a bluff exposure, the overlying rock being the New Providence shale which does not protect the shale as does the Fort Payne chert in the Eastern Highland Rim. The average uranium content at locality 22 is 51 ppm; that of locality C60, a drill hole about a mile north of the outcrop, is 55 ppm, the difference being within the precision of the analyses; but at locality 22 the upper part of the exposure is depleted as compared to the more "normal" distribution in the drill hole, whereas the interval 7.50 to 8.95 feet below the top contains 86 ppm uranium, by far the highest concentration found in the Northern Highland Rim. Locality 306 is an old road cut, which is described as weathered except for the interval 2.0 to 3.0 feet below the top, which is described as badly weathered. This badly weathered interval contains 27 ppm uranium; the average for the entire exposure is 51 ppm, and there has been some redistribution toward the base. Drill hole C62 is about 2.3 airline miles east-southeast of the outcrop, and contains 60 ppm uranium. Both the outcrop locality and the drill hole are in an area in which the shale is remarkably uniform in thickness and uranium content.

Although weathering undoubtedly has affected the uranium content of old road cuts and bluff exposures, the differences as compared to nearby drill holes are not great and it is unsafe to draw more than qualitative conclusions. In the case of waterfall exposures, which are confined largely to the Eastern Highland Rim, quantitative conclusions can be drawn. The three waterfalls in the Smithville area show uranium contents in the Gassaway member ranging from 35 to 48 ppm in an area where the shale, as shown by numerous drill holes, contains at depth about 60 ppm; the loss thus is 20 percent or more. The water running over the falls has clearly removed much of the uranium from the shale, probably by oxidizing processes.

The outcrop exposures in Walden Ridge are road cuts, and comparison of two of these exposures with drill holes a mile or less away is instructive. Locality 220 contains 51 ppm uranium, whereas the nearby drill hole C48 contains 69 ppm. The difference is even more marked between locality 221, which contains 55 ppm uranium, and nearby drill hole C47 which contains 80 ppm. Throughout this part of Walden Ridge the shale both at outcrops and in drill cores is more or less broken; it seems obvious that some of the uranium has been removed from the outcrops by weathering, but the drill cores are difficult to interpret. Apparently, on the basis of analyses of cores taken farther north in the ridge, the actual uranium content of the shale at depth is about 70 ppm, the approximate content at locality C48; but it is possible that at locality C47, the farthest south of the Walden Ridge localities and the one in which the core is most broken, there has been some enrichment due to uranium-bearing water moving through the broken rock from the outcrop to the drill hole, which is close enough to the outcrop for this to be a reasonable assumption. Certainly the high uranium content (80 ppm) of this core and the distribution of the element, require explanation.

General conclusions that can be drawn from comparison of the uranium content of outcrop samples with that of drill holes in the same general area are:

1. Except in areas of marked facies changes, the uranium content of drill cores taken from a considerable distance below the surface (a somewhat arbitrary depth of 50 feet or more is suggested) represents that of the shale over areas of several square miles. This is true also of new highway cuts comparable distances below the original surface.

2. Old road cuts, particularly those not far below the original surface, may have lost locally as much as 10 percent of their original uranium, and locally some uranium has been redistributed toward the bottom of the section. It should be added that at a few localities of this nature there is evidence of slight enrichment, but data are too few for tenable conclusions to be drawn.

3. Badly broken outcrops, which in the area of this report are limited to Walden Ridge, probably have lost 10 percent or more of their original uranium, and the cores of nearby drill holes possibly have been enriched to some extent.

4. Bluffs protected by overhanging Fort Payne chert apparently have lost some, but not a great deal, of their original uranium.

5. Unprotected bluff exposures have lost from as much as 10 percent of their original uranium, and redistribution of the element toward the base of the section is noteworthy.

6. Waterfall exposures, which in the area of this report are confined largely to the Eastern Highland Rim, have lost 20 percent or more of their original uranium.

7. On the basis of only a few localities, stream-bed exposures appear to have lost little if any of their uranium, and locally the possibility of enrichment cannot be ruled out.

In general, it appears that deep drill holes, and new deep highway cuts, can be used safely for estimating the uranium resources of the shale over areas of several square miles, except in Walden Ridge where the rocks are badly broken. Old shallow road cuts and bluff exposures should be used with caution if at all, and waterfall exposures have lost so much uranium that they give a badly distorted picture of the situation.)

Uranium content of the shale by members and units

Estimates of the uranium content of the Chattanooga shale here given are not reserve estimates in the usual meaning of the term, partly because the uranium content of the rock is too low for the shale to be considered uranium ore, and partly because, except for the Smithville area, the data are too scattered for such estimates to be meaningful. On the other hand, there is sufficient information to show that the thickness and uranium content of the shale are sufficiently uniform over large areas to justify more extrapolation than ordinarily would be permissible, and thus it is possible to make reasonably reliable estimates of the uranium content of the units and members of the shale in specified areas.

The provinces for which estimates are given are the Eastern Highland Rim, the Northern Highland Rim, the Cumberland Plateau, and Valley Ridge, all in Tennessee. Because of lack of data on the shale in certain areas, the portions of each province for which estimates are made are limited somewhat arbitrarily, as shown in figure 21. The eastern

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Figure 21. Sketch map showing areas for which uranium resources are estimated.

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boundary of the Northern Highland Rim is placed along the eastern boundary of Clay County, extended southward through Livingston in Overton County to the Roaring River line. Estimates for the Northern Highland Rim are limited to an area extending an average of about 15 miles behind the outcrops, the southern limit being the southern corner of Davidson and Cheatham Counties. So little is known of the shale north of this restricted area that estimates would be meaningless.

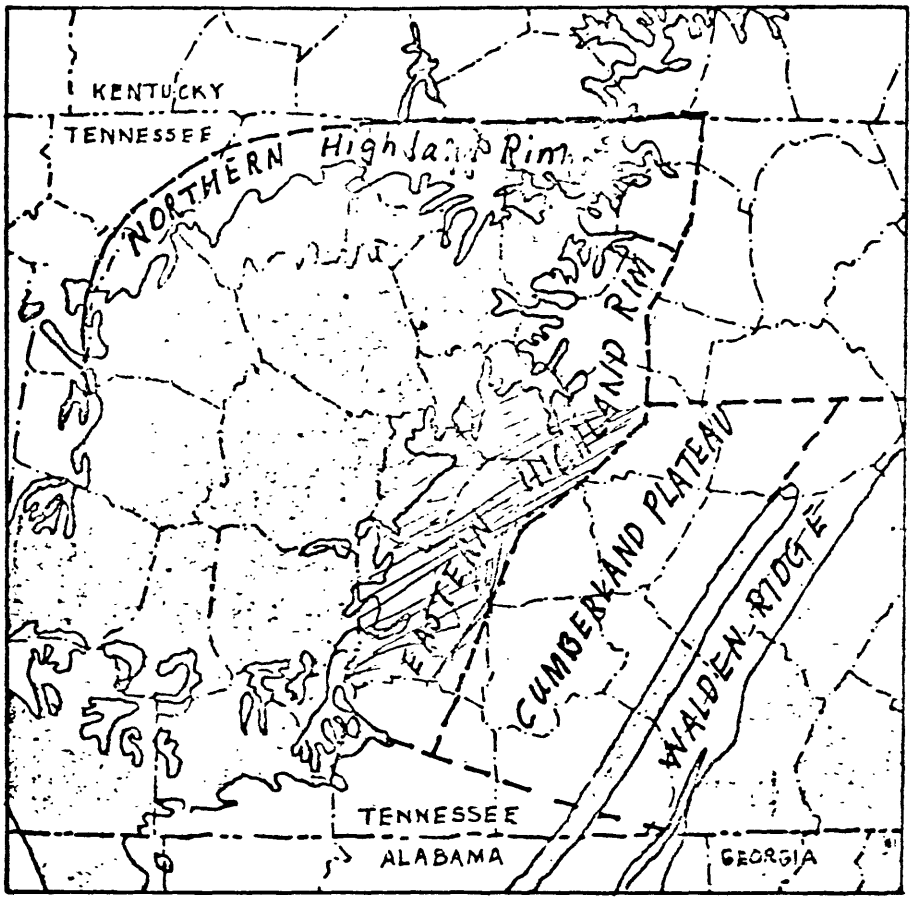

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Fig. 1 Sketch map ~~showing~~ showing areas for which resource estimates are made.

Shaded area is that for which resources estimates of the upper unit of the Gassaway member were made separately.

The southern boundary of the Eastern Highland Rim and the Cumberland Plateau is a line drawn north of east from the junction of the Sequatchie and Tennessee Rivers in Marion County to the Elk River in Franklin County, where it makes a sharp turn to the west (see fig. 2*), and then across the southern part of Moore County. It has been necessary to fix an arbitrary dividing line between the Eastern Highland Rim and the Cumberland Plateau, simplifying the highly irregular natural boundary which is usually drawn at the base of the Pennsylvanian rocks (see fig. 2*). For the purposes of this report the boundary is considered as extending from the Roaring River line south of Livingston through Cookeville, Sparta, and McMinnville to the common corner of Warren, Grundy, and Coffee Counties, thence through Elk River Lake and along the Elk River to the southern boundary of the two provinces. In the Eastern Highland Rim as here redefined the shale nearly everywhere is under less than 300 feet of cover, which would be an important consideration in any mining operations.

No estimates are given, because of lack of information, on that part of the Cumberland Plateau north of the 36th parallel of latitude. Walden Ridge is separated from the Cumberland Plateau proper by a continuation northeast of the west side of the Sequatchie Valley; its northern boundary is the 36th parallel, its southern boundary the Tennessee River in Marion County.

*Missing.

Estimates of the uranium content of the shale are given for both the upper and lower units of the Dowelltown member in the Eastern Highland Rim, the Cumberland Plateau, and Walden Ridge; for the undivided Dowelltown member in the Northern Highland Rim; and for the Gassaway member in all provinces. Although the three units and one subzone of the Gassaway range considerably in their content of uranium, it is almost certain that should the shale ever be mined for uranium the entire member would be recovered. There is, however, an area in and around the Smithville area in which the upper unit of the Gassaway member is unusually high in uranium content and is of mineable thickness; estimates for that area, which is shown in figure 21, are given separately.

The data on uranium content used in the estimates are from table 9; thicknesses used include not only the localities for which analyses are given, but other localities for which thickness measurements, but not precise analytical data, have been obtained (see Conant and Swanson, 1961, p. 77-83). Other explanations of the estimates are:

1. Data on the Dowelltown member, particularly the upper unit, are comparatively sparse; this reflects the early decision that only the Gassaway member had any potential as a source of uranium.

2. Estimates of the uranium content of the shale in the Cumberland Plateau are based on three widely separated drill holes--C211, C212, and C46--all near the western edge of the Plateau. Ordinarily such limited information would not justify any conclusions as to the shale beneath the Plateau; but the known uniformity of the rock over large areas, and the fact that the thickness and uranium content of the shale at the Plateau localities are consistent with the thickness and uranium content of the rock in the Eastern Highland Rim and Walden Ridge, make it possible to extrapolate data into the Plateau with much more assurance than ordinarily would be the case.

3. All sampled localities in Walden Ridge are in the west flank of the ridge, and interpretations of grade are somewhat difficult because of the condition of all outcrops and some of the cores. The extrapolation of data beneath the entire ridge is therefore somewhat questionable.

The only specific gravity determinations made on the shale are on samples from drill hole C15 in the Smithville area (analyses by Collin Davis, U. S. Geol. Survey, 1952, TEC 2727). These determinations give specific gravities at that locality of 2.34 for the Gassaway member of the shale, 2.42 for the lower unit of the Dowelltown member, and 2.53 for the upper unit of the Dowelltown. These determinations are considered to be fairly representative of the shale in Tennessee, though additional data would be desirable. In this report, estimates of uranium contents are based on specific gravities of 2.3 for the Gassaway member, 2.4 for the lower Dowelltown, and 2.5 for the upper Dowelltown. The 2.3 specific gravity figure for the Gassaway is that used by Kehn (1955, p. 26-27) and Conant and Swanson (1961, p. 70) based on a large number of Jolley balance determinations. Kehn calculated that a bed of shale having a specific gravity of 2.3, 1 foot thick and containing 10 ppm uranium, has a uranium content in 1 square mile of 20 tons of metallic uranium. A bed of the same size, thickness, and uranium content of the lower unit of the Dowelltown member, or of the undivided Dowelltown member, following the same calculations, contains 21 tons of uranium, whereas the upper Dowelltown, for the same sized bed containing the same uranium content, would have 22 tons of uranium. These figures are those used in preparing the estimates.

Because of the nature and spacing of the data the estimates of uranium in the shale cannot be considered precise and no attempt has been made to make them so. Not only is the uranium content of the shale in each area rounded, but the average thicknesses are rounded to the nearest foot, and the areas underlain by the shale in the counties within the provinces are, except for the Smithville area, rounded to the nearest 5 square miles. Some minor adjustments have been made to take care of the known depletion of uranium at waterfall exposures and some other localities. In summary, although the estimates are not precise, they are of the correct order of magnitude, and are sufficiently accurate to provide a usable foundation for future work.

Dowelltown member

Lower unit

The lower unit of the Dowelltown member is present throughout much of the Eastern Highland Rim, more than half of the Cumberland Plateau as here redefined, and in the northern part of Walden Ridge; it underlies about 3,000 square miles in the areas for which estimates are made. The analytical data used includes analyses of the shale from 23 localities in the Smithville area, 2 localities in the northern part of the Eastern Highland Rim, 9 localities in the southern part of the Eastern Highland Rim, 2 localities in the Cumberland Plateau, and 3 localities in Walden Ridge. Estimates of the uranium content of the unit in the 4 provinces are given in table 11.

Table 11.—Estimated uranium resources of lower unit of the Dowelltown member of the Chattanooga shale, by provinces and counties

Area or county	Average thickness (feet)	Average U content (ppm)	Estimated tons U per sq. mile	Sq. miles underlain by unit	Total uranium (tons) 1/
Eastern Highland Rim					
Smithville area:					
Cassaway quadrangle	5	35	355	26	9,000
Smithville quadrangle	6	31	390	55	21,000
Sligo Bridge quadrangle	6	31	390	49	19,000
Total, Smithville area	—	—	—	130	49,000
Overton County	3	15	95	30	3,000
Jackson County	3	15	95	60	6,000
Putnam County	3	15	95	190	18,000
Smith County	6	20	250	15	4,000
DeKalb County 2/	6	30	385	80	31,000
White County 2/	4	30	250	140	35,000
Cannon County 2/	7	30	440	130	57,000
Warren County	5	30	315	230	73,000
Coffee County	6	30	390	205	80,000
Total Eastern	—	—	—	1,210	356,000

Table 11.—Estimated uranium resources of lower unit of the Dowelltown member of the Chattanooga shale, by provinces and counties—Continued

Cumberland Plateau					
White County	2	25	105	190	20,000
Warren County	6	30	385	210	81,000
Coffee County	5	30	315	70	22,000
Grundy County	3	25	155	180	28,000
Van Buren County	3	25	160	225	36,000
Sequatchie County	2	25	105	100	11,000
Bledsoe County	2	25	105	140	15,000
Cumberland County	2	25	105	250	26,000
Total Cumberland Plateau	—	—	—	1,365	239,000
Walden Ridge					
Cumberland County	2	35	170	135	23,000
Bledsoe County	1	30	65	120	8,000
Total Walden Ridge	—	—	—	255	31,000
Total, lower unit Cassaway member				2,830	626,000

1/ Rounded to nearest 1,000 tons.

2/ Excluding part of county in Smithville area.

Upper unit

The upper unit of the Dowelltown member is everywhere thicker than the lower unit, and extends considerably farther to the south and southeast (see figs. 7 and 8). Relatively little analytical data on the unit have been obtained; samples analyzed include those from 20 localities in the Smithville area, 1 locality in the northern part of the Eastern Highland Rim, 2 localities in the Cumberland Plateau, and 4 localities in Walden Ridge. The range of uranium content of all samples ranges from 8 to 13 ppm, and the average for each area is about 10 ppm. In the estimates in table 12 this average content of 10 ppm is assumed to be applicable to the unit in all areas.

Table 12.—Estimated uranium resources of upper unit of the Dowelltown member of the Chattanooga shale, by provinces and counties

Area or county	Average thickness (feet)	Average U content (ppm)	Estimated tons U per sq. mile	Sq. miles underlain by unit	Total uranium (tons) 1/
Eastern Highland Rim					
Smithville area	9	10	210	130	27,000
Overton County	2	10	45	30	1,000
Jackson County	3	10	65	60	4,000
Putnam County	6	10	130	190	25,000
Smith County	5	10	110	15	2,000
DeKalb County 2/	9	10	200	80	16,000
White County 2/	8	10	175	140	25,000
Cannon County 2/	9	10	200	130	26,000
Warren County	9	10	200	230	46,000
Coffee County	9	10	200	305	61,000
Franklin County	2	10	45	100	4,000
Moore County	4	10	90	24	2,000
Total Eastern Highland Rim	—			1,435	239,000
Cumberland Plateau					
White County	8	10	175	190	33,000
Warren County	9	10	190	210	40,000
Coffee County	8	10	175	70	12,000
Grundy County	8	10	175	350	61,000

Table 12.--Estimated uranium resources of upper unit of the Dowelltown member of the Chattanooga shale, by provinces and counties--Continued

Van Buren County	8	10	175	255	45,000
Franklin County	2	10	45	100	4,000
Marion County	2	10	45	160	7,000
Sequatchie County	6	10	130	135	18,000
Bledsoe County	6	10	130	180	23,000
Cumberland County	7	10	155	250	39,000
Total Cumberland Plateau	—	—	—	1,990	282,000
Walden Ridge					
Cumberland County	8	10	175	135	24,000
Bledsoe County	8	10	175	120	21,000
Rhea County	7	10	155	120	19,000
Sequatchie County	4	10	90	75	7,000
Hamilton County	2	10	45	90	4,000
Marion County	2	10	45	35	2,000
Total Walden Ridge	—	—	—	575	77,000
Total, upper unit Dowelltown member				3,910	598,000

1/ Rounded to nearest 1,000 tons.

2/ Excluding part of county in Smithville area.

Undivided member

Analytical as well as thickness data on the undivided Dowelltown member, which is limited to the Northern Highland Rim as redefined for this report, are comparatively sparse. The member was measured at all of the 11 drill holes in the Northern Highland Rim, but samples from only 5 of these localities were analyzed. Thus, the available data is limited to these 5 drill holes and 3 outcrops. Because of these limitations the estimates of the uranium content of the undivided Dowelltown member as given in table 13 reflect more "educated guessing" than those for any other province, even including the Cumberland Plateau. The scarcity of data is particularly applicable to estimates of the thickness of the member; the uranium content follows a fairly distinct regional pattern.

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Table 12.--Estimated uranium resources of the undivided Dowelltown member of the Chattanooga shale in the Northern Highland Rim

County	Average thickness (feet)	Average U content (ppm)	Estimated tons per sq. mile	Sq. miles underlain by member	Total uranium (tons) 1/
Cheatham	8	10	170	110	19,000
Davidson	12	10	250	80	20,000
Robertson	12	10	250	160	40,000
Sumner	12	10	250	260	65,000
Macon	8	12	200	185	37,000
Clay	4	15	125	150	19,000
Jackson	4	15	125	55	7,000
Overton	4	15	125	105	13,000
Total	—	—	—	1,105	220,000

1/ Rounded to nearest 1,000 tons.

In summary, the total uranium content of the Dowelltown member in the area shown in figure 23 is estimated at 1,444,000 tons, divided as follows:

Lower unit, Dowelltown member	626,000 tons
Upper unit, Dowelltown member	598,000 tons
Undivided Dowelltown member	220,000 tons
Total Dowelltown member	1,444,000 tons

Gassaway member

Data on the uranium content of the Gassaway member of the Chattanooga shale include analyses of the shale from 69 drill holes and 47 outcrop localities in the areas in Tennessee for which estimates are made. The distribution of the points of information, by provinces, follows:

Area or province	Drill holes	Outcrops	Total localities
Smithville area	44	8	52
Eastern Highland Rim, outside of Smithville area	7	27	34
Total, Eastern Highland Rim	51	35	86
Cumberland Plateau	3	0	3
Walden Ridge	4	4	8
Northern Highland Rim	11	8	19
Totals	69	47	116

The localities used in estimating the uranium content of the shale are shown on figures 2* and 3*; estimates of the uranium content are given in table 14.

* Missing.

Table 14.--Estimated uranium resources of the Gassaway member of the Chattanooga shale, by provinces and counties

Area or county	Thickness (feet)	Average U content (ppm)	Estimated tons U per sq. mile	Sq. miles underlain by member	Total uranium (tons) 1/
Eastern Highland Rim					
Smithville area:					
Gassaway quadrangle	12	59	1,410	26	37,000
Smithville quadrangle	14	60	1,680	55	92,000
Sligo Bridge quadrangle	16	60	1,920	49	94,000
Total Smithville area	—	—	——	130	223,000
Overton County	16	42	1,344	30	40,000
Jackson County	16	45	1,440	60	86,000
Putnam County	16	55	1,760	190	334,000
Smith County	16	55	1,760	15	26,000
DeKalb County 2/	13	60	1,560	80	125,000
White County 2/	16	60	1,920	140	269,000
Cannon County 2/	14	57	1,596	130	207,000
Warren County	18	62	2,232	230	513,000
Coffee County	13	59	1,534	305	468,000
Bedford County	13	64	1,664	25	42,000
Moore County	14	64	1,792	20	36,000
Franklin County	8	60	960	80	77,000
Total Eastern Highland Rim	—	—	——	1,435	2,436,000

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Table 13.—Estimated uranium resources of the Gassaway member of the Chattanooga shale, by provinces and counties—Continued

Cumberland Plateau					
White County	11	62	1,364	190	259,000
Warren County	16	66	2,112	210	444,000
Coffee County	14	59	1,652	70	116,000
Franklin County	8	60	960	140	134,000
Marion County	10	60	1,200	210	252,000
Grundy County	17	60	2,040	360	734,000
Van Buren County	13	62	1,612	255	321,000
Sequatchie County	14	60	1,680	110	185,000
Bledsoe County	12	60	1,440	140	201,000
Cumberland County	18	55	1,980	250	495,000
Total Cumberland Plateau	—	—	——	1,935	3,141,000
Walden Ridge					
Cumberland County	20	70	2,680	135	362,000
Bledsoe County	13	65	1,820	120	218,000
Rhea County	13	65	1,820	120	218,000
Sequatchie County	13	65	1,820	75	137,000
Hamilton County	10	60	1,200	90	108,000
Marion County	10	60	1,200	75	90,000
Total Walden Ridge	—	—	——	615	1,133,000

Table 14.—Estimated uranium resources of the Gassaway member of the Chattanooga shale, by provinces and counties—Continued

Northern Highland Rim					
Cheatham County	8	53	848	110	93,000
Davidson County	12	60	1,440	80	115,000
Robertson County	12	56	1,344	160	215,000
Sumner County	12	55	1,320	260	334,000
Macon County	13	50	1,300	185	241,000
Clay County	14	53	1,484	150	223,000
Jackson County	15	46	1,380	55	79,000
Overton County	15	42	1,260	105	132,000
Total Northern Highland Rim	—	—	-----	1,105	1,432,000
Grand total	—	—	-----	5,090	8,142,000

1/ Rounded to nearest 1,000 tons.

2/ Excluding part of county within Smithville area.

Upper unit of the Gassaway member in part of the Eastern Highland Rim

It has been stated previously that the three units and one subzone of the Gassaway member differ considerably in their uranium content. Where the units can be distinguished--throughout the Eastern Highland Rim and the Cumberland Plateau--the highest uranium concentration is in the upper unit, except where the phosphatic zone is present; the next highest is in the lower unit, the lowest in the middle unit. Where the phosphatic zone is present at the top of the Gassaway member not only is the uranium content of the shale in that zone considerably less than in the underlying unit, but the upper unit itself, below the phosphatic zone, is also depleted. This condition can be understood by study of the analyses given in table 9.

The southern limit of the phosphatic zone in the Eastern Highland Rim as here restricted is approximately the 36th parallel of latitude, which is also the northern boundary of the Smithville area extended eastward. South of this line the upper unit of the Gassaway member contains from 72 to 80 ppm uranium, 20 to 33 percent more than the average content of the whole Gassaway member in the same area. Except in the western part of the Smithville area, where it thins to an average of 4.6 feet, the unit averages about 5.5 feet thick, though it varies locally from 3 to 7 feet. Despite the comparative thinness of the bed for mining, and the differences in thickness from place to place, the relatively high uranium content justifies an estimate of the uranium content of the unit where the concentration is highest, in the Eastern Highland Rim in Warren, Coffee, and Cannon Counties, and those parts of DeKalb and White Counties south of the 36th parallel of latitude. These estimates are given in table 15.

Table 15.—Estimated uranium resources of the upper unit of the Gassaway member of the Chattanooga shale in part of the Eastern Highland Rim, Tennessee

Area or county	Thickness (feet)	Average U content (ppm)	Estimated tons U per sq. mile	Sq. miles underlain by unit	Total uranium (tons) 1/
Smithville area:					
Gassaway quadrangle	4.6	74	681	26	18,000
Smithville quadrangle	5.5	79	869	55	48,000
Sligo Bridge quadrangle	5.6	79	885	49	43,000
Total Smithville area	---	--	---	130	109,000
White County 2/	5.5	72	792	80	63,000
DeKalb County 2/	5.5	80	1,040	40	42,000
Cannon County 2/	5.5	75	825	130	107,000
Warren County	5.5	75	825	230	190,000
Coffee County	5.5	75	825	305	252,000
Total	---	--	-----	915	763,000

1/ Rounded to the nearest 1,000 tons.

2/ Excluding parts of the county within the Smithville area.

Data on which the estimates are based include 44 drill holes and 8 outcrops in the Smithville area, 1 drill hole and 5 outcrops in Cannon County, 2 drill holes and 4 outcrops in Coffee County, and 1 drill hole in Warren County; the total is 48 drill holes and 17 outcrops. No data are available for White and DeKalb Counties outside the Smithville area, but information can readily be extrapolated. Although the upper unit of the Gassaway member at the one locality in Warren County is 6.5 feet, this drill hole probably entered an unusually thick section, and the average thickness for the county is estimated as 5.5 feet, in line with that of surrounding areas.

The Chattanooga shale as a uranium resource

Under present conditions no part of the Chattanooga shale can be considered as uranium ore because of the low concentrations of the element. The generally accepted lower grade cut-off for the deposits in the Colorado Plateau and elsewhere is about 0.1 percent uranium, about 125 times the content of the richest part of the shale. Therefore, under the classification of McKelvey and others (1961) the shale must be considered a potential marginal or submarginal resource of uranium.

The dividing line between marginal and submarginal resources, always in the case of rocks such as the Chattanooga an arbitrary one, is here drawn at a uranium concentration in the rock of 50 ppm, about 20 times the crustal abundance of the element. Under this classification the Gassaway member, except for a comparatively small area in Jackson and Overton Counties in the eastern part of the Northern Highland Rim and the northern part of the Eastern Highland Rim, is considered a potential marginal resource. Both units of the Dowelltown member, and the undivided member, are classed as potential submarginal resources.

The spacing of data is such that only the Gassaway member in the Smithville area can be considered a known potential marginal resource; this area contains about 223,000 tons of uranium in an area of 130 square miles. A case can be made for considering the Gassaway in the Eastern Highland Rim south of the Smithville area--approximately the area for which estimates of the uranium content of the upper unit of the Gassaway were made--as being also a known potential resource. Although the points of information are mostly along the Rim outcrop, the demonstrated uniformity of the shale throughout the area might justify such a classification. If this be accepted, the Gassaway member in that area contains about 2 million tons of potential known resources of uranium. With somewhat less justification the Gassaway member in the western part of the Northern Highland Rim, which contains about 1,200,000 tons of uranium, might also be considered a known potential resource.

Because of the scarcity of data the Gassaway member in the Cumberland Plateau must be considered an undiscovered potential marginal resource. In Walden Ridge the situation is complicated by the broken condition of the rock and the consequent uncertainty about the actual content of the shale behind the outcrops and drill holes, which are all in the western flank of the ridge; it therefore seems safer to classify the shale in that area as an undiscovered potential marginal resource.

Although most of the discussion of uranium resources, and all of the estimates are limited to Tennessee, parts of southern Kentucky may contain uranium in quantities comparable to those in the Northern Highland Rim. Also, it is possible that the Alabama embayment may be a richer source of uranium than the reconnaissance studies made to date indicate.

Uranium in the Maury shale

Although the uranium content of the Maury shale is too low to be of economic value, analyses of that rock are of some interest for comparison with analyses of the underlying Chattanooga shale. Equivalent uranium and chemical uranium analyses of the Maury from all the holes drilled during the 1953 drilling program are given in table 17. Most of the analyses of shale from outcrops were made early in the program and are not as precise as those of the cores; as they would have only limited value, they are not given.

The uranium content of the Maury shale ranges from 2 or 3 *ppm*—approximately the crustal abundance of the element—to about 30 *ppm* and, in one sample from locality C52 in the northern part of the Eastern Highland Rim, 47 ppm. The average is on the order of 10 to 12 *ppm*. The few localities that show unusually high uranium contents probably contain black shale that occurs locally in the Maury as logged, but which may actually represent small-scale interfingering between the upper unit of the Gassaway member of the Chattanooga and the Maury. The uranium content of the typical greenish Maury claystone is everywhere low. Analyses are given in table 16.

Thorium content of the Chattanooga shale and the Maury shale

During the Survey's field investigations of the Chattanooga shale thorium was of little interest as a source material, and analyses for that element were laborious and time-consuming. The Survey laboratories, however, did considerable work on improved methods of thorium analysis (Grimaldi and others, 1954), and in the summer of 1951 a small study of thorium-bearing areas was begun. All of the areas investigated, except the monazite deposits of the southeast Atlantic coastal plain, were in the western states.

The only recorded analysis of the Chattanooga shale for thorium during this period was made by Adams and others (1958) of a sample of the upper unit of the Gassaway member, which contained 8.1 to 8.2 ppm thorium and 74 to 78 ppm uranium when analyzed by two different methods. The locality from which the sample was taken is not stated, but in all probability was either the adit (locality 79) or outcrop locality 99.

Table 16.—Equivalent uranium and uranium content of the Ivory shale (Analysts: Carmen Hoy, Joseph Budinsky, J. J. Warr, Joan Smith, Ethel Mackney, Mary Joslyn, Blanche Ingram, Carmen Hoy, Maryse Deleveaux, Alice Cammerer, Audrey Pietsch, Audrey Smith, B. A. McCall, and J. E. Goode)

Locality	Thickness (feet)	Laboratory no.	Analyses, %	Percent U
		Smithville area		
C1	1.57	111422	0.005	0.0024
C2	1.45	108859	.004	.0004
C3	1.43	108889	.004	.0013
C4	1.77	108916	.003	.0008
C6	1.48	111123	.004	.0011
C7	1.01	111152	.006	.0030
C9	1.43	111644	.004	.0009
C10	1.92	111180	.004	.0018
C11	1.65	111207	.003	.0007
C12	1.34	111236	.003	.0003
C13	1.51	111265	.004	.0023
C14	2.07	111671	.003	.0007
C15	2.05	112317	.004	.0010
C16	1.60	114249	.003	.0005
C17	2.26	113223	.003	.0007

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Table 13.--Equivalent uranium and uranium content of the Mowry shale--Continued

C18	2.26	111697	0.003	0.0002
C19	1.80	112191	.004	.0015
C20	2.27	112167	.004	.0021
C21	2.03	112217	.003	.0009
C22	2.28	111724	.003	.0008
C23	2.50	112248	.004	.0009
C24	2.41	113271	.004	.0004
C25	2.25	112759	.004	.0015
C26	2.92	112736	.003	.0008
C27	2.94	112432	.004	.0011
C28	3.20	112838	.004	.0005
C29	3.90	113242	.003	.0005
C30	2.45	113190	.004	.0015
C31	1.97	114169	.006	.0028
C32	2.08	114175	.004	.0016
C33	3.10	112480	.003	.0003
C34	3.43	112458	.003	.0004
C35	3.19	112502	.003	.0020
C36	3.06	112815	.003	.0008
C37	1.35	114181	.004	.0018

Table 13.—Equivalent uranium and uranium content of the Maury shale—Continued

C38	1.28	114187	0.005	0.0024
C39	3.77	114193	.003	.0006
C40	2.93	114255	.003	.0013
Unweighted averages	2.21		.004	.0012
Eastern Highland Rim south of Smithville area				
C41	3.57	114261	.003	.0005
C42	2.53	114267	.002	.0006
C44	2.45	114273	.003	.0015
C45	.95	115873	.004	.0017
Unweighted average	2.38		.003	.0011
Cumberland Plateau				
C46	1.42	115048	.004	.0020
Eastern Highland Rim north of Smithville area				
C51	1.30	117623	.003	.0011
C52	2.17	117730	.008	.0047
Unweighted average	1.74		.006	.0029
Walden Ridge				
C47	2.71	115779	.003	.0013
C48	2.56	115060	.002	.0004
C49	2.57	114279	.003	.0003
C50	2.70	115769	.003	.0007

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Table 3.—Equivalent uranium and uranium content of Chattanooga shale—Continued

Unweighted average	2.63		0.003	0.0007
		Northern Highland Rim		
C53	1.10	115861	.005	.0030
C54	1.61	115785	.003	.0016
C55	1.63	115887	.003	.0006
C56	.80	115054	.004	.0013
C57	1.00	115882	.003	.0020
C58	.30	115866	.004	.0018
C59	.33	115791	.003	.0002
C60	2.75	116544	.003	.0007
C61	3.27	116549	.003	.0006
C62	.88	115764	.004	.0022
Unweighted average	1.37		.004	.0014
		Blount County, Alabama		
C64	4.60	120216	.003	.0005
C65	6.10	120190	.004	.0014
C66	2.24	120206	.005	.0024
Unweighted average	4.31		.004	.0014

In the summer of 1959 the Oak Ridge National Laboratory requested assistance from the Survey in preparing an estimate of the thorium resources of the Nation, and in connection with this request the Survey laboratories analyzed samples of the Chattanooga shale from 9 drill holes. The localities included one in the Northern Highland Rim (C56); 4 in the Eastern Highland Rim (C51, C52, C37, and C44; only the Gassaway member at locality C51 and the Dowelltown member at locality C52 were analyzed); one locality (C46) in the Cumberland Plateau; 2 localities in Walden Ridge (C49 and C50); and one locality in Blount County, Alabama. Locations of these drill holes [and a summary of the data] are given in figure 22; complete analytical data are given in table 17

Figure 22. Sketch map showing localities analyzed for thorium, and thorium content by members and units.

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which shows also, for purposes of comparison, the uranium content of the same samples. Analyses of the thorium content of the Maury shale at three localities are also given.

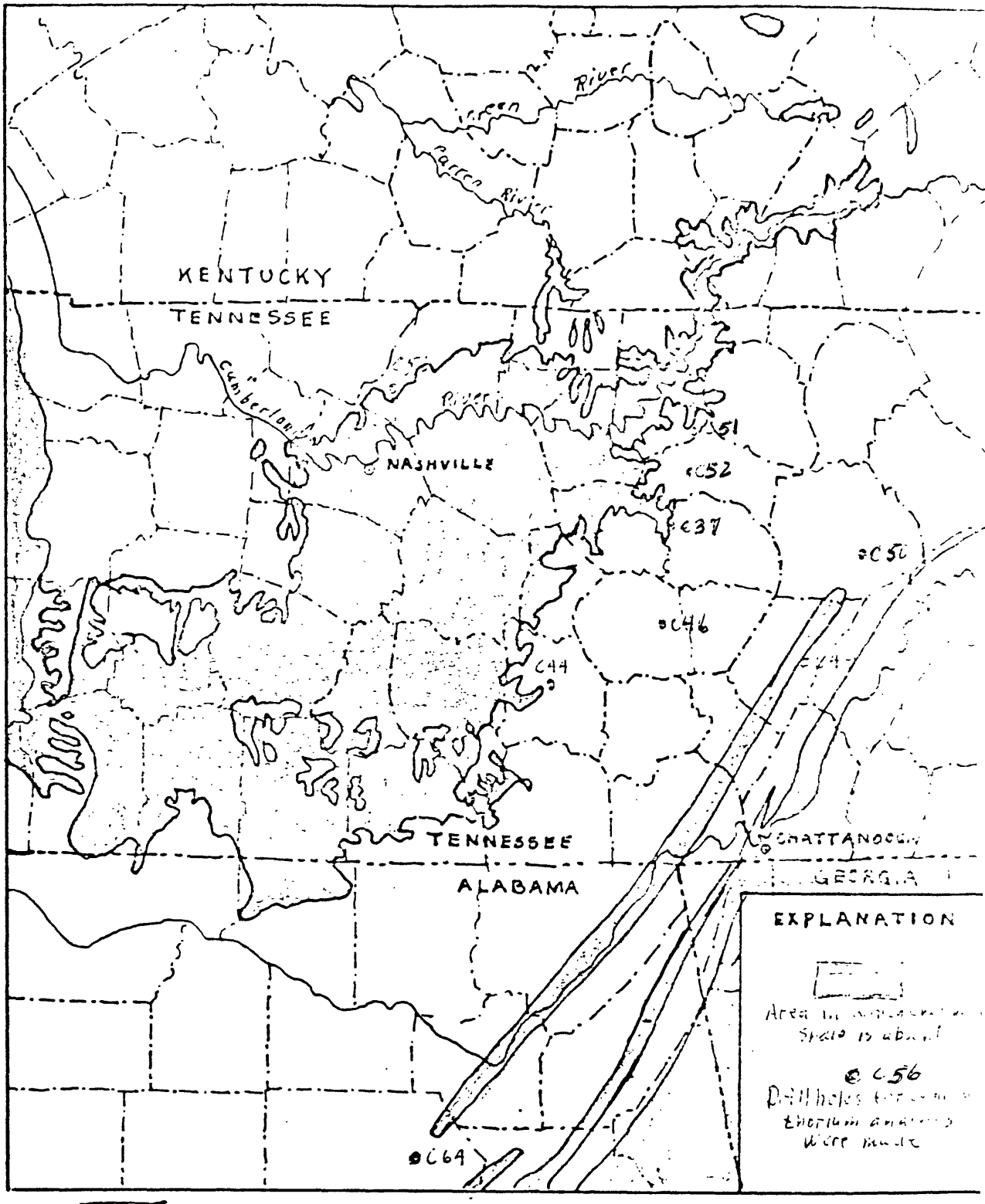

Fig. 22 Index map showing drill holes analyzed for thorium analytical data in table 18

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Table 26.--Thorium and uranium contents of samples of Chattanooga shale and Maury formation

(Thorium analyses by R. Moore, A. Caemmerer, L. Jenkins, Esma Campbell, and J. J. Warr)

Locality and sample no.	Unit 1/	Laboratory no.	Thickness (feet)	Thorium (ppm)	Uranium (ppm)
Northern Highland Rim					
C56-1	M	115054	1.42	11.5	13
C56-2	Cz	115055	6.00	8.4	56
-2	Cz	115056	3.67	7.9	55
Total and average	Cz		9.67	8.2	56
C56-3	Dz	115057	5.00	10.0	12
-4	Dz	115058	5.00	10.5	8
-5	Dz	115059	3.15	11.5	9
Total and average			13.15	10.5	10
Eastern Highland Rim					
C51-12, 13	Gu	117624-5	10.13	6.8	57
-21	Gm	117626	2.74	9.3	38
-31	Gl	117627	4.02	8.8	39
Total and average	G		16.89	7.6	50
C52-51	Dl	117738	6.91	9.8	n.a. 2/
-52	Dl	117739	6.15	9.6	n.a.
Total and average	Dl		13.06	9.7	n.a.

Table 17.—Thorium and uranium contents of samples of Chattanooga shale and Maury formation—Continued

C37-2	Gu	114182	6.80	8.4	86
-3	Gm	114183	3.01	10.0	33
-4	Gl	114184	7.62	9.7	57
Total and average	G		17.43	9.2	57
C37-5	Du	114185	11.50	12.0	12
C37-6	Dl	114186	5.11	13.0	34
C44-2	Gu	114274	6.64	7.2	85
-3	Gm	114275	1.97	7.7	48
-4	Gl	114276	6.19	7.5	49
Total and average	G		14.80	7.4	65
C44-5	Du	114277	9.25	10.0	10
C44-6	Dl	114278	5.41	9.0	35
Cumberland Plateau					
C46-2	Gu	115049	5.18	6.0	84
-3	Gm	115050	2.27	9.6	58
-4	Gl	115051	8.95	7.2	57
Total and average	G		16.40	7.3	66
C46-5	Du	115052	9.63	10.5	10
C46-6	Dl	115053	6.16	9.4	30
Walden Ridge					
C49-1	M	114279	2.57	13.0	3

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Table 15.—Thorium and uranium contents of samples of Chattanooga shale and Maury formation—Continued

C49-11	Gl	114280	4.00	15.0	29
-21	Gup	114281	4.00	11.0	38
-31	Gu	114282	5.40	8.5	92
-32	Gm	114283	1.72	10.5	61
-33	Gl	114284	2.85	11.0	62
Total and average	G		17.97	11.1	58
C49-41	Du	114285	6.46	12.5	11
C50-1	M	115769	2.70	12.0	7
C50-12, 13	Gu	115770-1	10.41	8.7	78
-21	Gm	115772	1.87	11.5	57
-31, 32	Gl	115773-4	8.76	12.0	60
Total and average	G		21.04	10.3	70
C50-41	Du	115775	5.06	12.0	9
-42	Du	115776	5.95	14.0	8
Total and average	Du		11.01	13.1	8
C50-51	Ml	115777	1.50	9.5	41
-52	Ml	115778	1.34	10.5	45
Total and average			2.84	10.0	43

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Table 15.--Thorium and uranium contents of samples of Chattanooga shale and Fury formation--Continued

Blount County, Alabama					
C64-12	Gz	120217	3.75	7.8	40
-13	Gz	120218	3.76	8.6	46
-14	Gz	120219	4.44	8.6	45
Total and average	Gz		11.95	8.4	44
C64-15	Dz?	120220	5.08	11.0	17
-16	Dz?	120121	2.32	9.8	24
Total and average	Dz?		7.40	10.6	19

1/ Explanation of unit symbols: Gu, upper unit, Gassaway member; Gup, phosphatic zone, upper unit, Gassaway member; Gu?, unit of doubtful correlation (locality C-9); Gm, middle unit, Gassaway member; Gl, lower unit, Gassaway member; Gz, undivided Gassaway member; Du, upper unit, Dowelltown member; Dl, lower unit, Dowelltown member; Dz, undivided Dowelltown member.

2/ These samples not analyzed for uranium.

Except for thorium minerals in residual sediments, such as monazite, most of the thorium in the sedimentary cycle is precipitated in the argillaceous sediments (Goldschmidt, 1955, p. 431). Unlike uranium, thorium has no affinity for carbonaceous material, and the contents of the two elements in the Chattanooga shale show a generally inverse correlation. The thorium content is highest (10 to 13 ppm) in the upper unit of the Dowelltown member, which has the lowest (about 10 ppm) uranium content; this unit contains as much or more thorium than uranium. On the other hand, the Gassaway member, which contains about 60 ppm uranium over much of the area discussed in this report, contains only 7 to 9 ppm thorium. An exception is Walden Ridge, where the content at two localities is 10 and 11 ppm respectively.

The regional distribution of thorium, like that of many other trace elements in the Chattanooga shale, is remarkably uniform. This uniformity suggests that most of the thorium is in the clay minerals, which are disseminated throughout all units of the shale; in that connection the comparatively high thorium content of the argillaceous Maury shale is of interest. The somewhat higher thorium content of the Chattanooga shale in Walden Ridge than elsewhere may be due to an increased amount of detrital material in that area, perhaps because of closeness to the shore line. However, at locality C64 in Alabama, which was also close to the shore line, the thorium content of the shale is approximately the same as that in the Eastern and Northern Highland Rims. Mention should also be made of the high (15 ppm) thorium content of the anomalous upper 4 feet of the Gassaway member at locality C49 in Walden Ridge. This sample, as shown by both study of the core and chemical analyses, is more argillaceous than the underlying beds containing less thorium.

On the basis of scattered data, it appears that the Gassaway member of the Chattanooga shale in Walden Ridge contains 10 to 11 ppm thorium and in other parts of Tennessee covered by this study, 7 to 9 ppm. In the same area the lower unit of the Dowelltown member and the undivided member contain about 10 ppm thorium, and the upper unit of the Dowelltown member contains 10 to 12 ppm. These figures compare with estimates of 11.5 ppm for thorium in sediments (Goldschmidt, 1955, p. 75) and 10.5 ppm thorium in shales (Goldschmidt, 1955, p. 431). Thus the thorium content of the Chattanooga shale is approximately the same as the average for sediments and shales.

The thorium content of the Chattanooga shale is too low for the rock to be considered an ore; the lowest concentration currently being considered for processing is about 40 ppm (George Phair, U. S. Geological Survey, and Keith B. Brown, Oak Ridge National Laboratories, personal communications, 1959); this is the content of the Conway granite of New Hampshire over considerable areas and thicknesses. The thorium in the Chattanooga shale must be considered, therefore, as a potential submarginal resource.

Estimates of the thorium content of the Chattanooga shale in the areas for which uranium contents are estimated, which are highly tentative because of the wide spacing of the data, are given in table 18.

Table 18.—Estimates of the thorium content of the Chattanooga shale, by members, units, and physiographic provinces

Province	Member or Unit	Estimated tons thorium
Northern Highland Rim	Gassaway	200,000
	Undivided Dowelltown	200,000
Eastern Highland Rim	Gassaway	300,000
	Upper Dowelltown	240,000
	Lower Dowelltown	130,000
Cumberland Plateau	Gassaway	400,000
	Upper Dowelltown	300,000
	Lower Dowelltown	80,000
Walden Ridge	Gassaway	200,000
	Upper Dowelltown	80,000
	Lower Dowelltown	10,000
Total		2,240,000

Summarizing the figures in table 17, the Chattanooga member in the area for which resources are estimated contains about 1,100,000 tons of thorium; the upper unit of the Dowelltown member contains about 620,000 tons; the lower unit of the Dowelltown member contains about 220,000 tons; and the undivided Dowelltown member contains about 200,000 tons.

Pyrolitic oil yield of the shale

The Chattanooga shale does not contain oil as such, and thus is not a source bed for petroleum. The oil yield of the shale is obtained by pyrolisis from the kerogen in the rock, kerogen being defined as that organic material that yields volatile hydrocarbons when subjected to destructive distillation. Kerogen includes various types of organic matter, the principal ones being sapropelic material, from which most of the oil yield is derived, and humic or woody material (Swanson, 1960, p. 6, 22).

The first recorded tests of the Chattanooga shale and its correlatives as possible sources of oil were made by the Kentucky Geological Survey between 1920 and 1925. The tests were made on hand samples that were not clearly representative of the shale as a whole, and the results reported appear, in the light of later work, to be high by a factor of about 1. During the Survey's investigations of the Chattanooga shale oil yields were determined on samples from 31 localities; 3 in Kentucky, 1 in the Cumberland Plateau, Tennessee; 5 in the Northern Highland Rim of Tennessee; 19 in the Eastern Highland Rim, Tennessee, 2 in Walden Ridge, Tennessee, and 1 in Blount County, Alabama. These localities, with the oil yields in gallons per ton of the Gassaway member and of the lower unit of the Gassaway member, are shown in figure 23.*

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*Figure 23. Map showing localities for which oil yield has been determined, and oil yield by members and units.

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*Figure missing.

Individual samples of the black units of the Chattanooga shale yield oil in quantities ranging from a trace to about 17 gallons per ton; for the entire thickness of a member or unit at a given locality the maximum yield is 10 to 11 gallons per ton. Assay data on 5 localities, which have not been published, are given in table 19, and a summary of all data on the shale, taken from table 18 and from Swanson (1960, table 1) is given in table 20. All of the samples were tested by the modified Fischer assay method except those from localities C44, C49, C56, and C64 (see table 20), which were analyzed by a photometric method (Cuttitta, 1953) which gives results comparable to, but not as complete as, those obtained by the Fischer assays.

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Table 2.—Oil yield of certain Chattanooga shale samples

(Analyses by Joseph W. Budinsky, U. S. Geological Survey, Job no. 5132)

Sample no.	Thickness (feet)	Weight percent			Gals. per ton Sp. gr. of oil at 60°/60°F		
		Oil	Water	Gas and loss	Oil	Water	
C48-2	5.00	Trace	15.0	5.4	Trace	35.9	Ins. oil
C48-3	5.00	0.30	6.5	2.8	1.0	15.6	Ins. oil
C48-4	5.07	.40	2.6	2.6	1.2	6.2	Ins. oil
C50-12	5.20	.70	6.5	2.0	1.7	15.6	Ins. oil
C50-13	5.21	.90	5.3	1.0	2.4	12.7	Ins. oil
C50-21	1.87	.40	2.8	.3	1.7	6.7	Ins. oil
C50-31	4.38	.60	3.4	.9	1.9	8.2	Ins. oil
C37-2	6.80	3.4	3.7	3.4	8.6	8.9	0.947
C37-3	3.01	1.4	1.9	1.6	3.8	4.6	Ins. oil
C37-4	7.62	4.0	2.0	3.2	10.2	4.8	0.936
C37-5	11.50	1.1	1.9	1.1	2.6	4.6	Ins. oil
C37-6	5.11	2.9	2.3	1.6	7.6	5.5	0.911
323-A	5.00	4.25	5.15	4.10	10.5	12.3	0.966
323-B1	6.00	3.15	4.55	4.10	7.6	10.9	0.993
323-B2	6.00	2.00	5.20	3.90	4.9	12.5	0.972
323-C	13.00	1.50	6.80	.90	3.8	16.3	0.980
C42-2	6.50	1.7	3.0	3.9	4.5	7.2	0.914
C42-3	1.86	1.5	1.2	2.8	4.0	2.9	0.898
C42-4	9.99	2.0	1.5	3.1	5.2	3.6	0.908

Table 19.—Oil yield of the Chattanooga shale, summarized from table 20 and from Swanson (1960, table 1)

(Key to unit symbols: Gz, undivided Gassaway member; Gu, upper unit, Gassaway member; Gm, middle unit, Gassaway member; Gl, lower unit, Gassaway member; G, total, Gassaway member; Dz, undivided Dowelltown member; Du, upper unit, Dowelltown member; Dl, lower unit, Dowelltown member)

Locality	Sample no.	Thickness (feet)	Unit	Gals. per ton Oil	Gals. per ton Water	Gas and loss (percent)	Organic isolate (percent)
				Kentucky			
4	1-5	10.25	Gz	14.0	7.0	2.6	n.a. 1/
	6-16	22.00	Gz	7.5	7.6	1.7	n.a.
	17-19	6.50	Gz	10.4	7.8	1.2	n.a.
Total and average		38.75	G	9.1	7.5	1.8	n.a.
12	1-5	10.00	Gz	12.6	4.1	2.6	n.a.
	6-8	6.00	Gz	8.2	3.7	2.5	n.a.
	9-12	8.00	Gz	9.4	4.1	2.9	n.a.
Total and average		24.00	G	10.4	4.0	2.7	n.a.
323	A	5.00	Gz	10.5	12.3	4.1	21.6
	B	12.00	Gz	6.0	11.7	4.0	16.7
	C	13.00	Gz	3.8	16.3	.9	15.3
Total and average		30.00	G	5.9	13.8	2.7	16.9

Table 20.—Oil yield of the Chattanooga shale, summarized from table 19 and from Swanson (1960, table 1)—Continued

Northern Highland Rim, Tennessee							
16	11a–11c	6.00	Gz	7.0	5.9	1.3	18.6
	11d–11f	5.50	Gz	3.5	8.3	1.1	18.3
	11g–13	5.15	Gz	6.3	3.8	2.0	24.0
Total and average		16.65	G	5.6	6.0	1.4	20.2
22	11a–11c	6.00	Gz	8.4	5.4	1.2	n.a.
	11d	1.50	Gz	6.7	8.6	1.8	n.a.
	11e–13	5.73	Gz	9.2	6.2	2.2	n.a.
Total and average		13.23	G	8.6	6.1	1.7	n.a.
27	11a–12	5.85	Gz	4.8	8.7	1.3	n.a.
	13	2.00	Gz	4.2	12.0	1.4	n.a.
	14–16	6.00	Gz	8.5	6.2	2.6	n.a.
Total and average		13.85	G	6.3	8.0	1.9	n.a.
C56 2	2–3	9.67	Gz	7.7	—	—	26.3
	4–6	13.15	Dz	6.5	—	—	10.2
Cumberland Plateau, Tennessee							
C211	12–14	6.7	Gu	7.7	2.8	2.7	n.a.
	15	2.0	Gm	7.9	2.4	2.3	n.a.
	16–18	2.8	Gl	11.0	3.2	2.3	n.a.
Total and average		11.5	G	8.2	2.7	2.4	n.a.
	41–45	8.4	Du	2.4	2.9	.7	n.a.
	51	2.0	Dl	9.8	3.1	1.5	n.a.

Table 19.—Oil yield of the Chattanooga shale, summarized from table 20 and from Swanson (1960, table 1)—Continued

Northern part of Eastern Highland Rim, Tennessee							
58	12-16	8.57	Gu	10.0	5.5	2.7	n.a.
	21-22	2.82	Gm	5.9	5.6	1.8	n.a.
	31-32	3.85	Gl	9.8	6.6	2.7	n.a.
Total and average		15.24	G	9.2	5.8	2.5	n.a.
	51-53	4.57	Dl	1.5	8.2	1.7	n.a.
60	11b-15	10.83	Gu	9.7	7.7	3.4	n.a.
	21-22	3.02	Gm	1.6	7.8	1.2	n.a.
	31	2.00	Gl	7.8	7.7	1.4	n.a.
Total and average		15.85	G	7.9	7.7	2.7	n.a.
64	12-16	8.87	Gu	11.0	4.9	2.9	n.a.
	21-22	2.87	Gm	5.9	6.3	.8	n.a.
	31-33	5.75	Gl	8.8	6.3	3.3	n.a.
Total and average		17.49	G	9.5	5.6	2.7	n.a.
	51-53	5.15	Dl	8.2	4.8	1.7	n.a.
66	12-15	7.11	Gu	7.9	6.1	2.2	n.a.
	21-22	2.63	Gm	1.8	6.1	.5	n.a.
	31-33	4.65	Gl	3.0	8.4	2.0	n.a.
Total and average		14.39	G	5.2	6.8	1.8	n.a.
	51-53	6.05	Dl	3.2	7.8	.3	n.a.

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Table B.—Oil yield of the Chattanooga shale, summarized from table 2, and from Swanson (1960, table 1)—Continued

73	11b-16	11.66	Cu	11.6	7.9	2.0	n.a.
	21-22	2.84	Cm	5.6	5.3	1.0	n.a.
	31-34	7.01	Cl	13.4	5.8	1.8	n.a.
Total and average		21.51	C	11.1	7.0	1.8	n.a.
	51-53	5.59	Dl	10.6	3.4	.8	n.a.
Smithville area, Eastern Highland Rim, Tennessee							
037	2	6.80	Cu	8.6	8.9	3.4	29.3
	3	3.01	Cm	3.8	4.6	1.6	13.0
	4	7.62	Cl	10.2	4.8	3.2	23.8
Total and average		17.43	C	8.1	6.4	3.0	24.1
	5	11.50	Du	2.6	4.6	1.1	5.9
	6	5.11	Dl	7.6	5.5	1.6	17.3
077	12-14	5.85	Cu	11.8	4.3	3.6	n.a.
	21-22	2.50	Cm	5.0	3.1	1.8	n.a.
	31-34	7.10	Cl	9.7	3.1	2.4	n.a.
Total and average		15.45	C	9.7	3.6	2.8	n.a.
	41-45	9.61	Du	2.4	3.8	.2	n.a.
	51-53	5.74	Dl	8.2	3.4	1.8	n.a.
78	12-15	6.70	Cu	2.2	14.9	2.4	n.a.
	21-22	3.35	Cm	Trace	8.0	1.1	n.a.
	31-35	7.90	Cl	8.6	8.1	2.4	n.a.
Total and average		17.95	C	4.6	10.9	2.2	n.a.
	51-54	4.80	Dl	Trace	10.8	.2	n.a.

Table 20.--Oil yield of the Chattanooga shale, summarized from table 19 and from Swanson (1960, table 1)--Continued

87	12-14	5.12	Gu	9.7	6.5	1.4	n.a.
	21-22	2.85	Gm	4.7	7.7	.4	n.a.
	31-35	8.53	Gl	8.7	7.4	1.0	n.a.
Total and average		16.50	G	8.3	7.2	1.0	n.a.
	51-54	6.47	Dl	10.0	4.6	1.1	n.a.
92	12-15	6.94	Gu	7.4	6.4	2.2	n.a.
	21	1.97	Gm	4.1	5.5	.0	n.a.
	31-33	6.18	Gl	7.6	6.6	2.8	n.a.
Total and average		15.09	G	7.0	6.4	2.1	n.a.
	51-53	6.10	Ml	5.1	7.7	1.1	n.a.
C93	12-14	6.20	Gu	9.1	2.8	2.2	n.a.
	21	1.10	Gm	7.9	2.1	2.4	n.a.
	31-33	7.00	Gl	12.5	2.5	1.7	n.a.
Total and average		14.30	G	10.7	2.6	2.0	n.a.
	41-44	9.00	Du	1.2	2.8	.6	n.a.
	51-54	6.40	Dl	9.0	3.2	2.3	n.a.
C94	12-15	5.00	Gu	10.3	2.1	1.6	n.a.
	21	1.35	Gm	7.9	1.7	.7	n.a.
	31-35	7.65	Gl	11.6	2.2	2.5	n.a.
Total and average		14.00	G	10.8	2.1	2.0	n.a.
	41-45	9.60	Du	3.1	2.4	.8	n.a.
	51-53	5.85	Ml	10.3	2.8	2.2	n.a.

Table 19.—Oil yield of the Chattanooga shale, summarized from table 20 and from Swanson (1960, table 1)—Continued

Southern part of Eastern Highland Rim, Tennessee							
97 C3'	12-15	6.38	Gu	6.3	11.7	1.7	n.a.
	21-22	3.67	Gm	13.3	6.8	2.0	n.a.
	31-32	3.37	Gl	11.7	6.1	.6	n.a.
Total and average		13.42	G	9.6	9.0	1.5	n.a.
	51-52	2.48	Dl	12.3	4.3	.0	n.a.
101	12-15	6.02	Gu	7.1	5.2	2.2	n.a.
	21	1.22	Gm	9.1	4.1	1.9	n.a.
	31-34	6.11	Gl	10.1	4.1	2.6	n.a.
Total and average		13.35	G	8.7	4.6	2.3	n.a.
	51-54	7.33	Dl	4.1	7.4	1.5	n.a.
107	12-13	4.22	Gu	5.9	5.9	4.1	n.a.
	21-22	2.75	Gm	1.5	7.1	1.2	n.a.
	31-33	5.81	Gl	5.3	6.4	2.6	n.a.
Total and average		12.78	G	4.7	6.3	2.9	n.a.
	51-54	7.81	Dl	5.9	5.4	1.3	n.a.
C42	2	6.50	Gu	4.5	7.2	.9	28.6
	3	1.86	Gm	4.0	2.9	2.8	15.9
	4	9.99	Gl	5.2	3.6	3.1	20.4
Total and average		18.35	G	4.8	4.3	2.3	22.3

Table 19.—Oil yield of the Chattanooga shale, summarized from table 20 and from Swanson (1960, table 1)—Continued

C44[2]	2	6.64	Gu	6.2	—	—	n.a.
	3	1.97	Gm	2.3	—	—	n.a.
	4	6.19	Gl	4.5	—	—	n.a.
Total and average		14.80	G	5.0	—	—	n.a.
	5	9.25	Du	3.0	—	—	n.a.
	6	5.41	Dl	4.3	—	—	n.a.
113	12-15	7.17	Gu	4.0	5.0	1.9	n.a.
	21	.79	Gm	1.3	2.8	1.3	n.a.
	31-33	5.68	Gl	4.1	5.5	3.3	n.a.
Total and average		13.64	G	3.9	5.1	2.5	n.a.
	51-54	7.33	Dl	3.2	5.3	6.5	n.a.
118	12-18	13.00	Gz	6.8	8.7	1.0	n.a.
			Walden Ridge, Tennessee				
C48	2-4	15.07	Gz	0.7	1.92	3.6	23.3
C49[2]	11,21,31	13.40	Gu	3.6	—	—	22.3
	32	1.72	Gm	1.7	—	—	17.7
	33	2.85	Gl	2.8	—	—	20.0
Total and average		17.97	G	3.3	—	—	21.4
	41	6.46	Du	0.5	—	—	6.9
C50	12-13	10.21	Gu	2.0	14.2	1.5	26.5
	21	1.87	Gm	1.7	6.7	.3	16.8
	31-32	8.76	Gl	1.9	8.2	.9	20.6
Total and average		21.04	G	1.9	10.9	1.1	23.2

Table 19.--Oil yield of the Chattanooga shale, summarized from table 20 and from Swanson (1960, table 1)--Continued

Blount County, Alabama							
C64 [2]	12-14	11.95	Cz	0.6	---	---	16.7
	15-16	7.40	Dx?	1.2	---	---	8.4

[1] Not analyzed.

[2] These samples assayed by photometric method; water and gas and loss not determined.

In addition to the samples listed in table 20, pyrolitic oil yield has been determined on two samples of coaly material from the upper part of the undivided Gasaway member at locality 203B in the Northern Highland Rim; the uranium content of these samples has been discussed previously. These samples contain 130 and 250 ppm uranium, and have pyrolitic oil yields of 37.4 and 18.3 gallons per ton respectively (Swanson, 1961, table 1). Both the uranium content and the oil yield are 2 to 5 times greater than those of the total shale in the area, but the oil yield and the uranium content in the two samples have an inverse relationship. The high-uranium sample has an oil yield about half that of the low-uranium sample, and the sample having the high oil yield has a uranium content about half that of the low oil-yield sample.

Included in the Fischer assays are determinations of the specific gravity of the oil; a summary of these determinations is given in table 21. For many localities the record is not complete, and for some samples the amount of oil obtained was insufficient for determinations of specific gravity to be made; the figures given, however, are sufficiently accurate for estimates of regional and vertical differences in the specific gravity of the oil.

Table 21.—Specific gravity of oil, and oil yield, of Chattanooga shale localities, summarized from table 19 and from Swanson (1960, table 1)

Locality	Oil from Caseyway member		Oil from lower unit Dowelltown member	
	Sp. gr.	Gals/ton	Sp. gr.	Gals/ton
Kentucky				
4	0.904	9.1	—	—
12	.904	10.4	—	—
323	.979	5.9	—	—
Northern Highland Rim, Tennessee				
16	.893	5.7	—	—
22	.917	8.6	—	—
27	.907	6.3	—	—
Northern part Eastern Highland Rim, Tennessee				
58	.931	9.2	0.908	1.5
60	.926	8.9	—	—
64	.924	9.5	.907	8.2
73	.918	11.1	.905	10.6
Smithville area, Eastern Highland Rim, Tennessee				
077	.922	9.7	.908	8.2
92	.918	7.0	.895	5.1
094	.915	10.8	.895	10.3

Table 21.—Specific gravity of oil, and oil yield, of Chattanooga shale localities, summarized from table 19 and from Swanson (1960, table 1)—Continued

Southern part Eastern Highland Rim, Tennessee				
101	0.903	8.7	0.886	4.1
C42	.909	4.8	—	—
107	.894	4.7	.875	5.9
118	.896	8.7	—	—
Cumberland Plateau, Tennessee				
C211	.933	8.2	—	—

The mean specific gravity of oil obtained from the Gassaway member at the localities included in table 21 is 0.916, and that from the lower unit of the Dowelltown member is 0.900. In both the Gassaway and Dowelltown members in the Eastern Highland Rim the specific gravity of the oil shows an increase from south to north; but in the Northern Highland Rim and at localities 4 and 12 in Kentucky it is lower than in the Eastern Highland Rim. At locality 323 in Kentucky, however, the specific gravity of the oil is much higher than elsewhere—0.979. This locality is in the New Albany rather than the Chattanooga shale, and in addition is about 40 miles north and northwest of the nearest other localities, 4 and 12. Although it is known that the character of the shale changes as one goes northward into Kentucky, this great increase in the specific gravity of the oil at locality 323 has not been explained.

Effect of weathering on oil yield

Of the 31 localities for which the pyrolitic oil yield of the Chattanooga shale has been determined, 12 are drill holes and one—locality 12—is a deep cut for a dam foundation which, because of the depth at which the shale was entered, is here considered equivalent to a drill hole. As is the case with the uranium content of the shale, the oil yield of core samples may be assumed to represent that of the unweathered shale for considerable distances around the holes. The oil yield of outcrop samples, however, like the uranium content, has unquestionably been affected by weathering processes.

The oil yield of the shale in Walden Ridge and Alabama is so low that no comparisons can be drawn as to the effects of weathering on outcrop samples. In other areas, however, despite the scattered data, fairly reliable comparisons can be made between the oil yield of cores and that of samples from outcrops of different types; the data available include determinations from 7 drill holes (considering locality 12 as a drill hole); 1 waterfall locality; 2 stream-bed localities; 3 bluff exposures; and 11 road cuts.

A most striking example of loss of oil yield at an outcrop is locality 78 in the Smithville area. This locality is an abandoned highway cut gouged into a steep hillside, and the present outcrop is nowhere more than 20 to 30 feet behind the outcrop before the road was cut. It is about 140 feet from the adit (locality 79), which supplied a clue as to conditions that might be expected in the cut; and it is 0.3 mile south of drill hole C77, which affords a valid comparison.

In driving the adit the first rounds were drilled without water, and it was noticed that for the first 30 feet or so the dust was black and dry; behind that point, however, the dust was brownish in color and noticeably greasy. No determinations of oil yield were made on adit samples; but at locality 78 the oil yield of the upper unit of the Gassaway (in which the adit was driven) was 2.2 gallons per ton, and of the entire Gassaway member, 4.6 gallons per ton. At the nearby drill hole C77, however, the oil yield of the Gassaway was 9.7 gallons per ton which, on the basis of the yield from other holes in the same general area, may be considered representative.

Comparison of the assays from localities 78 and C77 focused attention on the relationship between the oil yield and water yield as shown by the Fischer assays, and the oil-water ratios. For the Cassaway member at locality 78 the water yield was 10.2 gallons per ton, the oil-water ratio, 0.42; but at locality C77, the water yield was only 3.6 gallons per ton, the oil-water ratio, 2.70. It appears from these figures that the oil-water ratios in shale samples can be used as a guide to the effect of weathering of the rock on its oil yield. Such data are given in table 22, which shows the oil yield and oil-water ratios from samples from drill-holes and different types of outcrop exposures, by regions. Averages are given for localities in the northern part of the Eastern Highland Rim, the only area for which sufficient data are available for averages to have any meaning.

Table 22.—Oil yield and oil-water ratio of samples of the Cassanny member of the Chattanooga shale, by regions and type of locality.

Data summarized from table 20.

Locality no.	Drill holes		Waterfall		Stream bed		Bluff		Road cut	
	A [1]	A 2]	A	B	A	B	A	B	A	B
Kentucky										
4	---	---	---	---	---	---	---	---	9.1	1.21
12	10.4	2.6	---	---	---	---	---	---	---	---
Northern Highland Rim										
16	---	---	---	---	---	---	---	---	5.6	0.93
22	---	---	---	---	---	---	8.6	1.41	---	---
27	---	---	---	---	---	---	---	---	6.3	0.79
Cumberland Plateau										
C211	8.2	3.04	---	---	---	---	---	---	---	---
Northern part, Eastern Highland Rim										
58	---	---	---	---	---	---	---	---	9.2	1.59
60	---	---	---	---	---	---	---	---	7.9	1.03
64	---	---	---	---	---	---	9.5	1.70	---	---
66	---	---	---	---	---	---	---	---	5.2	0.77
73	---	---	11.1	1.60	---	---	---	---	---	---
C37	8.1	1.26	---	---	---	---	---	---	---	---
C77	9.7	2.70	---	---	---	---	---	---	---	---

Table 22.—Oil yield and oil-water ratio of samples of the Gassaway member of the Chattanooga shale, by regions and type of locality. Data summarized from table 20—Continued.

78	---	---	---	---	---	---	---	---	4.6	0.42
87	---	---	---	---	---	---	8.3	1.15	---	---
88	---	---	---	---	9.6	1.07	---	---	---	---
92	---	---	---	---	---	---	---	---	7.0	1.09
C93	10.7	5.14	---	---	---	---	---	---	---	---
C94	10.8	4.21	---	---	---	---	---	---	---	---
101	---	---	---	---	---	---	---	---	8.7	1.89
Average	9.8	3.30	11.1	1.60	9.6	1.07	8.9	1.43	7.1	1.13

Southern part, Eastern Highland Rim

107	---	---	---	---	---	---	---	---	4.7	0.75
C42	4.8	1.12	---	---	---	---	---	---	---	---
113	---	---	---	---	---	---	---	---	3.9	0.76
118	---	---	---	---	6.8	0.78	---	---	---	---

1/ A = Oil yield, gallons per ton.

2/ B = Oil-water ratio.

Both the oil yields and the oil-water ratios show a considerable range at localities of the same general type. As one example, drill hole C37 contains an unusually thick middle unit, and the low yield of that unit lowers the yield of the total Gassaway appreciably. The three bluff exposures--two sheltered by the Fort Payne, the other not so sheltered--show only small differences in oil yield and oil-water ratios, although, as has been mentioned, they differ much more widely in uranium content. Of the road cuts, localities 27 in the Northern Highland Rim, and 66 in the Eastern Highland Rim are obviously weathered, but the other road cuts do not appear to have suffered much weathering. Taking these variations into consideration, and assuming that the drill-hole samples are unweathered, it is clear that all outcrop exposures have acquired some combined water, but that the bluff exposures, the one waterfall exposure, and the one stream-bed exposure in the northern part of the Eastern Highland Rim, have lost but little of their oil yield. However, at least a majority of the road cuts have not only acquired additional water, but have lost appreciable percentages of their oil yield.

The observations above apply particularly to localities 4 and 12 in Kentucky, the Northern Highland Rim, and the northern part of the Eastern Highland Rim. In the southern part of the Eastern Highland Rim, where the oil yield of the Chattanooga drops sharply, the low oil-water ratios are somewhat misleading because of that fact. As the figures in table 20 show, the actual water yield of samples from that area is approximately the same as that of samples taken farther north, and the ratio represents mostly the lower oil yield. The situation at locality 323 in Kentucky, which is not shown in the table, is unusual. The upper 5 feet or so is an abandoned quarry that, when sampled was fresh; the oil yield from the quarry samples was 10.5 gallons per ton, the oil-water ratio, 0.83. The lower part of the exposure, which is described as deeply weathered, is 25 feet thick, in a road cut and stream bed; it has an oil yield of 5.0 gallons per ton, and an oil-water ratio of 0.40. Thus the oil yield of 5.9 gallons per ton, and the oil-water ratio of 0.43 for the entire section is somewhat misleading.

In the discussion of uranium loss at outcrop exposures (p. ?) it was shown that the heaviest loss—up to about 20 percent—was at waterfall exposures. This loss is attributed primarily to water running over the falls, removing some of the uranium and redistributing some of the remainder toward the bottom of the exposure. Although more profound weathering processes may enter into the loss, they apparently are of minor importance. As regards oil-yield loss, however, the situation is different. The oil-yield from locality 73 is the highest of all the localities studied, and the oil-water ratio is comparatively high, indicating the shale is not deeply weathered. The reason probably is that at exposures such as locality 73 the outcrop is being cut back continually; any weathered rock falls into the talus pile at the bottom, and only fresh shale is sampled.

Stream bed exposures, on the basis of comparatively few localities studied, appear to have lost little uranium and little of their oil yield. Except for locality 88, which is now covered by the waters of the Center Hill Reservoir, the stream-bed localities are on relatively steep slopes, and are being cut back fairly rapidly, at least in terms of geologic time; there also may be a certain amount of case-hardening, as most of the streams are intermittent. All of the bluff exposures follow joint surfaces; water runs over them intermittently, and there is visual evidence of some case-hardening.

Of the road cuts listed in table 22, localities 16, 107, and 58 are deep cuts, fairly new when sampled. Locality 101 follows a prominent joint, thus resembling a bluff exposure. The other cuts are in general much like locality 78 in that they are cut into the sides of steep hills, and the present outcrop is not far behind the original outcrop of the shale. At such places weathering processes have been able to operate for [decades or] centuries, and to extend a considerable distance behind the original outcrop—at least 30 or more feet as evidenced by conditions at the adit (locality 79). Probably the first effect was the absorption of water by the clay minerals in the shale, followed by actual loss of kerogen content which was carried off as bicarbonate by the alkaline waters from the overlying limestones passing over and through the rock. The degree of weathering, and the depth to which it extended, differs from one locality to another that visually is almost identical; an example is locality 92, which is almost identical with locality 78 in appearance and situation; yet the oil yield and the oil-water ratio at locality 92 are much higher than at locality 78. Despite local differences, however, the general premise probably is valid.

The discussion above has been limited to the Gassaway member of the shale. The oil yield of the upper gray unit of the Dowelltown member at the 4 drill holes from which samples were analyzed ranges from 1.2 to 3.1 gallons per ton, the oil-water ratio from 0.43 to 1.29. No outcrop samples of the upper Dowelltown were analyzed. The oil yield and oil-water ratios of samples from the lower black unit of the Dowelltown member, as shown by the figures in table 20, are generally comparable to those of the Gassaway member at the same localities.

Figure 24. Relation between water yield and oil-water ratio of Chattanooga shale samples

Figure 24 shows the relation between the water yield and the oil-water ratio in samples from drill holes and outcrops. Only the black parts of the shale - the Gassaway member and the upper unit of the Dowelltown member - are shown in the figure. Samples of the gray upper Dowelltown are not included, partly because of the scarcity of data and partly because of the extremely low oil yield of that unit.

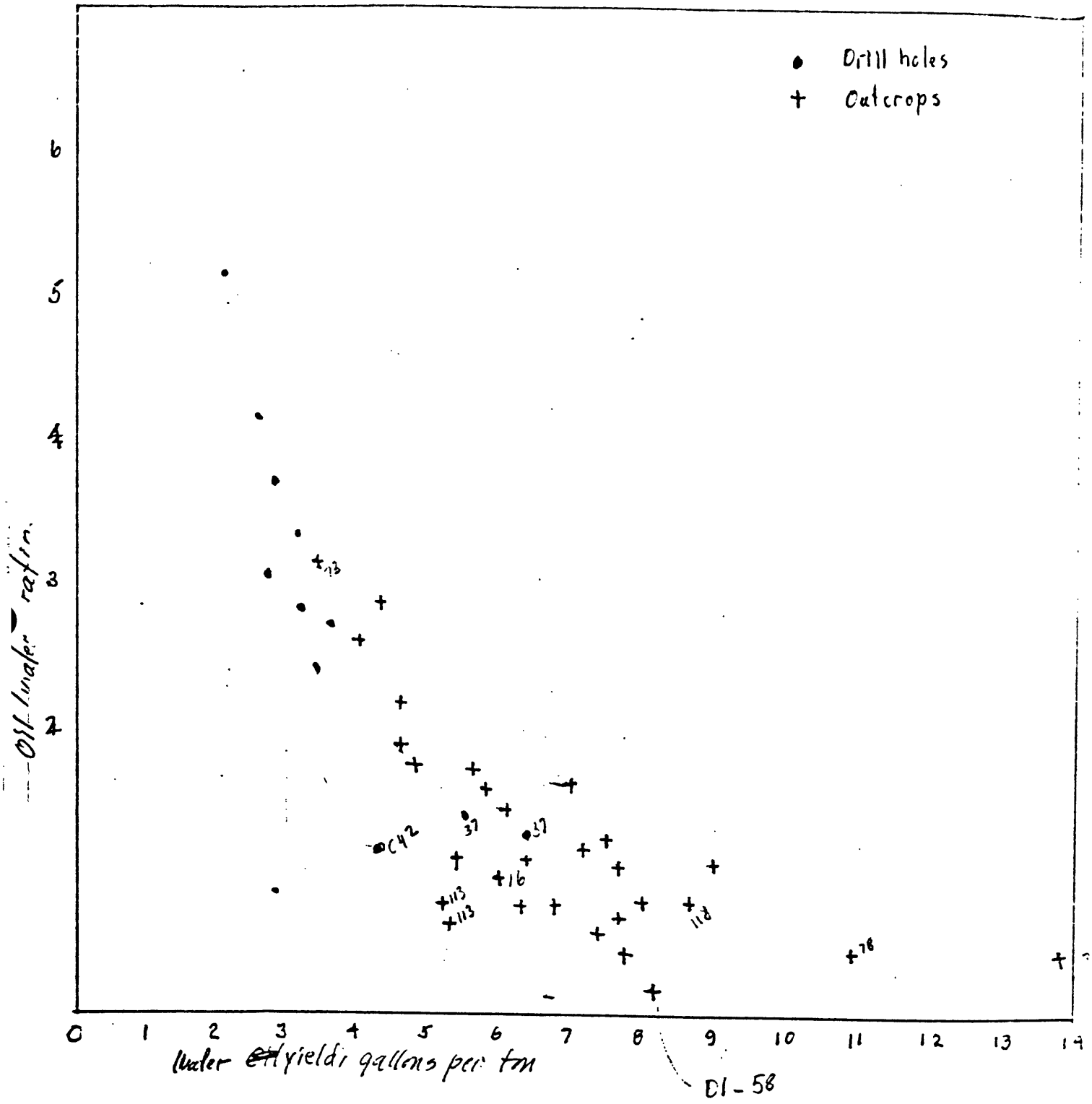

Fig 24. Relation between water yield and oil-water ratio in samples of Chattanooga Shale from deep wells and outcrops.

Potential of the Chattanooga shale as a source of oil

Data on the oil yield of the Chattanooga shale are sparse and scattered when compared to that on uranium content of the shale, and loss of yield in the shale from certain outcrop localities is less consistent and therefore more difficult to evaluate than loss of uranium content. The estimates given herein, therefore, are rough estimates only, based on such data as are available.

Although the shale at some localities has a Fischer assay oil yield of 10 to 11 gallons per ton, it appears that this yield is not applicable to any unit of the shale over large areas. Taking the generally used if unofficial cutoff point of 10 gallons per ton for marginal resources in rocks such as the Chattanooga, it follows that the oil yield of even the richest portions of the shale must be considered a submarginal potential resource. Further, the yield of the upper unit of the Dowelltown member—0.5 to 3.1 gallons per ton on the basis of assays from 7 drill holes—is too low to be placed in even that low category, and is not included in the estimates. The same is true of the entire formation in the Walden Ridge area, where the oil yield of the entire Chattanooga falls within the 0.5 to 3.1 gallon range. The shale in the Cumberland Plateau is also excluded because of lack of data; unlike the uranium content, which appears to follow a regular pattern between the Eastern Highland Rim and Walden Ridge, the oil yield of the shale drops so rapidly from west to east that no tenable estimate for that region is possible. Thus the resource estimates include only the Northern and Eastern Highland Rims, as defined for estimates of uranium resources and shown in figure 21. One change, however, has been made; in the southern part of the Eastern Highland Rim the oil yield of the Gassaway member in particular drops rather sharply south of the Smithville area, and for that reason the yield in Warren, Coffee, Bedford, and Moore Counties (see fig. 2)* is separated from that in the more northerly parts of the Rim. This regional pattern of oil yield, which is not the same as the pattern of uranium content, is discussed more fully in the succeeding section.

*Missing.

Estimates of the potential oil yield of the Chattanooga shale in Tennessee, subject to the restrictions named above, are given in table 23. The specific gravity of the shale is taken as 2.3, the figure used in estimating uranium resources of the Gassaway member; the lower unit of the Dowelltown member, and the undivided Dowelltown, have a specific gravity of about 2.4, which was used in estimating uranium resources; but in view of the highly generalized oil estimates here given, the gravity of 2.3 is used for both units, as the differences, if the two weights were used, would be negligible. Assuming a specific gravity of 2.3, a bed of shale 1 foot thick in an area of 1 square mile contains approximately 2 million tons of shale, which is the figure used in table 22. The square miles underlain by the Chattanooga in the different areas are taken from tables 11, 13, and 14, and the thickness figures for the regions are averages of the figures in those tables, rounded to the nearest foot. The oil yields of the Gassaway member—8 gallons per ton in the Northern Highland Rim and 9 gallons per ton in the northern part of the Eastern Highland Rim, are lower than the estimate of 10 gallons per ton used in some previous work. This change reflects in part some data that were not available to previous workers, in part an effort to keep the oil-yield estimates on the conservative side.

Table 23.—Estimated potential oil yield of the Chattanooga shale in the Northern and Eastern Highland Rims, Tennessee.

Area	Sq. miles underlain by shale	Average thickness (feet)	Tons of shale (millions)	Est. oil yield, Gal. ton	Gallons oil 1/ (millions)	Barrels oil 1/ (millions)
Lower unit Dowelltown member, and undivided Dowelltown member						
Northern Highland Rim	1,105	9	19,200	6	115,000	2,700
N. part Eastern Highland Rim	645	4	5,500	8	44,000	1,000
S. part Eastern Highland Rim	565	6	6,600	5	32,900	700
Total Dowelltown	2,315	—	31,300	—	191,900	4,400
Gassaway member						
Northern Highland Rim	1,105	12	27,600	8	220,600	5,200
N. part Eastern Highland Rim	775	15	23,300	9	209,500	5,000
S. part Eastern Highland Rim	660	14	18,700	5	93,500	2,200
Total Gassaway	2,540	—	69,600	—	523,600	12,400

1/ Rounded to nearest 100 million.

Relation between organic material, uranium content, and oil yield

The uranium content of the Chattanooga shale is related directly to the percentage of organic material in the rock, and the oil yield is derived from the same constituent. Within this general condition, however, there are important differences.

It has been shown (fig. 20) that the uranium content of the shale is in general directly proportional to the total amount of organic material in the rock, as expressed by the organic isolate. A comparable diagram (fig. 25) in which the oil yield in gallons per ton is

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Figure 25. Diagram showing relationship between organic isolate and oil yield of the Chattanooga shale.

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plotted against the total organic isolate in percent, and in which the Gassaway member and the lower unit of the Dowelltown member are differentiated by pattern, shows a random pattern for the Gassaway member but, considering the small sample, a fairly good correlation for the lower unit of the Dowelltown. The upper unit of the Dowelltown, which is very low in both uranium content and oil yield, is not included.

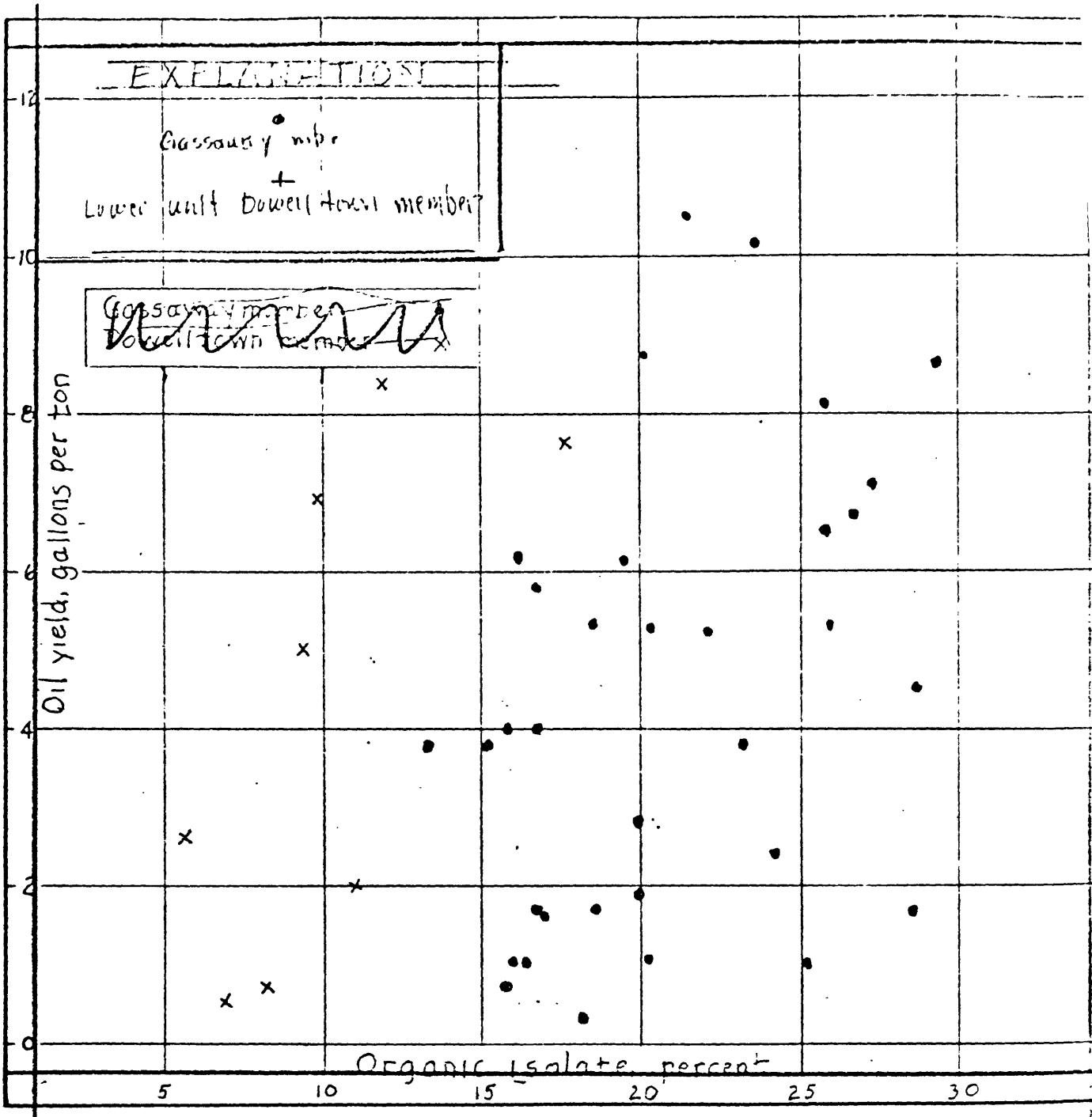

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Fig. 5. Oil yield vs. organic isolate

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As the oil yield of the Chattanooga shale, particularly that of the Cassaway member, cannot be correlated except in a most general way with the total amount of organic material, it follows that it must be derived from some type of such matter. It has long been known that the sapropelic fraction of the organic material, composed of spores, cuticles, and related materials, yields more oil than humic or woody matter (Francis, 1961, p. 183-188; Theissen, 1925). So far as is known no attempt has been made, except possibly on a very small scale, to segregate physically the different types of organic matter in the Chattanooga shale; but an index of the proportion of sapropelic material in the rock may be gained from the hydrogen content of the organic isolate, which is higher in sapropelic material than in humic matter (White, 1908, p. 310). As the Chattanooga shale contains both sapropelic and humic matter the differences in the hydrogen content are not great, but are sufficient to form a basis for valid conclusions.

Data on the percent of organic isolate, the hydrogen content of the organic matter, the oil yield, and the uranium content of the shale are given in table 24, which shows that the hydrogen content of the organic isolate and consequently the proportion of sapropelic matter in the rock, varies both vertically among members and units of the shale, and regionally. Vertically, the hydrogen content of the organic isolates is somewhat higher in the lower unit of the Dowelltown member and the lower unit of the Gassaway member than in the middle and upper units of the Gassaway. However, data on the lower unit of the Dowelltown are scant and additional analyses might change the picture.

Table 23.—Data on oil yield and uranium content of samples of Chattanooga shale in Tennessee and adjoining states

Locality and sample no.	Member and unit 1/	Thickness of sample (feet)	Organic isolate in shale (percent)	Hydrogen in organic isolates (moisture and ash free) (percent)	Oil yield of shale (gals/tons)	Uranium in shale (ppm)
323-A	Cz	5.00	21.6	6.2	10.5	36
323-B	Cz	12.00	16.7	6.1	6.2	39
323-C	Cz	13.00	15.3	5.9	3.8	37
C56-A	Cz	9.67	26.3	5.5	7.6	56
C56-B	Dz	13.15	10.2	6.7	6.5	9
16-A	Cz	6.00	18.6	5.4	7.0	46
16-B	Cz	5.50	18.3	5.2	3.5	52
16-C	Cz	5.15	24.2	4.9	6.3	59
C37-2	Cu	6.80	29.3	5.5	8.6	86
C37-3	Cm	3.01	13.0	5.1	3.8	33
C37-4	Cl	7.62	23.8	5.6	10.2	57
C37-5	Du	11.50	5.9	6.3	2.6	12
C37-6	Dl	5.11	17.3	6.4	7.6	34
C42-2	Cu	6.50	28.6	4.9	4.5	80
C42-3	Cm	1.86	15.9	4.9	4.0	49
C42-4	Cl	9.99	20.4	5.3	5.2	52
C49-31 2/	Cu	5.40	26.0	4.0	5.3	92
C49-33	Cl	2.85	20.0	4.4	2.8	63
C49-41	Du	6.46	8.3	4.3	Trace	11

Table 24.--Data on oil yield and uranium content of samples of Chattanooga shale in Tennessee and adjoining states--Continued

C48-A	Gz	15.07	23.3	3.8	0.7	69
C64-A	Gz	11.95	16.7	3.9	.7	44
C64-B	Du	7.40	8.4	4.1	1.2	19

1/ Explanation of member and unit symbols: Gm, undivided Gassaway member; Gu, upper unit, Gassaway member; Gm, middle unit, Gassaway member; Gl, lower unit, Gassaway member; Dz, undivided Dowelltown member; Du, upper unit, Dowelltown member; Dl, lower unit, Dowelltown member.

2/ Incomplete section analyzed.

Regional differences in the oil yield and uranium content of the shale are shown in figure 26*, which shows by histograms for 23 localities the oil yield of the shale in gallons per ton plotted against the uranium content in parts per million. Comparison between the two is facilitated if the oil yield and uranium content of the shale in the southern part of the Eastern Highland Rim are used as bases for comparison. It can be readily seen that in Walden Ridge and Alabama the oil yield is proportionately lower than the uranium content, whereas in Kentucky, the Northern Highland Rim, and the northern part of the Eastern Highland Rim the uranium content is proportionately higher than the oil yield. These differences can be interpreted readily in the light of the position of the shore line of the Late Devonian sea, as shown in figure 6. The hydrogen content of the organic isolates increases northward and northwestward from the shore line, confirming, as would have been expected, that the proportion of sapropelic material also increases toward the center of the sea, whereas the proportion of humic matter is greatest near the shore line; this relationship has been discussed by Swanson (1960, fig. 20). The uranium content of the shale is highest in Walden Ridge, which was closest to the shore line, reflecting both nearness to a source area and the high total content of organic matter; but the oil yield of the shale in the same area is very low, reflecting the low proportion of sapropelic material. On the other hand,

* Figure 26. Histograms showing relation between uranium content and oil yield of the Chattanooga shale, by regions.

* Figure missing.

in the northern part of the Eastern Highland Rim, the Northern Highland Rim, and Kentucky, the uranium content of the shale remains relatively high, in line with the high percent of organic isolate, but the oil yield increases, reflecting the increased proportion of sapropelic material in the rock. Conditions in the southern part of the Eastern Highland Rim, where the uranium content of the shale is about the same as that in the northern part of the Rim but the oil yield much lower, probably are due to the east-west ridge shown in figure 6, which was not submerged until Late Gasaway time and thus was a shoreline while much of the Chattanooga was being deposited.

The comparatively high hydrogen content of the organic isolates from the lower units of the Dowelltown and Gassaway members may represent either a high original proportion of sapropelic matter in the slowly expanding sea, or decay of some of the humic material that was brought into the sea while the more stable sapropelic matter remained relatively unaltered.

Relations between the organic matter, the uranium content, and the oil yield of the Chattanooga shale may be summarized as follows:

1. Both the uranium content and the oil yield of the shale are related to organic matter in the rock. The uranium content is related directly to the total amount of organic matter, whereas the oil yield is derived from the sapropelic fraction of the organic matter.

2. The uranium content of the shale in the area of this report is highest near the shoreline of the Late Devonian sea (Walden Ridge), which probably indicates a uraniferous source area to the southwest.

3. The oil yield is lowest near the shoreline and highest in the interior parts of the sea, particularly in the northern part of the Eastern Highland Rim, the Northern Highland Rim, and Kentucky.

4. The uranium content of the shale is highest in the upper unit of the Gassaway member (except locally where the phosphatic zone is present), followed in descending order by the lower unit of the Gassaway, the middle unit of the Gassaway, the lower unit of the Dowelltown, and the upper unit of the Dowelltown. The oil yield follows much the same pattern over the area of this report, but in a large area in the Eastern Highland Rim the oil yield of the lower unit of the Gassaway member is higher than that of the upper unit, and locally the lower unit of the Gassaway has a higher yield than any unit of the Gassaway.

The Chattanooga shale as a source of gas

The earliest reported investigations of the Late Devonian shales in the region south of the Ohio River were made in the early 1920's by the Kentucky Geological Survey. The samples used in these studies apparently were grab samples of the New Albany shale, a correlative of the Chattanooga; they are described only as being taken "from widely scattered localities". Assays of the samples show an average oil yield of about 21 gallons per ton and a gas yield of 3,000 to 4,000 cubic feet per ton of fuel gas having a net fuel value of about 337 Btu per cubic foot (Crouse, 1925). Later work has shown that the oil values reported are high by a factor of about 1, and the gas yields, therefore, also are suspect.

The first study of the fuel values of the Chattanooga shale of Tennessee was made by the Battelle Memorial Institute in 1948 and 1949 under the sponsorship of the U. S. Atomic Energy Commission. The sample used was a split of a 5-ton sample collected by the U. S. Geological Survey from locality 54 in southern Jackson County, in the northern part of the Eastern Highland Rim; this locality originally was designated S-100, which is the number used in the Battelle report. The sample was of the upper 5 feet of the Gassaway member, and the chemical analysis of the shale is in line with that of other localities in the region (localities C56 and 16; see table 1). The loss on ignition was 22 percent; the ultimate organic analysis showed 14.6 percent total carbon, 1.8 percent hydrogen, and 0.41 percent hydrogen. The Fischer assay oil yield was 9.6 gallons per ton, the water yield 7.2 gallons per ton, again in line with later assays of the shale from other localities in the region.

The method used by Battelle, and reported by Foster and others (1949) was a combination of distillation and combustion. As it was believed that higher temperatures would result in loss of uranium recovery, which was the primary consideration of the Atomic Energy Commission at the time, the maximum permissible temperature of any process used was placed at 1,100°F (600°C). A good deal of preliminary work was done within this limitation, but the only result reported is the composition of a gas evolved at a temperature of 485°F, which for three duplicate runs showed 75 to 83 percent carbon dioxide, 0 to 3.7 percent carbon monoxide, 1.2 to 4.3 percent illuminants, 0 to 4.2 percent hydrogen, 4.3 to 6.2 percent methane, 0 to 14 percent nitrogen, and 0 to 3 percent oxygen. A gas of this composition was of no interest as a fuel, and before attempts to upgrade it could be made, the program was recessed on June 30, 1949.

Although the Battelle studies made only a beginning on recovery of fuel values from the Chattanooga shale, they brought out certain characteristics of the rock that were used to advantage in later studies. At that time the lower oil-yield cutoff considered to have economic potential was 30 gallons per ton, the yield of parts of the Green River shale of Colorado; the Chattanooga, with its indicated yield of less than 10 gallons, was therefore submarginal. Nevertheless, the kerogen content of the Green River and Chattanooga shales, assaying about 35 and about 10 gallons per ton respectively, was almost the same, and except for a higher sulfur content in the Chattanooga, analyses of the organic matter were equivalent. It was suggested that because of these similarities the gas potential of the Chattanooga shale might be higher than its oil potential.

For about 10 years after the Battelle project was recessed little or no work was done on the gas potential of the Chattanooga, but considerable success was attained in the production of synthetic gas of high heating value from the Green River shale. Investigations of that formation were conducted as part of a basic research program sponsored by the Institute of Gas Technology of Chicago. The sample used contained 15.4 percent total carbon and 1.59 percent hydrogen; the oil yield was 22.9 gallons per ton, the water yield, 3.0 gallons per ton. In tests at a temperature of about 1,300°F and reactor pressures of 2,000 psi or more, a net gas yield of 2,300 to 2,500 standard cubic feet per ton of rock, and having a heating value of about 1,000 Btc/SCF was obtained (Shultz and Linden, 1959).

Following the success of the studies of the Green River shale, investigations were extended to other black shales of the United States, including the New Albany shale of Indiana and Kentucky and the Chattanooga shale of Tennessee (Shultz, 1962). By this time uranium recovery was of little interest, and the temperature limitations under which Foster had worked did not apply. Samples of the New Albany shale from Jackson County, Indiana and Marion County, Kentucky, and of the Chattanooga shale from Cheatham County, Tennessee, were tested. The exact locations of the localities from which the samples were taken is not given, and there are no data on the type of sample—drill-hole or outcrop—nor on whether they represent the entire shale section or are grab samples. Comments must be interpreted in the light of these gaps in the data.

The Indiana sample is of minor interest to this report. The sample from Marion County, Kentucky is from the same general area as locality 323, and that from Cheatham County, Tennessee was taken [from] about 20 to 30 miles southwest of locality 056—these two localities are named because the shale from them has been analyzed chemically, and the oil yields determined, by the Geological Survey. Analyses of the Survey's samples and those used by Shultz are generally comparable, except that his samples show higher oil yields and much higher oil-water ratios than the Survey samples.

Hydrogasification assays of samples of the New Albany and ~~Cheatham~~ Chattanooga shales, made by the methods described by Shultz and Linden (1959) at a temperature of 1,300°F and reactor pressures of from 1,800 to 3,035 psi, were made by Shultz. The composition of the gases evolved under these conditions is given in table ~~24~~ 25.

Table 25.—Properties of product gas plus unreacted H_2, from New Albany and Chattanooga shales (from Shultz, 1962, p. 15).

	New Albany shale		Chattanooga shale
	Jackson County Indiana	Marion County Kentucky	Cheatham County Tennessee
Laboratory no.	4588	4408	4586
Composition, mole percent			
H_2S	0.6	0.3	3.5
N_2 + CO	3.9	4.5	.9
CO_2	11.1	8.3	1.5
H_2	14.2	12.4	13.0
CH_4	69.2	72.6	79.3
C_2H_6	.7	1.6	1.0
Higher hydrocarbons	.3	.3	.8
Total	100.0	100.0	100.0
Specific gravity (air = 1)	.662	.609	.551
Heating value (Btu/SCF)	767.0	809.8	899.1

From the batch hydrogasification and Fischer assay data, Shultz computed the gross resources of natural gas equivalent in the New Albany shale, and gave a starting point for estimates for the Chattanooga. First, a conversion factor was derived empirically, relating the gas production of the shales by hydrogasification to the oil yield as obtained by the Fischer assay. The formula used involves subtraction of the heat input of the feed hydrogen from the gross heat output, and correction to a 1035 Btu/SCF basis (Shultz, 1962, p. 17). From his formula, Shultz arrives at a figure of 310 standard cubic feet of 1,035 Btu natural gas equivalent per gallon of oil per ton as determined by the Fischer assay for the Chattanooga shale; the comparable figure for the New Albany shale, the average of determinations from two localities, is 260. The tentative estimate of gas yield of the Chattanooga given herein uses the factor of 310, but must be interpreted in the light of the following conditions:

1. Tying the gas yield of the Chattanooga shale to its oil yield is an indirect, and possibly not the best, method. As both Foster (1949) and Shultz (1959) have stated, the kerogen content of the Chattanooga is higher than its oil yield, particularly as compared to the Green River shale, would indicate, and it would be logical to expect a higher gas yield, proportionately, than oil yield. Shultz's determinations and his factor of 310 probably are useful for the Northern Highland Rim and the northern part of the Eastern Highland Rim, but may be far afield for the southern part of the Eastern Highland Rim and for Walden Ridge, where the organic isolate content of the shale, and presumably its kerogen content, are as high as in the other regions, but its oil yield is much lower; the yield in Walden Ridge is negligible. Regardless of the methods used, any usable evaluation of the gas yield of the Chattanooga shale in Tennessee must be based on data covering all the regions in which the shale occurs.

2. Sufficient Fischer assay data are available to permit reasonably good estimates of the potential oil yield of the shale (see table 25). The factor used for converting oil yield to gas yield, however, is based on only one sample which may or may not be representative of the shale in the Northern and Eastern Highland Rims, but probably is not representative of that in Walden Ridge.

3. Fischer assay data for both the Cassaway member and the lower (black) unit of the Dowelltown member are available. The gas-yield data, however, are based on a sample that presumably but not certainly is of the Cassaway member. There are differences between the Cassaway and the lower unit of the Dowelltown, however, that could affect the gas yield of the units (Breger and Brown, 1962).

The Cassaway member of the Chattanooga shale in the Northern and Eastern Highland Rims, restricted as shown in figure 21, is estimated to have a potential oil yield of about 524 billion gallons of oil, and the lower unit of the Dowelltown member in the same area, 192 billion gallons (see table 25). Using Smith's factor of 310, this would indicate, for the same areas, about 162 trillion standard cubic feet of gas having a heating value of 1,035 Btu/SCF in the Cassaway member, and 60 trillion cubic feet in the lower unit of the Dowelltown member. As is the case in estimates of oil yield, no figures are given for the upper unit of the Dowelltown member, nor for any part of the shale in the Cumberland Plateau and Waldan Ridge.

Economic potential of the Chattanooga shale

Under present conditions, the Chattanooga shale has marginal or submarginal potential as a source of uranium, thorium, and possibly other metals, as well as of heat values recoverable as oil or gas. Further, economic recovery of the values in the rock presents problems that have not yet been solved, although some preliminary studies that provide a basis for future work have been made.

An investigation of the possible recovery of the uranium values in the shale was made by the Minerals Beneficiation Laboratory of Columbia University in the early and middle 1950's. The samples used were taken by the Survey from the adit (locality 79), and tests were made on both the Gassaway member as a whole and the most uraniferous part, the upper unit of the member; the samples contained 63 ppm and 83 ppm uranium respectively. After experimentation with various other processes, two methods of treatment were recommended—countercurrent leaching with sulfuric acid, and leaching under oxygen pressure in which uranium production and acid production were effected simultaneously. Thermal pretreatment of the rock was not recommended. Each process yielded a recovery of 73 percent of the uranium in the shale as shown by the analyses (Pollara and others, 1958).

No studies of the possible recovery of the thorium in the Chattanooga shale or in comparable rocks have been reported; most investigations in that field have been made on monazites and thorites, although a method has been developed for recovering thorium from the uranium-barren effluents from uranium-processing plants in the Blind River area of Canada (Dudley and others, 1958). Whether a comparable method would be effective with the Chattanooga shale, which is much lower in both uranium and thorium than the Blind River area, is not known. Similarly, no data are available on the recovery of trace elements in the shale, some of which are present in amounts that have been recovered on a by-product basis in other places. The yield of oil from the shale in a commercial operation is generally considered to be about 80 percent of that shown by the Fischer assays (Karrick, 1926, p. 29).

Economic processing of a rock such as the Chattanooga shale requires the recovery of as much of the metal and heat values as can be obtained. This necessity raises the question of what effect the temperatures required for production of oil or gas would have on the recovery of uranium and other metals. When the first investigations on recovery of heat values were made by the Battelle Memorial Institute, at a time when uranium recovery was a prime consideration, the allowable temperature was restricted to 1,100°F, or about 600°C; this temperature is not much above the maximum used in the Fischer assay process, and probably was chosen for that reason. The Battelle studies were released before any conclusions could be drawn, but Pollara and others (1958) state, without giving any quantitative data, that retorting decreases the recovery of uranium markedly. On the other hand, Breger, Meyrowitz, and Deul (1954) found that dry distillation of the shale at a temperature of 500°C did not cause any appreciable loss of uranium from the ash, indicating that little or no uranium was carried off in the volatiles. Their studies were directed toward learning the amount of uranium left after distillation, not the amount that could be recovered; thus the conflict between their findings and the statement of Pollara is apparent rather than real. It seems safe to say that the production of oil from the shale would entail some loss of uranium recovery because of fusing of the ash and for other reasons, but no estimate can be given as to the amount of such loss. If the heat values should be recovered as gas instead of oil the loss almost certainly would be higher because of the higher temperatures (more than 700°C) used in the oil-production process.

Evaluation of the Chattanooga shale as a source of uranium and thorium, and of oil or gas, must take into consideration the fact that in the present state of technology a recovery of 70 to 75 percent of the uranium in the shale is about all that can be expected in a large-scale operation, and that recovery of oil values will be only about 80 percent of the yield shown by the Fischer assays. The experiments on production of gas have not reached the point where it is possible to make an estimate of the efficiency of a commercial operation as compared to the batch tests.

Although the most obvious potential of the Chattanooga shale is as a source of uranium and oil or gas, the rock contains a number of other materials which probably could be recovered on a by-product basis should the shale ever be mined and processed. Thorium has already been mentioned; another metal, that in other operations has been recovered even though the content was less than that of the Chattanooga, is manganese, which is present throughout the Northern and Eastern Highland Rims in concentrations, calculated from chemical analyses for MnO, of about 150 ppm; in Walden Ridge the content is somewhat higher. Data on other trace elements are largely qualitative because they are based on semiquantitative spectrographic determinations; but as the histograms in figure 16 show, several are distributed rather evenly throughout the Eastern Highland Rim and Walden Ridge, in concentrations of at least 100 ppm and probably on the order of 200 ppm. Among these are copper, and (in the black parts of the shale only) nickel and molybdenum. The content of these elements is somewhat lower in the Northern Highland Rim than in other regions. Cobalt, in concentrations not much above or below 100 ppm, shows much the same distribution. Other elements, which are present in smaller concentrations or which show irregular distribution, are discussed in the section on the composition of the shale, which includes comments on the economic possibilities of some of the elements.

The following summary of the economic potential of the shale is restricted to the Cassaway member, which is the only part of the formation likely to be considered worth mining and processing in the foreseeable future. It is true that locally the lower unit of the Dowelltown member contains almost half as much uranium and has practically the same oil yield as the Cassaway member; but it is separated from the Cassaway by a thick sequence of the almost barren (except for its comparatively high thorium content) upper gray unit of the Dowelltown. Thus stratigraphic conditions, as well as low values, would appear to eliminate the Dowelltown member from serious consideration in the light of present knowledge.

The potential of the Cassaway member varies somewhat in different regions. The highest potential for uranium and thorium is in Walden Ridge, where the shale contains about 70 ppm uranium and 10 to 11 ppm thorium. The oil potential of that region, however, is negligible, as is the gas potential in the light of present information. Also, mining conditions in Walden Ridge probably will be more difficult than is the case in other regions. The potential of the Eastern Highland is different in the northern and southern parts of the area. The uranium content is highest—about 60 ppm—south of an east-west line drawn across the Highland Rim about 5 miles north of the 36th parallel of latitude, which is also the northern boundary of the Smithville area. The oil yield, however—about 9 gallons per ton—is highest north of an east-west line drawn about 5 miles south of the southern boundary of the Smithville area. The thorium content in both areas is the same, about 8 ppm. Thus the area in which the combined uranium and oil potential is greatest is about 20 miles wide north and south, and 30 miles long east and west from the Highland Rim escarpment to the vicinity of Sparta; it is likely that additional data would extend this area farther east, at least to the base of the Cumberland Plateau. The area [illegible] covers about 500 square miles, in which the shale is about 14 feet thick and is under from about 100 to 500 feet of cover. The total uranium content is estimated at about 840,000 tons and the thorium content at about 76,000 tons, and the oil yield at about 3 billion barrels.

Another area in which the shale has comparatively high combined potential covers about 500 square miles in western Sumner, northern Davidson, and southeastern Robertson Counties in the Northern Highland Rim. [~~See fig.~~]. The shale in this area has a rather uniform thickness of about 10 feet; no estimate of the amount of cover has been made, but it probably is less than the cover in the Eastern Highland Rim. The uranium content is about 55 ppm, the thorium content about 8 ppm, and the oil yield about 9 gallons per ton. The total uranium content of the area is estimated at about 600,000 tons, the thorium content at about 54,000 tons, and the oil yield at about 2.2 billion barrels.

The estimates above are for material in the ground, without regard to mining or processing losses; the probable processing losses, however, have been discussed above. Nor do they take into consideration the recovery of trace elements, which, as has been stated, probably would be higher in the Eastern Highland Rim than in the Northern Highland Rim.

Mining conditions

Although mining as such is outside the province of a Geological Survey report, certain observations based on the geologic work, the drilling program, and the driving of the adit can profitably be made.

The first observation is the more or less obvious one that any mining plans should be based on a drilling program, and that only drill-hole samples should be used in evaluating the grade of the ore. The effect of weathering processes on the uranium content and the oil yield of the shale is so marked that samples from outcrops should be used only as a last resort if at all. The drilling, however, need not be spaced as closely as is desirable in many types of deposits. In most areas a spacing of 1 mile should be ample, except in the Walden Ridge area; there, because of the dips and the condition of the rock, closer spacing is desirable.

A second basic observation is that any mining of the shale in the foreseeable future probably would be by underground methods, particularly in the Eastern Highland Rim and Walden Ridge where the shale is overlain, above the thin Maury formation, by the highly resistant Fort Payne chert. The lower 60 feet or so of Fort Payne is extremely difficult to drill and blast, and above this unit the formation is deeply weathered, the weathering extending locally as deep as 60 feet. Because of the cliff-forming character of the Fort Payne, the cover over the shale is generally 100 feet or more only a short distance behind the outcrop.

In much of the Northern Highland Rim the cover over the shale is the New Providence shale, which is not as resistant as the Fort Payne. In that area consideration might be given to strip-mining, although the ratio of overburden to the shale would be high. In both the Eastern and Northern Highland Rims the regional dip of the Chattanooga shale is away from the Nashville Basin, whereas the drainage is into the basin; thus the cover over the shale increases with the distance from the escarpment.

The thickness of the Gassaway member is fairly uniform over large areas and no sudden thickening or thinning is to be expected. There are, however, in the Eastern Highland Rim small rolls which generally trend northeast with the strike of the formation (see Conant and Swanson, 1961, p. 37). These rolls show thinning at the top of the upper unit of the Gassaway member which could be important if that unit only should be mined; their effect on mining of the total member is of less importance. Because the shale dips away from the outcrops, provision must be made for pumping water from the mine.

Both the Chattanooga shale and the overlying rocks are rather strongly jointed, the dominant joints trending generally northeast with the strike of the formations. No faults of any consequence have been observed in any region, although some rather severe faulting would not be unexpected in the Walden Ridge area, where the dip is about 20 degrees to the southeast into the ridge, and the rocks locally are badly broken. In brief, mining conditions in the western flank of Walden Ridge, from which all the data used in this report are taken, are likely to be bad in several respects. Conditions in the trough of the syncline are not known.

Drilling the shale presents no particular problems. The cores of the shale, except in Walden Ridge, are generally solid. Locally, in all regions, cores show some slickensiding that indicates lateral movements, but, again with the exception of Walden Ridge, such movements apparently have been minor. The shattering of the rock in Walden Ridge is greatest at the southern drill hole, C47, and decreases northeastward. The core from drill hole C50, at the north end of the Walden Ridge area, shows much slickensiding and contains considerable breccia which has been recemented.

The only mining experience with the Chattanooga shale was gained from the adit (locality 79) driven in the upper unit of the Cassaway member in 1948 and 1949, and deepened in 1953 to obtain samples of the entire Cassaway member. The original adit was about 5 feet ~~high~~ wide and 6 to 8 feet high, and went about 100 feet into the shale. The average footage per round was about 5 feet. The experimental nature of the adit and its small size limit its usefulness in planning large-scale mining operations, but some of the conditions encountered offer useful suggestions.

At the time the adit was driven little data on the composition of the shale were available, and the extreme abrasiveness of the rock was something of a surprise. Steel bits drilled only about 2 feet before losing gauge; tungsten carbide bits gave satisfactory footage. The drilling pattern called for shooting out a bottom wedge, best results being obtained when the angle of the wedge holes was not less than 25 degrees. The rock above the wedge was shot down easily from horizontal or almost horizontal holes, thus taking advantage of the numerous bedding planes in the shale. The first rounds were loaded with 60 percent gelatin dynamite, which did not give proper fragmentation; subsequently good results were obtained with 40 percent gelatin dynamite, but an even slower powder probably would have given better results. The most effective rounds were those in which the wedge holes were loaded rather heavily, the higher holes more lightly.

The Maury shale stood better than had been anticipated in those parts of the adit where it was not taken down, but how well it would stand over large areas is not known. Hopefully, it might be possible to remove the Chattanooga and shoot down the Maury later, thus avoiding dilution of the Chattanooga by the barren Maury.

It has been stated for years that the black parts of the Chattanooga shale would not support combustion, though they would burn if placed on a hot fire. When construction of the adit was started, shale from the facing cut was dumped into a ravine, for road-building purposes. On a Friday afternoon a fire was built on top of the shale and left burning when work ceased for the day. When the site was visited two days later, the shale had caught fire and was burning steadily, and it took a day's work, aided by a heavy rain, to extinguish the blaze. It was found later that the Tennessee Valley Authority had a similar experience with the shale during construction work at its New Johnsonville Steam Plant. The unexpected combustibility of the shale raises the possibility of explosions in mines in the Chattanooga, if adequate precautions to keep the dust down are not used.

The small size of the adit makes it impossible to hazard a guess as to how well the Fort Payne roof in a mine would stand, and therefore of the size of rooms that might be planned. The Fort Payne is strongly jointed, as is the Chattanooga, which complicates the problem. In the Northern Highland Rim, where the cover over the Chattanooga is the New Providence shale, a different type of roof problems would be encountered.

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Table 23.—Locations of outcrop localities and drill holes shown on maps accompanying this report

(All quadrangles are 7½' sheets except Lillydale, Red Boiling Springs, Carthage, Cainsboro, Gordonsville, and Woodbury, which are 15' sheets)

Locality no.	County	State	Topographic quadrangle	Description
4	Pulaski	Ky.	Science Hill	7.5 miles northwest of courthouse at Somerset; at Hogus on east bank of Fishing Creek cut on north side of road.
12	Russell	Ky.	Wolf Creek Dam	9.5 miles southwest of courthouse at Jamestown, cut for west end of Wolf Creek Dam; now concealed by dam.
16	Clay	Tenn.	Lillydale	About 3 miles east of courthouse at Celina and about 250 yards west of north end of Dale Hollow Dam; cut on north side of road.
17	Overton	Tenn.	Hilham	About 2 miles south-southwest of Timothy; west end of dam on Mill Creek in Standingstone State Park (analyses not given in table 9).

Table 26.—Locations of outcrop localities and drill holes shown on maps accompanying this report—Continued

22	Macon	Tenn.	Carthage	From intersection at Willette, 1.2 miles east on Tennessee Route 56, then 0.6 mile southeast on unimproved road, then 0.4 mile south-southwest on steep road leading to valley of Wartrace Creek; bluff on side of road.
25	Jackson	Tenn.	Gainsboro	About 5 miles northwest of Gainsboro, cut along Tennessee Route 85 at crest of ridge between Bullard and Cub Creeks.
27	Jackson	Tenn.	Gainsboro	About 6 miles southeast of Gainsboro and about 1 mile south of Pleasant Hill School on road leading to Sugar Creek.
29	Jackson	Tenn.	Gainsboro	Six miles east of courthouse at Gainsboro near top of steep slope overlooking Roaring River from south, and about 1 mile east of Blackman Fork; road cut.

Table 26.—Locations of outcrop localities and drill holes shown on maps accompanying this report—Continued

31	Jackson	Tenn.	Gainsboro	Seven miles east-southeast of Gainsboro, about 3 miles (airline) south of mouth of Blackman Fork and 0.5 mile east of stream; cut on road ascending steep east wall.
34	Jackson	Tenn.	Gainsboro	6.5 miles southeast of courthouse at Gainsboro on road leading east into valley of Blackman Fork from Freewill School on Seven Knobs road; cut on north side of road.
39	Jackson	Tenn.	Gainsboro	1.7 mile southeast of Gainsboro on Tennessee Route 56; cut on southwest side of highway.
43	Jackson	Tenn.	Gainsboro	2.5 miles south of courthouse at Gainsboro, 2.2 miles up Shakerag Hollow road from its intersection with Tennessee Route 53, and 0.8 mile northwest of New Salem School; cut on north side of road.

Table 25.--Locations of outcrop localities and drill holes shown on maps accompanying this report--Continued

54	Jackson	Tenn.	Gainsboro	6.5 miles south by east of Gainsboro on road leading northwest from Tennessee Route 56 to Flynn Creek; road cut 1.2 miles northwest of intersection with Tennessee Route 56 at south edge of Gainsboro quadrangle. Exposure destroyed by road construction in 1957.
58	Putnam	Tenn.	Baxter	From junction of U. S. Highway 70N at Double Springs, northwest about 2 miles on Tennessee Route 56 to Bloomington Springs, then northwest 1.5 miles and north-northwest 1.6 miles on road to Martin Creek; cut along road (analyses not given in table 9).

Table 26.—Locations of outcrop localities and drill holes shown on maps accompanying this report—Continued

59	Putnam	Tenn.	Baxter	About 12 miles west of courthouse at Cookeville, cuton road about 0.5 mile north of U. S. Highway 70N; 0.25 mile east of Lafayette School.
60	Smith	Tenn.	Gordonsville	From west city limit of Chestnut Mound, 0.8 mile northwest on U. S. Highway 70N from its intersection with Tennessee Route 53; cut on northeast side of highway.
64	Putnam	Tenn.	Silver Point	Gentrys Bluff, in bed and walls of Mine Lick Creek; about 2 airline miles east of Boma and 2.3 miles south of Baxter.
66	Putnam	Tenn.	Gordonsville	From Silver Point, 2.5 miles west on road to Center Hill Dam; cut along road (uranium analyses not given in table 9).
67	DeKalb	Tenn.	Gordonville	About 4 airline miles northeast of Dowelltown; road cut on west side of Dale Ridge near headwaters of Reynolds Branch.

Table 25.—Locations of outcrop localities and drill holes shown on maps accompanying this report—Continued

68	DeKalb	Tenn.	Silver Point	About 11 miles northeast of courthouse at Smithville on Tennessee Route 56; cut along highway near crest of ridge about 2 miles north of west end of Hurricane Creek Bridge over Center Hill Reservoir.
70	DeKalb	Tenn.	Silver Point	About 7 miles northeast of Smithville on Tennessee Route 56; highway cut along south approach to Hurricane Creek Bridge over Center Hill Reservoir.
73	Putnam	Tenn.	Burgess Falls	At Burgess Falls on Falling Water River, about 10 miles south-southwest of courthouse at Cookeville, about 0.3 mile downstream from dam of old Cookeville power plant.

Table 26.—Locations of outcrop localities and drill holes shown on maps accompanying this report—Continued

74	White	Tenn.	Burgess Falls	At Taylor Creek Falls on branch of Falling Water River, about 10 miles northwest of Sparta; east from Peeled Chestnut on Tennessee Route 26 1.7 miles, then north 2.6 miles to falls.
75	DeKalb	Tenn.	Sligo Bridge	Cut along private road (now abandoned), 0.5 mile northwest of old Tennessee Route 26 where it begins its descent to east end of Sligo Bridge over Center Hill Reservoir.
76	DeKalb	Tenn.	Sligo Bridge	About 7 miles east of Smithville on Tennessee Route 26 and 0.3 mile northeast of east end of Sligo Bridge over Center Hill Reservoir; deep highway cut on north side of road. Designated by Conant and Swanson (1961) as the standard locality of the Chattanooga shale (uranium analyses not given in table 9).

Table 26.—Locations of outcrop localities and drill holes shown on maps accompanying this report—Continued

78	DeKalb	Tenn.	Sligo Bridge	Road cut on old Tennessee Route 26 (now abandoned) about 1 mile southwest of its intersection with present Route 26 (uranium analyses not given in table 9).
79	DeKalb	Tenn.	Sligo Bridge	Adit driven 100 feet into upper unit of Gassaway member, portal of adit about 140 feet northwest of locality 78 (uranium analyses not given in table 9).
83	DeKalb	Tenn.	Sligo Bridge	2.25 airline miles south of west end of Sligo Bridge, and 1.5 miles northeast of Youngs Bend School; in bed of steep westward-flowing tributary of Short Creek.

Table 26.—Locations of outcrop localities and drill holes shown on maps accompanying this report—Continued

86	DeKalb	Tenn.	Sligo Bridge	9.5 miles southeast of Smithville; in bed of south-flowing tributary of Sink Creek at west side of Center Hill Reservoir. Cassaway member only exposed when sampled.
87	DeKalb	Tenn.	Sligo Bridge	Bluff on east side of Sink Creek, 2.4 miles northeast of Keltonburg (uranium analyses not given in table 9).
88	White	Tenn.	Campaign	In south bank at northernmost part of Horseshoe Bend in Caney Fork River, 4.8 miles west-northwest of Walling; now below water level of Center Hill Reservoir (uranium analyses not given in table 9).
89	DeKalb	Tenn.	Smithville	Main waterfall in Pine Creek, 4.3 miles south of courthouse at Smithville and 2.7 airline miles west of main part of Center Hill Reservoir.

Table 26.—Locations of outcrop localities and drill holes shown on maps accompanying this report—Continued

91	DeKalb	Tenn.	Smithville	Cut on unimproved road about 1 mile north of Tennessee Route 26, about 3.4 miles east of Smithville and near eastern edge of Smithville quadrangle.
92	DeKalb	Tenn.	Smithville	Cut on Holmes Creek road, 1.6 miles north of courthouse at Smithville.
95	DeKalb	Tenn.	Gassaway	Cut on old Tennessee Route 26 at Snows Hill, 3.1 miles southeast of Dowelltown and 6.5 miles west of Smithville (uranium analyses not given in table 9).
95A	DeKalb	Tenn.	Gassaway	Highway cut on Tennessee Route 26, about 0.6 mile east-northeast of locality 95 (cut made in 1955, and not sampled).
96	DeKalb	Tenn.	Smithville	About 3 miles west of Smithville and 5.5 miles southeast of Dowelltown; at Egypt Falls on tributary of Dry Creek.

Table 26.—Locations of outcrop localities and drill holes shown on maps accompanying this report—Continued

97	DeKalb	Tenn.	Cassaway	About 8 miles west-northwest of courthouse at Smithville and about 2 miles east of Cassaway; cut on north side of gravel road to Mt. Moriah School.
99	Cannon	Tenn.	Short Mountain	6.5 miles east-northeast of courthouse at Woodbury; 0.7 mile east on U. S. Highway 70S, then north and east on Stones River road 5.8 miles; 0.7 mile east of intersection with Short Mountain road; stream bed on south sideof road.
100	Cannon	Tenn.	Woodbury	South of Cassaway 5.0 and 5.4 miles on Tennessee Route 53; road cuts on north and south sides of ridge.
101	Cannon	Tenn.	Woodbury	Cut on west side of Auburntown road 2.6 miles north of its junction with U. S. Highway 70 on west edge of Woodbury.

Table 26.—Locations of outcrop localities and drill holes shown on maps accompanying this report—Continued

103	Cannon	Tenn.	Woodbury	About 4 miles south of courthouse at Woodbury and 1.4 miles west of Tennessee Route 53 at Sheboygan; road cut.
104	Cannon	Tenn.	Beech Grove	Cut on west side of road 3.7 miles northwest of Hollow Springs Crossroads and 2.9 miles south of the church at Bradyville.
106	Coffee	Tenn.	Beech Grove	3.3 miles northeast of U. S. Highway 41 on McBride Branch road; 0.2 mile southwestof Wilsons Chapel School at Hoodoo; cut along road.
107	Coffee	Tenn.	Noah	About 10 miles northwest of Manchester and 1 mile northeast of Noah; deep cut on U. S. Highway 41.
112	Coffee	Tenn.	Ovova	5.3 miles southwest of courthouse at Manchester and 1.6 miles west of Mountview School on road leading to Crumpton Branch; road cut.

Table 26.—Locations of outcrop localities and drill holes shown on maps accompanying this report—Continued

113	Coffee	Tenn.	Ovova	About 4 miles north-northwest of Tullahoma and 2.5 miles west-northwest of Ovova; cut along Cascade Branch road.
114	Moore	Tenn.	Normandy	In northeastern panhandle of Moore County; cut on northeast side of road below Ledfords Mill dam, 2.8 miles northeast of junction of Tennessee Routes 16 and 55.
118	Moore	Tenn.	Cumberland Springs	About 6 miles northeast of courthouse at Lynchburg; along Hurricane Creek just below dam at Cumberland Springs. (Uranium analyses not given in table 9.)
185	Williamson	Tenn.	College Grove	In southeastern part of Williamson County; 3.0 miles east of intersection at Bethesda and 1.2 miles east of Cross Keys; in gully on southeast side of road (uranium analyses not given in table 9).

Table 26.—Locations of outcrop localities and drill holes shown on maps accompanying this report—Continued

187	Williamson	Tenn.	Franklin	About 4 miles northeast of Franklin, on U. S. Highway 31, then north 1 mile on Holly Tree Gap road; bluff 50 feet north of road behind barn (uranium analyses not given in table 9).
203B	Davidson	Tenn.	Whites Creek	About 9 miles north of State Capitol at Nashville; 1.3 miles west along Campbells Lane from U. S. Highways 31W and 41; cut on both sides of road just east of crest of hill.
204	Davidson	Tenn.	Whites Creek	3.7 miles north-northwest of Goodlettsville on U. S. Highway 41E, then west 0.7 mile to L. & N. Railroad tracks at Bakers Station; cuts about 100 feet north and 1,500 feet south of crossing.

Table 26.—Locations of outcrop localities and drill holes shown on maps accompanying this report—Continued

209	Macon	Tenn.	Red Boiling Springs	From Red Boiling Springs west-southwest on Tennessee Route 52, 6.4 miles; cut along north side of road on east slope of Long Fork Creek.
210	Clay	Tenn.	Red Boiling Springs	About 3.7 miles southeast of Red Boiling Springs on the Hudson Creek road, about 0.15 mile northwest of the Clay-Macon county line; cut on northeast side of road.
213	Rhea	Tenn.	Roddy	0.9 mile west of Roddy; badly disturbed and weathered exposure in cut and ditch along road (uranium analyses not given in table 9).
214	Rhea	Tenn.	Evansville	From intersection of U. S. Highway 27 and Tennessee Route 30 in Dayton, northwest 1.8 miles on U. S. Highway 27 to Walnut Grove School, then northwest on county road 0.8 mile to intersection; road cut just west of intersection.

Table 26.—Locations of outcrop localities and drill holes shown on maps accompanying this report—Continued

215	Bledsoe	Tenn. Melvine	Two miles east of road junction near Cedar Ridge; on southwest side of road and on northeast side below road.
219	Bledsoe	Tenn. Mt. Airy	13.3 miles south-southwest of courthouse at Pikeville; from Stephen Chapel on east side of Sequatchie River 2.5 miles, then east 0.7 mile; on north side of McWilliams Creek just north of road.
220	Sequatchie	Tenn. Dunlap	About 5 miles south of courthouse at Dunlap; 1 mile south of junction with Tennessee Route 28 on Tennessee Route 8; highway cut.
221	Marion.	Tenn. Ketner Gap	From junction of Tennessee Routes 27 and 108 just south of Whitwell, about 4 miles east on Tennessee Route 27 and 1.3 miles east of Powells Crossroads; highway cut.

Table 26.—Locations of outcrop localities and drill holes shown on maps accompanying this report—Continued

222	Marion	Tenn.	Sequatchie	On U. S. Highways 41, 64, and 72 between Jasper and the bridge over the Tennessee River, 2.5 miles west of west end of bridge; cut on northeast side of highway.
306	Sumner	Tenn.	White House	From intersection about 0.1 mile east of schoolhouse at Shackle Island, north 3.0 miles to Drakes Creek road, then northeast 0.4 mile, take west fork 0.2 mile; cut on east side of road.
310	Macon	Tenn.	Lafayette	From courthouse at Lafayette, north on Tennessee Route 10, 4.6 miles, then west about 3.5 miles; outcrop on north side of road along Clifty Creek.

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Table 25.--Locations of outcrop localities and drill holes shown on maps accompanying this report--Continued

323	Marion	Ky.	Bradfords-ville	From post office at Bradfordsville, 2.0 miles west on Kentucky Route 49, then 3.1 miles west-southwest on secondary road, then 2.5 miles south on Arbuckle Creek Road; outcrop of New Albany shale in small quarry and creek bed.
C1	DeKalb	Tenn.	Sligo Bridge	Drill hole in northeastern part of Youngs Bend, 2.5 miles east-northeast of Youngs Bend cemetery and 2.1 miles east of south of Sligo Bridge. Elevation of collar, 960 feet; depth to top of Chattanooga, 186 feet.
C2	DeKalb	Tenn.	Sligo Bridge	Drill hole 0.5 mile southwest of locality C1 and 0.9 mile north of east of locality 83. Elevation of collar, 939feet; depth to top of Chattanooga shale, 198 feet.

Table 26.—Locations of outcrop localities and drill holes shown on maps accompanying this report—Continued

C3	DeKalb	Tenn.	Sligo Bridge	Drill hole 0.65 mile south-southwest of locality C1 and 0.4 mile southeast of locality C2. Elevation of collar, 943 feet; depth to top of Chattanooga shale, 166 feet.
C4	DeKalb	Tenn.	Sligo Bridge	On south side of Youngs Bend Road 1.5 airline miles east-northeast of Youngs Bend Cemetery and 0.6 mile south of west of locality C3. Elevation of collar, 944 feet; depth to top of Chattanooga shale, 213 feet.
C6	DeKalb	Tenn.	Sligo Bridge	Drill hole 0.95 airline mile northeast of Youngs Bend Cemetery and 0.25 mile south of locality 83, on north side of Youngs Bend road at Vaughn Cemetery. Elevation of collar, 977 feet; depth to top of Chattanooga shale, 226 feet.

Table 26.—Locations of outcrop localities and drill holes shown on maps accompanying this report—Continued

C7	DeKalb	Tenn.	Sligo Bridge	Drill hole on south side of Youngs Bend road, 0.3 mile northeast of Youngs Bend Cemetery. Elevation of collar, 948 feet; depth to top of Chattanooga shale, 205 feet.
C9	DeKalb	Tenn.	Sligo Bridge	Drill hole 0.7 mile southwest of locality C7 and 0.3 mile southwest of Youngs Bend Cemetery, at end of unimproved road running south from Youngs Bend road toward Pine Creek. Elevation of collar, 984 feet; depth to top of Chattanooga shale, 175 feet.
C10	DeKalb	Tenn.	Sligo Bridge	Drill hole on south side of Youngs Bend road, 0.8 mile west of Youngs Bend Cemetery and 0.6 mile east of New View School. Elevation of collar, 1,009 feet; depth to top of Chattanooga shale, 186 feet.

Table 26.—Locations of outcrop localities and drill holes shown on maps accompanying this report—Continued

C11	DeKalb	Tenn.	Sligo Bridge	Drill hole 0.7 mile northeast of locality C10, on west side of road leading northward from Youngs Bend road toward Fall Creek embayment of Center Hill Reservoir. Elevation of collar, 974 feet; depth to top of Chattanooga shale, 194 feet.
C12	DeKalb	Tenn.	Sligo Bridge	Drill hole 0.7 mile northeast of locality C11, and 2.0 airline miles almost due south of west end of Sligo Bridge. Elevation of collar, 970 feet; depth to top of Chattanooga shale, 187 feet.
C13	DeKalb	Tenn.	Sligo Bridge	Drill hole 0.5 mile north-northeast of Youngs Bend road at New View School. Elevation of collar, 994 feet; depth to top of Chattanooga shale, 154 feet.

Table 26.—Locations of outcrop localities and drill holes shown on maps accompanying this report—Continued

C14	DeKalb	Tenn.	Smithville	Drill hole on north side of Youngs Bend road 0.15 mile west of its junction with unimproved road leading south near New View School. Elevation of collar, 1,015 feet; depth to top of Chattanooga shale, 157 feet.
C15	DeKalb	Tenn.	Smithville	Drill hole 0.9 mile south of Youngs Bend road, at end of unimproved road leading south from near New View School; 0.15 mile north of Pine Creek and at eastern edge of Smithville quadrangle. Elevation of collar, 963 feet; depth to top of Chattanooga shale, 146 feet.

Table 26.—Locations of outcrop localities and drill holes shown on maps accompanying this report—Continued

C16	DeKalb	Tenn.	Smithville	Drill hole 0.4 mile northwest of locality 89 on Pine Creek and 0.15 mile east of road connecting Youngs Bend road on the north and Jefferson Road on the south. Elevation of collar, 1,006 feet; depth to top of Chattanooga shale, 147 feet.
C17	DeKalb	Tenn.	Smithville	Drill hole on north side of Irvins Mill road, 3.5 airline miles east-southeast of highway junction at Smithville; 0.6 mile northwest of locality C14. Elevation of collar, 1,007 feet; depth to top of Chattanooga shale, 136 feet.

Table 25.—Locations of outcrop localities and drill holes shown on maps accompanying this report—Continued

C18	DeKalb	Tenn.	Smithville	Drill hole on northeast side of road connecting Youngs Bend and Jefferson roads, 0.3 mile southeast of its junction with Youngs Bend road; 0.6 mile northwest of locality C16. Elevation of collar, 1,026 feet; depth to top of Chattanooga shale, 206 feet.
C19	DeKalb	Tenn.	Smithville	Drill hole on west side of Students Home road, about 1 mile north of where road crosses Pine Creek; 0.6 mile southwest of locality C18. Elevation of collar, 1,019 feet; depth to top of Chattanooga shale, 152 feet.

Table 26.—Locations of outcrop localities and drill holes shown on maps accompanying this report—Continued

C20	DeKalb	Tenn.	Smithville	From highway junction at Smithville, 2.1 miles south on Tennessee Route 56, then 1.3 miles east and southeast on road leading to Students Home road; drill hole on south side of road; Elevation of collar, 1,025 feet; depth to top of Chattanooga shale, 157 feet.
C21	DeKalb	Tenn.	Smithville	From highway junction at Smithville 1.6 miles east on Tennessee Route 26, then southeast and south 1.9 miles on Evins Mill road; drill hole on southwest side of road. Elevation of collar, 967 feet; depth to top of Chattanooga shale, 128 feet.

Table 35.--Locations of outcrop localities and drill holes shown on maps accompanying this report--Continued

C22	DeKalb	Tenn.	Smithville	From highway junction at Smithville, 1.5 miles south on Tennessee Route 56, then 2.2 miles east and south on road leading to Students Home road; drill hole on south side of road. Elevation of collar, 1,012 feet; depth to top of Chattanooga shale, 190 feet.
C23	DeKalb	Tenn.	Smithville	Drill hole in field 1 mile east of junction of Tennessee Route 56 with Bart Wright Wood road, which is 1.5 miles south of highway junction at Smithville; hole is north and east of road connecting Tennessee Route 56 with Students Home road. Elevation of collar, 1,031 feet; depth to top of Chattanooga shale, 145 feet.

Table 26.—Locations of outcrop localities and drill holes shown on maps accompanying this report—Continued

C24	DeKalb	Tenn.	Smithville	Drill hole 1.5 miles south of highway junction at Smithville, in southeast corner of intersection of Tennessee Route 56 with road leading to Students Home road. Elevation of collar, 1,041 feet; depth to top of Chattanooga shale, 166 feet.
C25	DeKalb	Tenn.	Smithville	Drill hole on southeast side of Short Mountain road, about 0.6 mile southwest of its junction with Jacobs Pillar road; hole is about 2.3 airline miles southwest of highway junction at Smithville. Elevation of collar, 1,071 feet; depth to top of Chattanooga shale, 128 feet.

Table 13.—Locations of outcrop localities and drillholes shown on maps accompanying this report—Continued

C26	DeKalb	Tenn.	Smithville	Drill hole on east side of Game Ridge road, 1 mile almost due west of locality C25. Elevation of collar, 1,074 feet; depth to top of Chattanooga shale, 151 feet.
C27	DeKalb	Tenn.	Gassaway	Drill hole 1 mile almost due west of locality C26, on west side of road connecting old Tennessee Route 26 near Martins Chapel and Short Mountain road at New Home Church. Elevation of collar, 1,081 feet; depth to top of Chattanooga shale, 161 feet.
C28	DeKalb	Tenn.	Gassaway	Drill hole on east side of road on ridge between Bluhatown Creek and Dry Creek, about 2 miles north of its junction with Short Mountain road just north of Pisgah Church and Cemetery. Elevation of collar, 1,093 feet; depth to top of Chattanooga shale, 144 feet.

Table 15.—Locations of outcrop localities and drill holes shown on maps accompanying this report—Continued

C29	DeKalb	Tenn.	Gassaway	Drill hole 1.1 miles south of locality C27 near eastern edge of Gassaway quadrangle, 0.5 mile northwest of junction of Short Mountain road and county road at New Home Church. Elevation of collar, 1,078 feet; depth to top of Chattanooga shale, 197 feet.
C30	DeKalb	Tenn.	Smithville	Drill hole on northwest side of Short Mountain road, 1.5 miles southwest of locality C25. Elevation of collar, 1,067 feet; depth to top of Chattanooga shale, 139 feet.
C31	DeKalb	Tenn.	Smithville	Drill hole on east side of Jacobs Pillar road 1.2 miles south of its junction with Short Mountain road; 1.4 miles almost due east of locality C30. Elevation of collar, 1,039 feet; depth to top of Chattanooga shale, 178 feet.

Table 5.--Locations of outcrop localities and drill holes shown on maps accompanying this report--Continued

C32	DeKalb	Tenn.	Smithville	Drill hole on west side of Tennessee Route 56, 2.8 road miles south of highway junction at Smithville, south of intersection of highway with side road. Elevation of collar, 967 feet; depth to top of Chattanooga shale, 107 feet.
C33	DeKalb	Tenn.	Gassaway	On Pea Ridge, between Clear Creek and Dry Creek; drill hole on south side of road leading to Dry Creek, about 1.1 miles northeast of Pea Ridge School. Elevation of collar, 1,123 feet; depth to top of Chattanooga shale, 133 feet.
C34	DeKalb	Tenn.	Gassaway	Drill hole in eastern corner of the road intersection at Pea Ridge School on Pea Ridge, about 3 road miles east of Gassaway. Elevation of collar, 1,140 feet; depth to top of Chattanooga shale, 152 feet.

Table 1.--Locations of outcrop localities and drill holes shown on maps accompanying this report--Continued

C35	DeKalb	Tenn.	Gassaway	Drill hole on west side of Pea Ridge road, about 1 road mile south of Pea Ridge School. Elevation of collar, 1,120 feet; depth to top of Chattanooga shale, 138 feet.
C36	DeKalb	Tenn.	Gassaway	Drill hole on east side of Pea Ridge road, about 0.1 mile north of Mt. Ararat Church and cemetery. Elevation of collar, 1,157 feet; depth to top of Chattanooga shale, 182 feet.
C37	White	Tenn.	Sligo Bridge	Drill hole in corner of school yard at Peeled Chestnut, a few feet east of White-DeKalb county line; depth to top of Chattanooga shale, 238 feet.

Table 13.—Locations of outcrop localities and drill holes shown on maps accompanying this report.—Continued

C38	DeKalb	Tenn.	Sligo Bridge	Drill hole at Indian Mound, south of road near Adcock Church and cemetery; south on Pinhook road from its intersection with Tennessee Route 26 at Shiloh Church about 3.8 miles, then west 1.2 miles to Indian Mound. Depth to top of Chattanooga shale, 262 feet.
C39	DeKalb	Tenn.	Smithville	Drill hole on north side of Tennessee Route 56 about 3.1 miles northeast of highway junction at Smithville and just west of road leading to radio towers. Depth to top of Chattanooga shale, 142 feet.
C40	DeKalb	Tenn.	Sligo Bridge	Drill hole at Keltonburg, in northeast corner of road intersection at church and cemetery. Depth to top of Chattanooga shale, 34 feet.

Table 26.—Locations of outcrop localities and drill holes shown on maps accompanying this report—Continued

C41	Cannon	Tenn.	Short Mountain	From Woodbury, 6.2 miles southeast on U. S. Highway 70 to Ionia road, and 0.6 mile southwest on Ionia road; drill hole on northeast bank of Porter Branch. Depth to top of Chattanooga shale, 128 feet.
C42	Warren	Tenn.	Centertown	Drill hole on north bank of Barren Fork 3.6 road miles south of Centertown on Trousdale road, and 0.6 mile north of Trousdale. Depth to top of Chattanooga shale, 124 feet.
C43	Coffee	Tenn.	Beech Grove	Drill hole on northwest side of road 0.1 mile southeast of road intersection at Hoodoo. Depth to top of Chattanooga shale, 88 feet.

Table 26.—Locations of outcrop localities and drill holes shown on maps accompanying this report—Continued

C44	Coffee	Tenn.	Manchester	Drill hole 2 airline miles west-northwest of courthouse at Manchester on bank of Brewer Creek; follow U. S. Highway 1.5 miles northeast from Manchester, turn left on unimproved road to creek. Depth to top of Chattanooga shale, 6 feet.
C45	Moore	Tenn.	Cumberland Springs	Drill hole on west side of road leading by Mt. Ethel Church to Tennessee Route 55, 0.5 mile north of dam at Cumberland Springs. Depth to top of Chattanooga shale, 9 feet.
C46	Warren	Tenn.	Cardwell Mountain	Drill hole on east side of North Shellsford road, 0.5 mile north of Shellsford on north bank of Collins River. Depth to top of Chattanooga shale, 186 feet.

Table 3.—Locations of outcrop localities and drill holes shown on maps accompanying this report—Continued

C47	Marion	Tenn.	Ketner Gap	Drill hole in east wall of Sequatchie Valley near Tennessee Route 27, about 1 airline mile south of Kelly Chapel, on jeep road leading southwest to the valley from hairpin turn in the highway. Depth to top of Chattanooga shale, 294 feet.
C48	Sequatchie	Tenn.	Dean	Drill hole about 5 miles south of Tennessee Route 8 on an abandoned road that descends to the valley from the highway at a point about a quarter of a mile south of a limestone quarry and mine. Depth to top of Chattanooga shale, 135 feet.

Table 26.--Locations of outcrop localities and drill holes shown on maps accompanying this report--Continued

C49	Bledsoe	Tenn.	Pikeville	Drill hole about 2 miles southeast of Pikeville and about 1,200 feet south of prominent north bend in Tennessee Route 30, along dirt road on south side of a stream. Depth to top of Chattanooga shale, 110 feet.
C50	Cumberland	Tenn.	Grassy Cove	Drill hole in lowest part of sink known as Grassy Cove, about 10 airline miles southeast of Crossville, about 900 feet north of road intersection at Grassy Cove community, and about 300 feet west of Tennessee Route 68. Depth to top of Chattanooga shale, 139 feet.

Table 25.—Locations of outcrop localities and drill holes shown on maps accompanying this report—Continued

051	Jackson	Tenn.	Cookeville West	From junction of Tennessee Route 56 with old Gainsboro road 10.3 miles south of Gainsboro, southeast on old Gainsboro road 0.9 mile, then east-northeast on road leading to Cummins Mill; drill hole on south side of road west of Blackburn Fork and about 0.2 mile southwest of Cummins Mill; depth to top of Chattanooga shale, 38 feet.
052	Putnam	Tenn.	Baxter	Southeast from its junction with Tennessee Route 56 in Baxter, 1.5 miles on road to east side of Maxwell Branch, then south 0.6 mile on unimproved road; drill hole on west side of road near cemetery on east side. Depth to top of Chattanooga shale, 147 feet.

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Table 7.—Locations of outcrop localities and drill holes shown on maps accompanying this report—Continued

C53	Davidson	Tenn.	Belleview	Drill hole on west side of Buffalo Road 1.6 miles north of its junction with U. S. Highway 70, northeast of junction with unimproved road leading northeast. Depth to top of Chattanooga shale, 51 feet.
C54	Davidson	Tenn.	Forest Grove	From Germantown, 1.3 miles southeast on U. S. Highway 41A, then west on unimproved road in valley of Caney Creek 1.3 miles; drill hole on north side of road. Depth to top of Chattanooga shale, 15 feet.
C55	Sumner	Tenn.	White House	Drill hole on north side of road leading east, 0.3 mile east of railroad crossing at Bakers Station. Depth to top of Chattanooga shale, 17 feet.

Table 26.—Locations of outcrop localities and drill holes shown on maps accompanying this report—Continued

056	Sumner	Tenn.	Cottontown	From Long Hollow Pike 1.5 miles west of where it crosses Camp Creek, 0.3 mile northeast along unimproved road, then 0.6 mile north, then 0.2 mile west; drill hole on south side of road. Depth to top of Chattanooga shale, 14 feet.
057	Sumner	Tenn.	Gallatin	From junction of South Tunnel road with Tennessee Route 109, 0.9 mile southwest of South Tunnel; west on road up valley of Station Camp Creek 0.3 mile; drill hole on north side of road. Depth to top of Chattanooga shale, 58 feet.
058	Sumner	Tenn.	Hartsville	Near southeast corner of Sumner County; 0.3 mile west-southwest of Wolf Hill; drill hole on unimproved road at intersection. Depth to top of Chattanooga shale, 52 feet.

Table 25.—Locations of outcrop localities and drill holes shown on maps accompanying this report—Continued

C59	Macon	Tenn.	Carthage	From Lafayette, 2.1 miles east on Tennessee Route 52, then south on road down Dark Hollow about 1.0 road mile; drill hole on west side of road. Depth to top of Chattanooga shale, 34 feet.
C60	Macon	Tenn.	Carthage	About 1.6 road miles east of road junction at Willette on Jennings Creek road; drill hole on north side of road. Elevation to top of Chattanooga shale, 59 feet.
C61	Macon	Tenn.	Red Boiling Springs	About 6 airline miles west-northwest of Red Boiling Springs and 0.7 mile southwest of Bugtussel on Tennessee-Kentucky state line; drill hole 0.1 mile southwest of Corinth School on west side of Lick Creek Road. Depth to top of Chattanooga shale, 73 feet.

Table 26.—Locations of outcrop localities and drill holes shown on maps accompanying this report—Continued

C62	Sumner	Tenn.	Cottontown	Drill hole on west side of unimproved road opposite Mt. Olive Church and Cemetery. Depth to top of Chattanooga shale, 68 feet.
C63	Sumner	Tenn.	Cottontown	Drill hole 0.5 mile west-northwest of locality C56 and 0.5 mile south-southeast of locality C62, on east side of road near junction. Depth to top of Chattanooga shale, 29 feet.
C64	Blount	Ala.	Brooksville	From Brooksville, 1.3 miles west on Alabama Route 74; at intersection turn east-southeast on dirt road 0.5 mile; drill hole on north side of road. Depth to top of Chattanooga shale, 87 feet.

Table 5.—Locations of outcrop localities and drill holes shown on maps accompanying this report—Continued

C65	Blount	Ala.	(no map)	From Blountsville, 2.3 miles northeast on Alabama Route 38, then 1.4 miles east-southeast on dirt road; drill hole about 500 feet north of road intersection. Depth to top of Chattanooga shale, 23 feet.
C66	Blount	Ala.	(no map)	From Blountsville 3.1 miles west-southwest on Alabama Route 38, then about 0.5 mile southeast on dirt road; drill hole on south side of road. Depth to top of Chattanooga shale, 79 feet.
C67	DeKalb	Tenn.	Sligo Bridge	Drill hole 0.6 mile southwest of locality C9. Depth to top of Chattanooga shale, 178 feet.
C68	DeKalb	Tenn.	Sligo Bridge	Drill hole 0.25 mile northeast of locality C67. Depth to top of Chattanooga shale, 168 feet.

Table 25.—Locations of outcrop localities and drill holes shown on maps accompanying this report—Continued

C69	DeKalb	Tenn.	Sligo Bridge	Drill hole 0.25 mile southwest of locality 68 and 0.5 mile southeast of locality C15. Depth to top of Chattanooga shale, 150 feet.
C77	DeKalb	Tenn.	Sligo Bridge	Drill hole on ridge between old Tennessee Route 26 and present Tennessee Route 26, about 0.3 mile north of locality 79 and 0.3 mile east of east end of Sligo Bridge. Depth to top of Chattanooga shale, 141 feet.
C93	DeKalb	Tenn.	Smithville	Drill hole on west side of Tennessee Route 56, 725 feet south of road intersection at Shining Rock and 3.7 miles south of courthouse at Smithville. Depth to top of Chattanooga shale, 139 feet.

Table 26.—Locations of outcrop localities and drill holes shown on maps accompanying this report—Continued

C94	DeKalb	Tenn.	Smithville	Drill hole in road fork about 450 feet south of Central Branch and 1 mile east of Tennessee Route 56; about 2.5 miles southeast of locality C93. Depth to top of Chattanooga shale, 136 feet.
C211	White	Tenn.	Lonewood	70 feet east of Caney Fork River and 75 feet north of road at Dodson's store, near western edge of Lonewood quadrangle. Depth to top of Chattanooga shale, 360 feet.
C212	Grundy	Tenn.	Tracy City	Magnolia Petroleum Co. Patterson no. 1 well, 650 feet northwest of road intersection at Greutli. Elevation of collar 1,880 feet; depth to top of Chattanooga shale, 1,455 feet.

Table 26.—Locations of outcrop localities and drill holes shown on maps accompanying this report — Continued.

C301	Logan	Ky.	Dot	Drill hole on Tom Brown property, 8 miles south of Russellville; from Russellville south on Kentucky Route 86, then west on unimproved road 0.4 mile; hole on south side of road. Depth to top of Chattanooga shale, 812 feet.
C302	Simpson	Ky.	Franklin	Drill hole 2 airline miles northeast ofcourthouse at Franklin; in southwest corner of road form on Jesse Stewart property, about 0.4 mile west of the West Fork of Drakes Creek.

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The precision of the determination of uranium in Chattanooga shale

By Irving May

Tables

Introduction

From the beginning of the Chattanooga shale program in 1947, the laboratories of the Geological Survey searched constantly for new methods or modifications of old methods for determining small amounts of uranium in shale. Investigations showed that the carbonate separation method was remarkably efficient and, in conjunction with the fluorimetric estimation of uranium, provided a simple method for determining small amounts of uranium in shales, lignites, and monazites. The method, described by Guttag and Grimaldi (1954), consists of igniting the shale and decomposing the ash with sulfuric and hydrofluoric acids. An aliquot of the sample is then mixed with a sodium and potassium carbonate solution and centrifuged. A portion of the clear solution is evaporated in a platinum dish and fused with a flux (9 parts by weight NaF and 45.5 parts each of Na_2CO_3 and K_2CO_3). The uranium is then determined fluorimetrically.

Until the beginning of the Bureau of Mines drilling program in the Chattanooga shale in 1953, determinations of the uranium in the shale were made with a precision of 10 ppm. Following a request that samples from the drilling be analyzed with a precision of 5 ppm, the Survey made an extensive study directed toward determining:

1. The precision to be expected in the determination of uranium in shales by the fluorimetric method.

2. Any systematic differences in the results obtained by different chemists.

3. Whether any inhomogeneity is introduced in the grinding and splitting of samples.

As a control measure, a standard shale sample was included with each batch of samples analyzed for the program. Because this control sample would be analyzed a large number of times, the work was so planned that without additional analytical effort valuable information regarding the precision of the analytical method and the adequacy of the sample grinding and splitting techniques could be obtained.

Nature of the control sample.—As the Chattanooga shale is rather homogeneous, grinding and splitting operations were not considered likely to result in inhomogeneity due to segregation. Nevertheless it was desirable to check the possibility of segregation occurring during grinding and splitting operations. The shale control sample was prepared from a large sample of three-inch drill core of the upper unit of the Gassaway member by crushing to 40 mesh in a jaw crusher. Five portions, referred to hereafter as splits 1 through 5, were separated from this crushed sample with a Jones splitter. Each of these splits was then finely ground in a hammer mill and portions of about 100 grams (the "A" samples) removed by quartering. The "B" samples were the remainder of each finely ground sample after removal of the "A" sample.

In the procedure usually followed for grinding samples, only split "1" would be finely ground (the remainder of the coarse material would be stored) and the "A" portion of finely ground split "1" would be submitted to the chemical laboratory.

The ten splits of the standard sample are referred to as control samples and designated as follows:

Table 1.—Designation of control samples

	Jones split				
	1	2	3	4	5
Sub-split A	a	b	c	d	e
Sub-split B	f	g	h	i	j

Chemical procedure.—The uranium content of each sample solution was determined in quadruplicate as follows: an analyst dissolved one charge of sample and then took two aliquots of the sample solution for the carbonate separation step. One melt was prepared from each of these aliquots and the fluorescence measured. The remaining sample solution was transferred to another analyst for check determinations, who in turn took two aliquots for the carbonate separation, prepared a melt from each aliquot and measured the fluorescence of each. In general, one or more days elapsed between the initial and check determinations on the same sample solution. Both the initial and checking analysts regularly prepared their own standard fluorescent melts for calibrating the instruments. Two reflection-type fluorimeters were used; these were modifications of the fluorimeter previously described (Fletcher and May, 1954) and had as a light detector a 1P21 photomultiplier tube whose output was measured with an electronic microammeter.

Assignment plan for control samples.—A pair of control samples was analyzed with every group of about 20 shale samples. The design for analyzing the control samples is summarized in table 2. The controls were assigned in 50 paired combinations designated by arabic numerals. As the members of any one pair were never separated during analysis, the treatment received by each was as uniform as possible. Therefore, during the course of the study ten separate solutions, two by each analyst, were prepared from each of the ten control samples and forty fluorimetric measurements were obtained for each sample.

Table 2.—Outline of assignment plan

Initial analyst		Checking analyst				
		I	II	III	IV	V
	I	a (1) b	d (11) h	j (21) g	c (31) f	f (41) a
		b (6) c	h (16) j	g (26) i	i (36) e	e (46) d
	II	d (2) c	g (12) e	f (22) h	b (32) i	i (42) d
		a (7) j	e (17) b	j (27) f	h (37) a	c (47) g
	III	f (3) e	b (13) j	i (23) c	g (33) a	c (43) h
		e (8) d	a (18) i	h (28) b	d (38) g	j (48) f
	IV	i (4) j	a (14) c	b (24) d	e (34) h	j (44) e
		g (9) f	c (19) g	d (29) a	f (39) b	h (49) i
	V	g (5) h	i (15) f	e (25) a	d (35) j	b (45) g
		h (10) i	f (20) d	c (30) e	j (40) c	a (50) b

The five analysts are indicated by Roman numerals in table 2. In some cases, the initial and checking analysts were the same person (the diagonal running from pairs 1,6 to 45,50) but in the tables below, check values are treated with those of the checking analysts.

Analytical results.—The uranium values in parts per million for the ten splits are given in table 3. The sample pairs and assignments are shown in a similar manner as in table 2. The values obtained for each of the two fluorimetric measurements by the analyst who prepared the sample solutions are given to the left of the sample designations (a through j) and the two obtained by the analyst checking the solutions are shown italicized to the right. Thus, analyst V analyzed two pairs (5,10), table 2, of control samples g,h and h,i, the solutions of which were then transferred to analyst I. In the case of sample g, analyst V obtained the values of 74 ppm U and 76 ppm U on two aliquots of the solution (table 3); analyst I obtained values of 80 ppm U and 83 ppm U on two other aliquots of the same solution.

The average results obtained for the ten splits in those determinations which were made by the initial analysts are tabulated in table 4. A similar tabulation for the check determinations (italics in table 3) is given in table 5.

Table 3.—Analytical results in parts per million

Initial analyst		Checking analyst I	II	III	IV	V
	I	77,81 a 77,80	77.79 d 80,86	83,84 j 77,77	74,73 c 80,80	76,80 f 72,74
		81,80 b 77,80	79.75 h 82,85	84,84 g 87,82	73.77 f 79,80	73,74 a 75,74
		74,79 b 76,75	80,76 h 77,75	70,76 g 75,77	73,76 i 80,80	73,78 e 78,75
		80,75 c 77,78	63,68 j 81,81	78,69 i 77,75	68,72 e 78,82	70;71 d 76,81
	II	77,78 d 80,82	71,75 g 72,70	83,81 f 78,74	80,80 b 79,79	84,82 i 68,69
		75,70 c 85,84	72,73 e 70,70	75,80 h 74,75	78,87 i 81,81	81,77 d 70,69
		76,76 a 78,83	75,87 e 81,77	77,77 j 71,76	82,76 h 79,80	84,73 c 75,73
		76,76 j 81,84	82,81 b 84,81	77,77 f 74,74	76,81 a 81,80	54,48 g 80,73
	III	76,73 f 87,83	79,78 b 77,80	83,88 i 75,75	76,83 g 83,83	79,75 c 79,79
		80,80 e 81,80	83,83 j 76,85	78,88 c 73,75	81,79 a 84,84	83,74 h 70,71
		73,76 e 80,80	78,78 a 84,83	78,78 h 76,76	80,78 d 78,80	79,79 j 82,81
		79,79 d 78,81	76,76 i 83,81	85,78 b 75,82	86,84 g 80,82	78,77 f 80,82

Table 3.—Analytical results in parts per million—Continued

	IV	82,82 i 83,82	82,82 a 79,78	82,82 b 75,77	83,83 e 83,84	83,82 j 82,80
		83,83 j 81,77	78,80 c 78,84	78,78 d 78,76	82,83 h 83,83	82,82 e 80,78
		85,83 g 86,88	83,85 c 75,75	85,85 d 83,79	79,81 f 80,79	82,82 h 78,80
		83,85 f 87,85	85,85 g 77,77	83,81 a 80,76	78,79 b 79,79	83,82 i 82,84
	V	74,76 g 80,83	73,74 i 78,78	79,81 e 73,73	69,69 d 87,87	75,76 b 74,75
		76,74 h 85,82	72,74 f 70,75	85,83 a 72,76	70,70 j 87,87	77,74 g 75,73
		75,73 h 81,84	85,86 f 79,78	80,77 c 76,73	65,66 j 85,85	75,75 a 75,75
		74,78 i 80,76	80,82 d 72,74	83,82 e 73,77	70,69 c 83,81	74,75 b 75,75

Table 4.--Average uranium content by initial analysts (ppm)

	Jones split					Average
	1	2	3	4	5	
Sub-split A	a 78.8	b 78.9	c 77.3	d 77.6	e 78.1	78.14
Sub-split B	f 78.6	g 76.5	h 78.2	i 78.9	j 76.5	77.74
Average	78.7	77.7	77.7	78.2	77.3	77.94

Table 5.--Average uranium content by checking analysts (ppm)

	Jones split					Average
	1	2	3	4	5	
Sub-split A	a 78.7	b 77.7	c 78.2	d 78.9	e 77.6	78.22
Sub-split B	f 78.5	g 79.2	h 78.8	i 78.4	j 80.8	79.14
Average	78.6	78.4	78.5	78.6	79.2	78.68

The results grouped by analysts are given in table 6. Determinations made by the initial analysts are given in the first row and determinations of the checking analysts in the second row.

Table 7 presents values, grouped by analysts, for the average difference between measurements on duplicate aliquots of each of the forty solutions run by each analyst. The first row gives the average differences for the initial analysts, the second row gives the differences for the check analysts.

The standard deviations of a single fluorimetric measurement calculated for each of the analysts are given in table 8.

Each of the ten control samples was analyzed twice and at different times by each of the analysts. Table 9 summarizes the data for the average differences between such values. In calculating this data, the value for each determination was obtained by averaging the duplicate fluorimetric measurements made on pairs of aliquots of each of the solutions.

In arriving at a uranium value for each of the samples analyzed, the arithmetic mean of the four fluorimetric determinations for each sample was used. A realistic measure of precision therefore is obtainable by calculating these means for each of the 100 decompositions made of the ten control samples, and then calculating the standard deviations. These standard deviations are given in table 10. Although tabulated by initial analysts, it is understood that almost half of the measurements entering into the means were made by analysts other than those at the head of the columns.

Table 6.—Results grouped by analysts (ppm)

	Analyst					
	I	II	III	IV	V	All
As initial analyst	75.8	76.8	79.4	82.2	75.6	77.94
As checking analyst	81.2	78.2	76.2	81.6	76.2	78.65

Table 7.—Average difference between analyses of duplicate aliquots (ppm)

	Analyst					
	I	II	III	IV	V	Average
Initial duplicate determinations	3.5	3.7	2.8	0.8	1.6	2.48
Check duplicate determinations	2.6	2.5	2.6	.8	1.9	2.08
Average of all	3.0	3.1	2.7	0.8	1.7	2.26

Table 8.—Standard deviations by analysts of a single fluorimetric measurement (ppm)

	Analyst					
	I	II	III	IV	V	All
Initial determinations	4.83	7.22	3.67	2.03	5.17	5.45
Check determinations	3.30	4.47	3.16	2.63	4.20	4.18
Both	4.91	6.01	3.76	2.35	4.69	4.91

Table 9.—Average differences between two determinations on the same sample analyzed at different times by the same analyst (ppm)

	Analyst					
	I	II	III	IV	V	Average
Difference by initial analyst	6.0	5.0	3.9	2.3	5.4	4.52
Difference by checking analyst	3.0	5.9	3.0	2.6	5.2	3.94
Average of both	4.5	5.5	3.5	2.4	5.3	4.23

Table 10.—Standard deviations of arithmetic means by analysts (ppm)

	Initial analyst					
	I	II	III	IV	V	All
Standard deviation	2.76	4.23	1.95	2.06	2.13	3.22

Discussion

Averaging all the determinations, the uranium content of the control samples is 78.3 ppm with a standard deviation for a single fluorimetric measurement of 4.9 ppm.

The differences in the average uranium contents of the five Jones splits and the "A" and "B" sub-splits (tables 4 and 5) are well within the errors of the determination. There is therefore no indication of any inhomogeneity being introduced by the grinding and splitting steps.

The results demonstrate that there are systematic differences between analysts. The uranium values summarized in table 6 show differences in the averages which exceed the error of an analysis and show that analysts may run high or low consistently.

Analysts may also differ in the reproducibility of their determinations. As can be seen from tables 7 through 9, analyst IV obtained consistently more reproducible results than the other four. His average difference between duplicates was about one-third those of the other analysts. Analyst IV also had the smallest differences between determinations on the same sample analyzed at different times (table 9), his difference being but one-half those of the other analysts.

In reporting analysis, we consider a determination as the average of the single fluorimetric measurements on each of the four replicate aliquots of the same solution. The standard deviation of 3.22 ppm (table 10) is the measure of the precision of such averaged results for the samples analyzed in the Chattanooga shale program. These results are reasonably within the requested precision of 5 ppm.

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Table 9:--Equivalent uranium and uranium analyses of Chattanooga shale

Unit designations:

Gassaway member:

Gup	Phosphatic zone at top of upper unit.
Gu	Upper unit, excluding phosphatic zone where present
Gm	Middle unit
Gl	Lower unit
Gzp	Phosphatic zone at top of undivided member
Gz	Undivided member, excluding phosphatic zone where present
G	Total member

Dowelltown member:

Du	Upper unit
Dl	Lower unit
Dz	Undivided member

n.s. Not sampled
n.a. Not analyzed

Sample			Analyses		
Field no.	Laboratory no.	Unit	Thickness, feet	eU, percent	U, percent
Locality 4 (Field no. 17R-6)					
/Samplers: R. C. Robeck, L. E. Shirley. Analysts (TWC-1535): Harry Levine, Norma Guttag, Alice Caemmerer (analyses to precision of ± .001 only). Oil yield analyses, table 19/					
1-3	17320-17322	Gzp	6.25	0.005	0.0026
4-19	17323-17338	Gz	32.50	.006	.0041
1-16 . . .	. . .	G	38.75	0.006	0.0038
Locality 12 (Field no. 16P-1)					
/Samplers: R. C. Robeck, L. E. Shirley. Analysts (WTC-1534): Harry Levine, Norma Guttag, Alice Caemmerer (analyses to precision of ± .001 only). Oil yield analyses, table 19/					
1-3	17291-17293	Gzp	6.00	0.005	0.0030
4-15	17294-17305	Gz	23.10	.007	.0052
1-15 . . .	. . .	G	29.10	0.007	0.0047
Locality 16 (Field no. 15N-12)					
/Samplers: J. R. Houston, J. C. Reed, Jr. Analysts (TWC-5485): R. Moore, W. P. Tucker, B. A. McCall. Chemical and oil yield analyses, tables 1, 19, 20. Spectrographic data, fig. 16/					
11a	2269	Gzp	3.00	n.a.	0.0028
11b-13 . . .	2270-2277	Gz	14.65	n.a.	.0056
11a-13 . .	. . .	G	17.65	n.a.	0.0053
21	2278	Dz	1.18	n.a.	0.0021

Table 9.-- Equivalent uranium and uranium analyses of Chattanooga shale - continued.

Sample			Analyses		
Field no.	Laboratory no.	Unit	Thickness, feet	eU, percent	U, percent
		Locality 22 (Field no. 14L-5)			
[Samplers: J. R. Houston, J. C. Reed, Jr. Analysts (TWC-1486, 5548): R. Moore, W. P. Tucker, B. A. McCall. Oil yield analyses, table 20. Spectrographic data, fig. 16]					
11a-11b . .	2191-2192	Gzp	4.00	0.004	0.0030
11c-13. . .	2193-2197	Gz	9.23	.008	.0060
11a-13 .	. . .	G	13.23	0.007	0.0051
21-23 . . .	. . .	Dz	5.41	n.a.	n.a.
		Locality 25 (Field no. 14M-6)			
[Samplers: J. R. Houston, J. C. Reed, Jr. Analysts (TWC-5530): R. Moore, W. P. Tucker, B. A. McCall.]					
11-12 . . .	2201-2202	Gzp	4.18	0.005	0.0039
13-16 . . .	2203-2206	Gz	8.44	.008	.0050
11-16 . .	. . .	G	12.62	0.007	0.0046
22-23 . . .	. . .	Dz	4.34	n.a.	n.a.
		Locality 27 (Field no. 14M-16)			
[Samplers: J. R. Houston, J. C. Reed, Jr. Analysts (TWC-2887): Joseph Budinsky, Carmen Hoy, W. P. Tucker, B. A. McCall]					
11a-11b . .	3353-3354	Gzp	3.85	0.005	0.0037
12-22 . . .	3355-3361	Gz	13.97	.007	.0048
11a-22. .	. . .	G	17.82	0.006	0.0046
23-24 . . .	3362.-3363	Dz	4.00	0.005	0.0018
		Locality 29 (Field no. 14M-9)			
[Samplers: J. R. Houston, J. C. Reed, Jr. Analysts (TWC-2887): Joseph Budinsky, Carmen Hoy, W. P. Tucker, B. A. McCall.]					
11a-11b . .	2219-2220	Gup	3.91	0.005	0.0021
11c-12. . .	2221-2223	Gu	5.85	.008	.0053
13	2224	Gm	1.95	.007	.0038
14-15 . . .	2225-2226	Gl	3.90	.006	.0035
11a-15	. . .	G	15.61	0.005	0.0038
21-23 . . .	2227-2229	Dz	4.90	0.004	0.0010
		Locality 31 (Field no. 14N-3)			
[Samplers: J. R. Houston, J. C. Reed, Jr. Analysts (TWC-2637): Audrey Pietsch, Mary Joslyn, Joan Smith, B. A. McCall]					
11-12 . . .	2246-2247	Gup	4.00	0.004	0.0023
13-16 . . .	2248-2251	Gu	7.83	.007	.0045
21-22 . . .	2252-2253	Gm	3.14	.007	.0044
31-32 . . .	2254-2255	Gl	3.66	.006	.0045
11-32 . .	. . .	G	18.63	0.005	0.0042
41	. . .	Dm	1.38	n.a.	n.a.
51-53 . . .	2256-2258	Dl	4.90	0.004	0.0016

Table 9.—Equivalent uranium and uranium analyses of Chattanooga shale - continued.

Sample			Analyses		
Field no.	Laboratory no.	Unit	Thickness, feet	eU, percent	U, percent
Locality 34 (Field no. 14M-14)					
[Samplers: J. R. Houston, J. C. Reed, Jr. Analysts (TWC-2887): Joseph Budinsky, Carmen Hoy, W. P. Tucker, B. A. McCall]					
11a-11b . . .	3327-3328	Gup	4.48	0.005	0.0034
12-17	3329-3334	Gu	11.23	.008	.0064
18	3335	Gm	1.66	.006	.0042
19-20	3336-3337	Gl	3.34	.006	.0044
11a-20 . .	. . .	G	20.71	0.007	0.0052
21,31-32 . .	3338-3341	Dz	6.92	0.004	0.0013
Locality 39 (Field no. 14M-8)					
[Sampler: J. R. Houston. Analysts (TWC-2887): Joseph Budinsky, Carmen Hoy, W. P. Tucker, B. A. McCall.]					
11a-11b. . .	3308-3309	Gup	3.01	0.005	0.0022
12-15. . . .	3310-3313	Gu	7.80	.008	.0054
16	3314	Gm	2.00	.006	.0036
17	3315	Gl	1.97	.006	.0040
11a-17 . .	. . .	G	14.78	0.006	0.0044
21-23. . . .	3316-3318	Dz	5.50	0.003	0.0016
Locality 43 (Field no. 14M-15)					
[Sampler: J. R. Houston. Analysts (TWC-2887): Joseph Budinsky, Carmen Hoy, W. P. Tucker, B. A. McCall]					
11-12 . . .	3342-3343	Gup	3.14	0.005	0.0025
13-16 . . .	3344-3347	Gu	8.00	.007	.0044
21-22 . . .	3348-3349	Gm	2.60	.006	.0025
31	3350	Gl	2.24	.006	.0038
11-31 . .	. . .	G	15.98	0.006	0.0037
41	. . .	Du	2.77	n.a.	n.a.
51-52 . . .	3351-3352	Dl	4.05	0.005	0.0033
Locality 54 (Field no. 14M-2)					
[Samplers: J. R. Houston, J. C. Reed, Jr. Analysts (TWC-2887): Joseph Budinsky, Carmen Hoy, W. P. Tucker, B. A. McCall]					
11a-11b . . .	3296-3297	Gup	3.00	0.004	0.0025
12-15	3298-3301	Gu	7.78	.007	.0052
21-22	3302-3303	Gm	4.53	.007	.0051
31	3304	Gl	1.93	.006	.0038
11a-31 . .	. . .	G	17.34	0.006	0.0046
41	. . .	Du	3.29	n.a.	n.a.
51-53	3305-3307	Dl	4.94	0.004	0.0009

Table 9:--Equivalent uranium and uranium analyses of Chattanooga shale - continued.

Sample			Analyses		
Field no.	Laboratory no.	Unit	Thickness, feet	eU, percent	U, percent
		Locality 59 (Field no. 13M-24)			
[Samples: V. E. Swanson. Analysts (TWC-1640): Alice Caemmerer, B. A. McCall (analyses to precision of ± .001 only).					
111-112 . . .	101782-101783	Gup	2.00	0.005	0.0045
113-120 . . .	101784-101791	Gu	7.98	.008	.0072
121-123 . . .	101792-101794	Gm	2.70	.005	.0038
131-133 . . .	101795-101797	Gl	3.25	.006	.0047
111-133 . .	. . .	G	15.93.	0.007	0.0058
41-42	. . .	Du	4.38	n.a.	n.a.
51-52	. . .	Dl	4.24	n.a.	n.a.
		Locality 60 (Field no. 13L-22)			
[Samplers: R. E. Smith, Edward Berry, Charles Katlin, Lee Willman. Analysts:(TWC-6336): Joseph Budinsky, B. A. McCall. Oil yield analyses in table 20]					
11a-11b . . .	2026-2027	Gup	2.84	0.005	0.0026
11c-15 . . .	2028-2032	Gu	9.03	0.008	.0054
21-22	2033-2034	Gm	3.02	.006	.0033
31	2035	Gl	2.00	.006	.0042
11a-31 . .	. . .	G	16.79	0.007	0.0040
41-43	. . .	Du	5.29	n.a.	n.a.
51-53	2039-2041	Dl	6.03	0.004	0.0021
		Locality 64 (Field no. 13M-7)			
[Samplers: J. E. Johnston, J. C. Reed, Jr., Charles Katlin. Analysts (TWC-2808): Mary Joslyn, Joseph Budinsky, W. P. Tucker, B. A. McCall. Oil yield analyses, table 20.]					
11	2042	Gup	2.10	0.004	0.0022
12-16	2043-2047	Gu	8.87	.009	.0065
21-22	2048-2049	Gm	2.87	.006	.0037
31-33	2050-2052	Gl	5.75	.007	.0041
11-33 . . .	. . .	G	19.58	0.007	0.0053
41-43	. . .	Du	5.81	n.a.	n.a.
51-53	2053-2055	Dl	5.15	0.004	0.0015
		Locality 67 (Field no. 13L-13)			
[Samplers: J. E. Johnston, J. R. Houston. Analysts (TWC-5450): Roosevelt Moore, B. A. McCall.]					
12-14	2015-2017	Gu 1/	5.23	0.009	0.0066
21-22	2018-2019	Gm	2.96	.008	.0047
31-32	2020-2021	Gl	2.95	.008	.0064
12-32 . . .	. . .	G	11.14	0.008	0.0060
41-44	. . .	Du	7.57	n.a.	n.a.
51-53	. . .	Dl	5.40	n.a.	n.a.

1/ Top foot of sample 12 may be phosphatic zone, but was not separated in sampling.

Table 9--Equivalent-uranium and uranium analyses of Chattanooga shale - continued.

Sample			Analyses		
Field no.	Laboratory no.	Unit	Thickness, feet	eU, percent	U, percent
Locality 68 (Field no. 13M-32)					
[Sampler: V. E. Swanson. Analysts (TWC-2435), "Staff". (Analyses to precision of ± .001 only).]					
11-17	99837-99843	Gu	6.28	0.009	0.0073
21-23	99845-99846	Gm	3.00	.006	.0046
24-35	99847-99853	Gl	5.95	.007	.0055
11-35 . . .	. . .	G	15.23	0.007	0.0061
(Dowelltown member not measured nor sampled)					
Locality 70 (Field no. 13M-30)					
[Sampler: V. E. Swanson. Analyst (TWC-6335): Joseph Budinsky]					
11-21	99819-99825	Gu	7.10	n.a.	0.0080
22-23	99826-99827	Gm	1.98	n.a.	.0037
31-36	99828-99833	Gl	6.14	n.a.	.0060
11-36 . . .	. . .	G	15.22	n.a.	0.0066
(Dowelltown member notmeasured nor sampled).					
Locality 73 (Field no. 13M-1)					
[Samplers: Andrew Brown, Lee Willman, J. C. Reed, Jr., Analysts (TWC-2661): Mary Joslyn, Audrey Pietsch, B. A. McCall. Oil yield analyses, table 20.]					
11b	1944	Gup	1.98	0.005	0.0020
12-16	1945-1949	Gu	9.68	.008	.0049
21-22	1950-1951	Gm	2.84	.006	.0040
31-34	1952-1955	Gl	7.01	.006	.0050
11b-34. . .	. . .	G	21.51	0.007	0.0045
n.s.	. . .	Du	8.03	n.a.	n.a.
51-53	1956-1958	Dl	5.59	0.005	0.0025
Locality 74 (Field no. 13M-4)					
[Samplers: J. C. Reed, Jr., Lee Willman, EdwardBerry, L.E.Shirle Analysts (TWC-2661): Mary Joslyn, Audrey Pietsch, B. A. McCa					
11a-11b . . .	1959-1960	Gup	2.56	0.005	0.0023
12-15	1961-1964	Gu	7.38	.007	.0038
21-22	1965-1966	Gm	3.06	.005	.0024
31-34	1967-1970	Gl	8.42	.007	.0040
11a-34 . .	. . .	G	21.42	0.006	0.0035
n.s.	. . .	Du	9.29	n.a.	n.a.
51-54	1971-1974	Dl	5.71	0.005	0.0020
Locality 75 (Field no. LC-4)					
[Samplers: Andrew Brown, R. E. Smith. Analyst (TWC-5443): Roosevelt Moore.]					
12-16	12-16	Gu	7.69	n.a.	0.0070
21-22	17-18	Gm	2.87	n.a.	.0034
31-34	194-197	Gl	7.67	n.a.	.0062
12-34 . . .	. . .	G	18.23	n.a.	0.0062
41-47	. . .	Du	9.77	n.a.	n.a.
51-54	. . .	Dl	6.77	n.a.	n.a.

Table 9.--Equivalent uranium and uranium analyses of Chattanooga shale - continued.

Sample			Analyses		
Field no.	Laboratory no.	Unit	Thickness, feet	eU, percent	U, percent
Locality 83 (Field no. LC-50)					
[Samplers: Andrew Brown, R. E. Smith. Analysts (TWC-2570): Blanche Ingram, B. A. McCall]					
12-14	115-117	Gu	5.67	0.010	0.0078
21-22	118-119	Gm	2.57	.007	.0039
31-35	287-291	Gl	10.05	.008	.0054
12-35	. . .	G	18.29	0.008	0.0059
41-46	. . .	Du	10.76	n.a.	n.a.
51-54	. . .	Dl	7.05	n.a.	n.a.
Locality 86 (Field no. LC-8)					
[Samplers: R. E. Smith, W. A. Heck. Analysts (Twc-5451): Roosevelt Moore, Carmen Hoy, Mary Joslyn.]					
12-15	49-52	Gu	6.25	n.a.	0.0074
21-22	53-54	Gm	2.49	n.a.	.0042
31-35	213-217	Gl	8.70	n.a.	.0062
12-35 . . .	. . .	G	17.44	n.a.	0.0063
(Dowelltown member covered, not measured)					
Locality 89 (Field no. LC-30)					
[Samplers: Andrew Brown, R. C. Robeck, R. E. Smith. Analysts (TWC-2570): Blanche Ingram, B. A. McCall.]					
12-14	89-91	Gu	4.96	0.010	0.0058
21-22	92-93	Gm	2.50	.005	.0033
31-34	94-97	Gl	7.73	.008	.0047
12-34 . . .	. . .	G	15.19	0.008	0.0048
41-45	. . .	Du	9.27	n.a.	n.a.
51-52	. . .	Dl	3.51	n.a.	n.a.
Locality 91 (Field no. LC-17					
[Samplers: R. E. Smith, Andrew Brown. Analyst (TWC-5479): W. P. Tucker]					
12-15	81-85	Gu	7.00	n.a.	0.0058
21-22	85-86	Gm	2.36	n.a.	.0043
31-34	262-265	Gl	7.55	n.a.	.0058
12-34	. . .	G	16.91	n.a.	0.0056
41-46	. . .	Du	9.29	n.a.	n.a.
51-53	. . .	Dl	5.95	n.a.	n.a.
Locality 92 (Field no. LC-15)					
[Samplers: R. E. Smith. Andrew Brown. Analysts (TWC-2915): Carmen Hoy, Alice Caemmerer. Oil yield analyses, table 20]					
12-15	41-44	Gu	6.94	n.a.	0.0069
21	45	Gm	1.97	n.a.	.0036
31-33	253-255	Gl	6.18	n.a.	.0049
12-33	. . .	G	15.09	n.a.	0.0055
41-45	. . .	Du	8.98	n.a.	n.a.
51-53	. . .	Dl	6.10	n.a.	n.a.

Sample			Analyses		
Field no.	Laboratory no.	Unit	Thickness, feet	eU, percent	U, percent

Locality 96
Field no. RC-8)

[Samplers: R. C. Robeck, L. E. Shirley. Analysts (TWC-2636): Audrey Pietsch, Blanche Ingram, B. A. McCall.]

12-15	1912-1915	Gu	5.33	0.009	0.0067
21	1916	Gm	1.85	.006	.0042
31-34	1917-1920	Gl	5.54	.008	.0056
12-34 . . .	. . .	G	12.72	0.008	0.0059
41-44	. . .	Du	8.60	n.a.	n.a.
51-53	1921-1923	Dl	5.11	0.006	0.0027

Locality 97
(Field no. RC-5)

[Samplers: J. E. Johnston, L. E. Shirley. Analysts (TWC-2523): F. S. Grimaldi, Irving May, B. A. McCall.]

12-14	18889-18891	Gu	4.01	0.009	0.0072
21	18892	Gm	1.50	.006	.0051
31-34	18893-18896	Gl	5.99	.008	.0061
12-34 . . .	. . .	G	11.50	0.007	0.0064
41-45	. . .	Du	8.23	n.a.	n.a.
51-53	. . .	Dl	4.71	n.a.	n.a.

Locality 99
(Field no. RC-4)

[Samplers: J. E. Johnston, L. E. Shirley. Analysts (TWC-2522): F. S. Grimaldi, Irving May, B. A. McCall. Oil yield analyses, table 20.]

12-14	2107-2109	Gu	4.12	0.011	0.0094
21	2110	Gm	1.93	.007	.0046
31-35 .1/. .	2111-2115	Gl	8.00	.008	.0068
12-35 . . .	. . .	G	14.05	0.009	0.0073
41	. . .	Du	7.35	n.a.	n.a.
51-53	. . .	Dl	4.77	n.a.	n.a.

1/ Sample 33, 1.50 feet thick, analysed 0.0130 percent U. See text, page .

Locality 100
(Field no. LC-60)

[Sampler: C. E. Baker, Jr. Analysts (TWC-5448): Roosevelt Moore, B. A. McCall.]

12-14	968-970	Gu	5.56	0.009	0.0053
21	971	Gm	2.29	.007	.0039
31-33	971-974	Gl	6.17	.008	.0053
12-33 . . .	. . .	G	14.02	0.008	0.0051
41-44	. . .	Du	8.49	n.a.	n.a.
51-54	. . .	Dl	6.49	n.a.	n.a.

Locality 101
(Field no. RC-6)

[Samplers: R. C. Robeck, J. E. Johnston, L. E. Shirley. Analysts (TWC-2626): W. P. Tucker, B. A. McCall. Oil yield analyses, table 20.]

12-15	2119-2122	Gu	6.02	0.008	0.0063
21	2123	Gm	1.22	.006	0.0047
31-34	2124-2127	Gl	6.11	.007	.0052
12-34 . . .	. . .	G	13.35	0.007	0.0056
41-45	. . .	Du	7.82	n.a.	n.a.
51-54	2128-2131	Dl	7.33	0.006	0.0043

Table 9.--Equivalent uranium and uranium analyses of Chattanooga shale - continued.

Sample			Analyses		
Field no.	Laboratory no.	Unit	Thickness, feet.	eU, percent	U, percent
Locality 103 (Field no. RC-2)					
[Samplers: R. C. Roberk, J. E. Johnston, L. E. Shirley. Analysts (TWC-2522): F. S. Grimaldi, Irving May, B. A. McCall.]					
12-14	2076-2078	Gu	3.94	0.009	0.0079
21	2079	Gm	1.22	.008	.0048
31-34	2080-2083	Gl	7.10	.008	.0055
12-34 . . .	. . .	G	12.26	0.008	0.0062
41-44	. . .	Du	9.45	n.a.	n.a.
51-54	. . .	Dl	6.48	n.a.	n.a.
Locality 104 (Field no. RC-3)					
[Samplers: R. C. Roberk, J. E. Johnston, L. E. Shirley. Analysts (TWC-2626): W. P. Tucker, B. A. McCall.]					
12-13	2088-2089	Gu	2.00	0.010	0.0072
21	2090	Gm	1.24	.006	.0044
31-34	2091-2094	Gl	6.46	.007	.0050
12-34 . . .	. . .	G	9.70	0.008	0.0054
41-47	2095-2101	Du	7.40	0.004	0.0011
51-55	2102-2106	Dl	8.89	0.005	0.0029
Locality 106 (Field no. 11K-2)					
[Samplers: Lee Willman, Charles Katlin. Analysts (TWC-2617): W. P. Tucker, B. A. McCall.]					
12-13	3275-3276	Gu	2.80	0.009	0.0084
21	3277	Gm	2.24	.007	.0038
31-33	3278-3280	Gl	4.42	.007	.0055
12-33 . . .	. . .	G	9.46	0.008	0.0059
Dowelltown member poorly exposed and not sampled.					
Locality 107 (Field no. 11K-1)					
[Samplers: Lee Willman, Charles Katlin. Analysts (TWC-2617): W. P. Tucker, B. A. McCall. Oil yield analyses, table 20.]					
12-13	3264-3265	Gu	4.22	0.008	0.0081
21-22	3266-3267	Gm	2.75	.007	.0063
31-33	3268-3270	Gl	5.81	.007	.0052
12-33 . . .	. . .	G	12.78	0.008	0.0063
n.s.	. . .	Du	10.48	n.a.	n.a.
51-54	3271-3274	Dl	7.81	0.006	0.0033
Locality 112 (Field no. 10K-4)					
[Samplers: Lee Willman, Charles Katlin. Analysts (TWC-2658): Norma Cuttag, Harry Levine, Alice Caemmerer, B. A. McCall.]					
12-15	2162-2165	Gu	7.43	0.010	0.0069
21	2166	Gm	0.86	.005	.0017
31-34	2167-2170	Gl	6.75	.008	.0049
12-34 . . .	. . .	G	15.04	0.008	0.0057
n.s.	. . .	Du	2.52	n.a.	n.a.
51-53	2171-2173	Dl	6.27	0.005	0.0028

Table 9--Continued

Sample			Analyses		
Field no.	Laboratory no.	Unit	Thickness, feet	eU, percent	U, percent
Locality 113 (Field no. 10K-5)					
[Samplers: Lee Willman, Charles Katlin. Analysts (TWC-2658): Norma Guttag, Harry Levine, Alice Caemmerer, B. A. McCall. Oil yield analyses, table 20.]					
12-15	2174-2177	Gu	7.17	0.008	0.0060
21	2178	Gm	0.79	.005	.0024
31-33	2179-2181	Gl	5.68	.008	.0043
12-33	...	G	13.64	0.008	0.0051
n.s.	...	Du	2.52	n.a.	n.a.
51-54	2182-2186	Dl	7.33	0.005	0.0022
Locality 114 (Field no. 10J-8)					
[Samplers: Charles Katlin, Lee Willman. Analysts (TWC-2658): Norma Guttag, Harry Levine, Alice Caemmerer, B. A. McCall.]					
12-15	2132-2135	Gu	8.62	0.009	0.0071
21	2136	Gm	0.73	.005	.0031
31-33	2137-2139	Gl	6.32	.008	.0052
12-33	...	G	15.67	0.008	0.0061
41-42	2140-2141	Du	3.98	0.004	0.0025
51	2142	Dl	1.07	0.005	0.0027
Locality 203B (Field no. 14G-5)					
[Samplers: T. M. Kehn, V. E. Swanson. Analyst (TWC-5950): Roosevelt Moore]					
11-19	91910-91918	Gz	8.10	0.007	0.0056
41-47	...	Dz	12.00	n.a.	n.a.
Locality 204 (Field no. 14G-14)					
[Samplers: V. E. Swanson, T. M. Kehn. Analysts (TWC-1636): Alice Caemmerer, Maryse Delevaux, Carmen Hoy, B. A. McCall. (Analyses to precision of ± 0.001 only)]					
11-21	87958-87968	Gz	9.70	0.008	0.0063
n.s.	...	Dz	13.50	n.a.	n.a.
Locality 209 (Field no. 15L-4)					
[Samplers: V. E. Swanson, T. M. Kehn. Analysts (TWC-1639): Ivan Barlow, Carmen Hoy, Maryse Delevaux, W. P. Tucker, B. A. McCall. (Analyses to precision of ± 0.001 only)]					
11-14	87928-87931	Gzp	4.00	0.005	0.0053
12-25	87932-87942	Gz	10.90	.007	.0065
11-25	...	G	14.90	0.007	0.0062
Dowelltown member absent; Gassaway rests on Ordovician limestone.					
Locality 210 (Field no. 15L-10)					
[Samplers: T. M. Kehn, V. E. Swanson. Analysts (TWC-1642): Lillie Jenkins, Ivan Barlow, Shirley Lundine, B. A. McCall (Analyses to precision of ± 0.001 only)]					
11-13	88171-88173	Gzp	3.00	0.005	0.0040
14-27	88174-88187	Gz	13.10	.007	.0055
11-27	...	G	16.10	0.007	0.0053
n.s.	...	Dz	12.80	n.a.	n.a.

Table 9.--Equivalent uranium and uranium analyses of Chattanooga shale - continued.

Sample			Analyses		
Field no.	Laboratory no.	Unit	Thickness, feet	eU, percent	U, percent
Locality 214 (Field no. 11P-1)					
[Samplers: T. M. Kehn, V. E. Swanson. Analysts (TWC-1646): Blanche Ingram, Carmen Hoy, B. A. McCall. (Analyses to precision of ±0.001 only)]					
11-15	99955-99959	Gu	5.20	0.006	0.0056
21-23	99960-99962	Gm	2.70	.005	.0034
31-34	99963-99966	Gl	4.00	.009	.0083
11-34	. . .	G	11.90	0.007	0.0060
Dowelltown member notmeasured nor sampled.					
Locality 215 (Field no. RS-6)					
[Samplers: R. C. Robeck, L. E. Shirley. Analysts (TWC-2802): Mary Joslyn, J. Budinsky, B. A. McCall.]					
11	527	Gup	2.60	0.005	0.0023
12-14	528-530	Gu	5.58	.011	.0078
15-16	531-532	Gm	2.69	.009	.0056
17-18	533-534	Gl	4.60	.010	.0084
11-18 . . .	. . .	G	15.47	0.009	0.0061
41-43	535-538	Du	7.19	0.004	0.0008
51	539	Dl	2.70	0.005	0.0022
Locality 219 (Field no. RS-17)					
[Samplers; R. C. Robeck, L. E. Shirley. Analysts (TWC-2757): J. Budinsky, Carmen Hoy, B. A. McCall.]					
11-14	559-561	Gu	7.76	0.010	0.0062
15	562	Gm	1.72	.008	.0044
16-17	563-564	Gl	3.25	.008	.0042
11-17 . . .	. . .	G	12.73	0.009	0.0055
41-42, 51 . .	565-567	Du	4.48	0.005	0.0014
Locality 220 (Field no. RS-1)					
[Samplers: L. E. Shirley, R. C. Robeck. Analysts (TWC-2759): Mary Joslyn, J. Budinsky.]					
11	570	Gzp	1.00	0.004	0.0022
12-19	571-578	Gz	13.47	.008	.0053
11-19 . . .	. . .	G	14.47	0.008	0.0051
41	579	Du	1.09	0.004	0.0018
Locality 221 (Field no. RS-2)					
[Samplers: R. C. Robeck, L. E. Shirley. Analysts (TWC-2818): Mary Joslyn, J. Budinsky, B. A. McCall.]					
11-17	583-589	Gz	13.27	0.009	0.0055
Dowelltown member not present.					

Table 9.--Equivalent uranium and uranium analyses of Chattanooga shale - continued.

Sample			Analyses		
Field no.	Laboratory no.	Unit	Thickness, feet	eU, percent	U, percent
Locality 222 (Field no. RS-15)					
[Samplers: R. C. Roback, L. E. Shirley. Analysts (TWC-2818): Roosevelt Moore.]					
11-16	592-597	Gz	8.76	0.007	0.0054
Dowelltown member not present.					
Locality 306 (Field no. 14H-4)					
[Samplers: V. E. Swanson, T. M. Kehn. Analyst (TWC-5281): Roosevelt Moore.]					
11-20	91782-91791	Gz	10.00	n.a.	0.0051
n.s.	. . .	Dz	13.00	n.a.	n.a.
Locality 310 (Field no. 15K-8)					
Samplers: T. M. Kehn, V. E. Swanson. Analyst (TWC-5286): Roosevelt Moore.]					
11-12	88154-88155	Gzp	2.00	n.a.	0.0052
13-26	88156-88169	Gz	13.60	n.a.	.0044
11-26 . . .	. . .	G	15.60	n.a.	0.0045
n.s.	. . .	Dz	12.30	n.a.	n.a.
Locality 323 (Field no. 18N-12)					
[Samplers: V. E. Swanson, T. M. Kehn. Analyst (TWC-5664): Joseph Budinsky. Chemical and oil yield analyses, tables 1, 19, 20. Spectrographic data, fig. 16.]					
A-C	90006-90036	Gz	30.00	n.a.	0.0039
n.s.	. . .	1/	7.80	n.a.	n.a.
1/ Badly weathered material, member not determined.					
Locality C1 (Field no. YB-1)					
[Sampler: T. M. Kehn. Analysts (TWC-2738): Mary Joslyn, Carmen Hoy, J. Budinsky, J. J. Warr, B. A. McCall.]					
A	111428A	Gu	4.79	0.010	0.0086
B	111430A	Gm	2.33	.006	.0037
C	111438A	Gl	8.28	.007	.0056
A-C	. . .	G	15.40	0.008	0.0062
41-45	111439-111443	Du	10.20	0.004	0.0012
51-57	111444-111450	Dl	7.25	0.006	0.0034
Locality C2 (Field no. YB-2)					
[Sampler: T. M. Kehn. Analysts (TWC-2607): Joan Smith, Ethel Hackney, B. A. McCall.]					
12-17	108860-108865	Gu	6.04	0.010	0.0081
21-23	108866-108868	Gm	2.71	.005	.0036
31-38	108869-108876	Gl	8.30	.007	.0055
12-38	. . . .	G	17.05	0.008	0.0061
41-45	108877-108881	Du	10.34	0.004	0.0012
51-57	108882-108888	Dl	6.66	0.005	0.0036

Table 91--Lithologic studies and uranium analyses of Chattanooga shale - continued.

Sample			Analyses		
Field no.	Laboratory no.	Unit	Thickness, feet	eU, percent	U, percent
		Locality C3 (Field no. YB-3)			
[Sampler: T. M. Kehn. Analysts (TWC-2606): Mary Joslyn, Blanche Ingram, Joan Smith, B. A. McCall.]					
12-15	108890-108893	Gu	3.70	0.009	0.0082
21-22	108894-108895	Gm	2.45	.005	.0037
31-38	108896-108903	Gl	8.32	.007	.0047
12-38	...	G	14.47	0.007	0.0054
41-45	108904-108908	Du	9.68	0.004	0.0010
51-57	108909-108915	Dl	6.39	0.006	0.0030
		Locality C4 (Field no. YB-4)			
[Sampler: T. M. Kehn. Analysts (TWC-2608): Joseph Budinsky, Joan Smith, B. A. McCall.]					
12-18	108917-108923	Gu	6.52	0.009	0.0078
21-23	108924-108926	Gm	2.57	.006	.0037
31-39	108927-108935	Gl	8.74	.007	.0054
12-39	...	G	17.83	0.008	0.0061
41-46	108936-108941	Du	11.00	0.004	0.0009
51-57	108942-108948	Dl	7.16	0.006	0.0027
		Locality C6 (Field no. YB-6)			
[Sampler: T. M. Kehn. Analysts (TWC-2712): Jesse Warr, Mary Joslyn. Joseph Budinsky, B. A. McCall.]					
12-17	111124-111129	Gu	6.16	0.009	0.0076
21-22	111130-111131	Gm	2.46	.006	.0033
31-38	111132-111139	Gl	8.29	.007	.0058
12-38	...	G	16.91	0.008	0.0058
41-45	111140-111144	Du	10.07	0.004	0.0013
51-57	111145-111151	Dl	6.83	0.006	0.0029
		Locality C7 (Field no. YB-7)			
[Sampler: T. M. Kehn. Analysts (TWC-2711): Carmen Hoy, Mary Joslyn, Joan Smith, B. A. McCall.]					
12-16	111153-111157	Gu	5.11	0.009	0.0076
21-22	111158-111159	Gl	2.45	.006	.0034
31-38	111160-111167	Gl	7.13	.007	.0054
12-38	...	G	15.69	0.008	0.0058
41-45	111168-111172	Du	10.54	0.004	0.0010
51-57	111173-111179	Dl	6.79	0.005	0.0033
		Locality C9 (Field no. YB-9)			
[Sampler: T. M. Kehn. Analysts (TWC-2713): Joseph Budinsky, Joan Smith, B. A. McCall.]					
A	111649A	Gu	4.87	0.009	0.0082
B	111651A	Gm	2.45	.006	.0038
C	111659A	Gl	7.72	.007	.0052
A-C	...	G	15.04	0.008	0.0060
41-45	...	Du	9.60	n.a.	n.a.
51-56	...	Dl	5.75	n.a.	n.a.

Sample			Analyses		
Field no.	Laboratory no.	Unit	Thickness, feet	eU, percent	U, percent
Locality C10 (Field no. YB-10)					
[Samplers: T. M. Kehn, L. C. Conant. Analysts (TWC-2713): Joan Smith, Mary Joslyn, Joseph Budinsky, Jesse Warr, B. A. McCall.]					
12-16	111181-111185	Gu	4.80	0.010	0.0079
21-22	111186-111187	Gm	2.35	.005	.0037
31-38	111188-111195	Gl	7.78	.008	.0054
12-38 . . .	. . .	G	14.93	0.008	0.0059
41-45	111196-111200	Du	9.43	0.004	0.0010
51-56	111201-111206	Dl	5.99	0.005	0.0030
Locality C11 (Field no. YB-11)					
[Samplers: T. M. Kehn, L. C. Conant. Analysts (TWC-2723): Maryse Delevaux, Joseph Budinsky, Jesse Warr, Mary Joslyn, B. A. McCall.]					
12-17	111208-111213	Gu	5.90	0.010	0.0078
21-22	111214-111215	Gm	2.35	.006	.0035
31-38	111216-111223	Gl	8.02	.007	.0056
12-38 . . .	. . .	G	16.25	0.008	0.0061
41-45	111224-111228	Du	10.25	0.005	0.0011
51-57	111229-111235	Dl	6.66	0.006	0.0032
Locality C12 (Field no. YB-12)					
[Samplers: L. C. Conant, T. M. Kehn. Analysts (TWC-2740): J. Budinsky, C. Hoy, M. A. Joslyn, J. Smith, Jesse Warr, J. H. Goode.]					
12-18	111237-111243	Gu	6.44	0.009	0.0079
21-22	111244-111245	Gm	2.24	.006	.0039
31-38	111246-111253	Gl	7.97	.007	.0053
12-38 . . .	. . .	G	16.65	0.008	0.0061
41-45	111254-111258	Du	10.58	0.004	0.0010
51-56	111259-111264	Dl	6.13	0.005	0.0031
Locality C14 (Field no. YB-14)					
[Samplers: T. M. Kehn, L. C. Conant. Analysts (TWC-2778): Mary Joslyn, Joan Smith, Alice Caommerer, B. A. McCall.]					
A	111675A	Gu	4.42	0.010	0.0073
B	111677A	Gm	2.12	.007	.0039
C	111685A	Gl	7.98	.008	.0052
A-C	. . .	G	14.52	0.008	0.0056
41-45	. . .	Du	9.14	n.a.	n.a.
51-56	. . .	Dl	5.75	n.a.	n.a.
Locality C13 (Field no. YB-13)					
[Samplers: L. C. Conant, T. M. Kehn. Analysts (TWC-2778): Mary Joslyn, Joan Smith, Alice Caommerer, B. A. McCall.]					
A	111270A	Gu	5.38	0.009	0.0079
B	111272A	Gm	2.21	.006	.0036
C	111280A	Gl	7.53	.007	.0056
A-C	. . .	G	15.12	0.008	0.0061
41-44	. . .	Du	8.07	n.a.	n.a.
51-56	. . .	Dl	5.43	n.a.	n.a.

Sample			Analyses		
Field no.	Laboratory no.	Unit	Thickness, feet	eU, percent	U, percent
Locality C15 (Field no. YB-15)					
[Sampler: T. M. Kehn. Analysts (TWC-2727,2739): Joan Smith, Maryse Delevaux, Mary Joslyn, Carmen Hoy, B. A. McCall.]					
A	112322A	Gu	4.52	n.a.	0.0082
B	112324A	Gm	2.29	n.a.	.0038
C	112332A	Gl	7.64	n.a.	.0059
A-C	. . .	G	14.45	n.a.	0.0063
41-45	112333-112337	Du	9.37	n.a.	0.0011
51-56	112338-112343	Dl	5.93	n.a.	0.0032
Locality C16 (Field no. YB-16)					
[Samplers: T. M. Kehn, L. C. Conant. Analysts (TWC-2909): Mary Joslyn, Carmen Hoy, B. A. McCall. Spectrographic data, fig. 16.]					
2	114250	Gu	4.72	0.009	0.0078
3	114251	Gm	2.19	.006	.0036
4	114252	Gl	7.68	.007	.0054
2-3	. . .	G	14.59	0.007	0.0059
5	. . .	Du	9.18	n.a.	n.a.
6	. . .	Dl	6.34	n.a.	n.a.
Locality C17 (Field no. YB-17)					
[Sampler: T. M. Kehn. Analysts (TWC-3835): Joseph Budinsky, Carmen Hoy, Julius Goode.]					
A	113239	Gu	5.13	0.009	0.0084
B	113240	Gm	2.15	.006	.0035
C	113241	Gl	7.51	.007	.0055
A-C	. . .	G	14.69	0.008	0.0062
41-45	. . .	Du	9.24	n.a.	n.a.
51-56	. . .	Dl	6.28	n.a.	n.a.
Locality C18 (Field no. YB-18)					
[Samplers: T. M. Kehn, L. C. Conant. Analysts (TWC-2747): Joseph Budinsky, Joan Smith, B. A. McCall.]					
A	111702A	Gu	5.14	0.009	0.0080
B	111704A	Gm	2.20	.006	.0038
C	111712A	Gl	7.76	.008	.0058
A-C	. . .	G	15.10	0.008	0.0063
41-45	. . .	Du	9.52	n.a.	n.a.
51-56	. . .	Dl	6.33	n.a.	n.a.
Locality C19 (Field no. YB-19)					
[Samplers: T. M. Kehn, L. C. Conant. Analysts (TWC-2750): Mary Joslyn, Jesse Warr, B. A. McCall.]					
A	112195A	Gu	4.46	0.009	0.0082
B	112197A	Gm	2.13	.005	.0033
C	112205A	Gl	7.66	.008	.0056
A-C	. . .	G	14.25	0.008	0.0061
41-45	. . .	Du	9.11	n.a.	n.a.
51-56	. . .	Dl	6.25	n.a.	n.a.

Table 9.--Locality data and chemical analyses of [illegible] continued.

Sample			Analysis		
Field no.	Laboratory no.	Unit	Thickness, feet	eU, percent	U, percent
Locality C20 (Field no. YB-20)					
[Samplers: T. M. Kehn, L. C. Conant. Analysts (TWC-2750): Maryse Delevaux, Jesse Warr, B. A. McCall.]					
A	112171A	Cu	4.25	0.008	0.0075
B	112173A	Cm	2.44	.006	.0043
C	112180A	Cl	6.95	.007	.0053
A-C	. . .	C	13.64	0.007	0.0058
41-44	. . .	Du	8.87	n.a.	n.a.
51-56	. . .	Dl	6.08	n.a.	n.a.
Locality C21 (Field no. YB-21)					
[Samplers: T. M. Kehn, L. C. Conant. Analysts (TWC-2749): Mary Joslyn, Jesse Warr, B. A. McCall.]					
A	112222A	Cu	5.28	0.009	0.0076
B	112224A	Cm	2.11	.006	.0036
C	112231A	Cl	7.45	.007	.0054
A-C	. . .	C	14.84	0.007	0.0059
41-35	. . .	Du	9.23	n.a.	n.a.
51-56	. . .	Dl	6.11	n.a.	n.a.
Locality C22 (Field no. YB-22)					
[Sampler: T. M. Kehn. Analysts (TWC-2746): Maryse Delevaux, Joan Smith, Joseph Budinsky, B. A. McCall.]					
A	111730A	Cu	6.36	0.009	0.0078
B	111732A	Cm	2.27	.005	.0035
C	111739A	Cl	7.42	.007	.0056
A-C	. . .	C	16.05	0.008	0.0063
41-45	. . .	Du	9.29	n.a.	n.a.
51-57	. . .	Dl	6.56	n.a.	n.a.
Locality C23 (Field no. YB-23)					
[Sampler: T. M. Kehn. Analysts (TWC-2751): Jesse Warr, Audrey Pietsch, Maryse Delevaux, B. A. McCall.]					
A	112253A	Cu	5.01	0.009	0.0077
B	112255A	Cm	1.96	.006	.0030
C	112262A	Cl	7.00	.008	.0055
A-C	. . .	C	13.97	0.008	0.0060
41-45	. . .	Du	9.12	n.a.	n.a.
51-56	. . .	Dl	6.43	n.a.	n.a.
Locality C24 (Field no. YB-24)					
[Samplers: Lynn Glover, T. M. Kehn. Analysts (TWC-2881): Joseph Budinsky, Carmen Hoy, Joan Smith, B. A. McCall.]					
A	113297	Cu	5.70	0.009	0.0078
B	113298	Cm	1.86	.006	.0032
C	113299	Cl	7.25	.007	.0056
A-C	. . .	C	14.81	0.008	0.0061
41-44	. . .	Du	8.59	n.a.	n.a.
51-56	. . .	Dl	6.26	n.a.	n.a.

Sample			Analyses		
Field no.	Laboratory no.	Unit	Thickness, feet	eU, percent	U, percent
Locality C25 (Field no. YB-25)					
[Sampler: T. M. Kehn. Analysts (TWC-2769): Joan Smith, Alice Caemmerer.]					
A	112783	Gu	3.93	0.009	0.0081
B	112784	Gm	1.86	.006	.0034
C	112785	Gl	6.59	.007	.0055
A-C	. . .	G	12.38	0.008	0.0060
41-45	. . .	Du	9.33	n.a.	n.a.
51-55	. . .	Dl	4.54	n.a.	n.a.
Locality C26 (Field no. YB-26)					
[Sampler: T. M. Kehn. Analysts (TWC-2784): Jesse Warr, Joseph Budinsky, B. A. McCall. Spectrographic data, fig. 16.]					
A	112792A	Gu	5.71	0.009	0.0080
B	112794A	Gm	1.73	.006	.0037
C	112801A	Gl	6.63	.007	.0060
A-C	. . .	G	14.07	0.008	0.0066
41-44	. . .	Du	8.04	n.a.	n.a.
51-56	. . .	Dl	6.00	n.a.	n.a.
Locality C27 (Field no. YB-27)					
[Sampler: T. M. Kehn. Analysts (TWC-2772): Jesse Warr, Joseph Budinsky, B. A. McCall.]					
A	112439A	Gu	4.03	0.010	0.0083
B	112441A	Gm	1.89	.006	.0038
C	112447A	Gl	6.40	.008	.0058
A-C	. . .	G	14.96	0.009	0.0066
41-44	. . .	Du	8.17	n.a.	n.a.
51-56	. . .	Dl	5.92	n.a.	n.a.
Locality C28 (Field no. YB-28)					
[Sampler: T. M. Kehn. Analysts (TWC-2779): Joseph Budinsky, Alice Caemmerer, J. H. Coode.]					
A	112842A	Gu	4.03	0.010	0.0082
B	112844A	Gm	1.62	.005	.0030
C	112850A	Gl	6.32	.008	.0057
A-C	. . .	G	11.97	0.008	0.0062
41-45	. . .	Du	9.39	n.a.	n.a.
51-54	112856-112859	Dl	4.34	n.a.	0.0040
Locality C29 (Field no. YB-29)					
[Samplers: T. M. Kehn, Lynn Glover. Analysts (TWC-2866): Carmen Hoy, Joseph Budinsky, Audrey Smith, Joan Smith, B. A. McCall.]					
12-13	113243-113244	Gup	2.00	0.005	0.0029
14-17	113245-113248	Gu	4.31	.009	0.0073
B	113269	Gm	1.85	.006	.0039
C	113270	Gl	6.65	.007	.0056
12-C	. . .	G	14.81	0.007	0.0055
41-44	. . .	Du	9.62	n.a.	n.a.
51-55	. . .	Dl	5.00	n.a.	n.a.

Table 91--Analyses of uranium [illegible]
Chattanooga shale - Continued.

Sample			Analyses		
Field no.	Laboratory no.	Unit	Thickness, feet	eU, percent	U, percent
Locality C30 (Field no. YB-30)					
/Samplers: Lynn Glover, T. M. Kehn. Analysts (TWC-2867): Carmen Hoy, Joseph Budinsky, B. A. McCall./					
A	113194A	Gu	4.02	0.009	0.0078
B	113196A	Gm	2.79	.006	.0043
C	113202A	Gl	5.90	.006	.0056
A-C . . .	. . .	G	12.71	0.008	0.0060
41-44 . . .	. . .	Du	8.45	n.a.	n.a.
51-56 . . .	. . .	Dl	5.80	n.a.	n.a.
Locality C31 (Field no. YB-31)					
/Samplers: T. M. Kehn, Lynn Glover. Analysts (TWC-2895): Joan Smith, Mary Joslyn, B. A. McCall./					
2	114170	Gu	4.82	0.009	0.0080
3	114171	Gm	1.95	.006	.0031
4	114172	Gl	7.58	.008	.0054
2-4 . . .	. . .	G	14.35	0.008	0.0060
5	114173	Du	8.53	0.004	0.0012
6	114174	Dl	6.00	0.006	0.0032
Locality C32 (Field no. YB-32)					
/Samplers: T. M. Kehn, M. L. Conant. Analysts (TWC-2897): Audrey Smith, Joseph Budinsky, B. A. McCall./					
2.	114176	Gu	4.93	0.008	0.0080
3	114177	Gm	2.02	.005	.0042
4	114178	Gl	7.43	.008	.0062
2-4 . . .	. . .	G	14.38	0.007	0.0065
5	114179	Du	8.92	0.004	0.0012
6	114180	Dl	6.29	0.006	0.0032
Locality C33 (Field no. YB-33)					
/Samplers: T. M. Kehn, M. L. Conant. Analysts (TWC-2760): Alice Caemmerer, Jesse Warr, Julius Goode./					
A	112484A	Gu	4.21	0.008	0.0074
B	112485	Gm	1.45	.005	.0038
C	112491A	Gl	6.43	.006	.0048
A-C . . .	. . .	G	12.09	0.006	0.0056
41-44 . . .	. . .	Du	7.22	n.a.	n.a.
51-56 . . .	. . .	Dl	6.11	n.a.	n.a.
Locality C34 (Field no. YB-34)					
/Sampler: T. M. Kehn. Analysts (TWC-2766, Rpt.WT54): Mary Joslyn, Carmen Hoy, R. Moore, A. Caemmerer, B. A. McCall./					
A	112462A	Gu	4.43	0.009	0.0071
B	112463	Gm	1.38	.005	.0034
C	112469A	Gl	6.10	.007	.0055
A-C . . .	. . .	G	11.91	0.007	0.0059
41-44 . . .	. . .	Du	7.77	n.a.	n.a.
51-55 . . .	112474-112479	Dl	6.00	n.a.	0.0030

Table 91

Sample			Analyses		
Field no.	Laboratory no.	Unit	Thickness, feet	eU, percent	U, percent
Locality C35 (Field no. YB-35)					
[Sampler: T. M. Kehn. Analysts (TWC-2755): Joan Smith, Mary Joslyn, Julius Goode.]					
A	112507A	Gu	3.64	0.009	0.0074
B	112508	Gm	2.00	.005	.0028
C	112514A	Gl	6.18	.007	.0052
A-C	. . .	G	11.91	0.007	0.0057
41-44	. . .	Du	8.14	n.a.	n.a.
51-56	. . .	Dl	5.77	n.a.	n.a.
Locality C36 (Field no. YB-36)					
[Sampler: T. M. Kehn. Analysts (TWC-2785): Carmen Hoy, Mary Joslyn, Julius Goode. Spectrographic data, fig. 16]					
A	112836	Gu	3.23	0.009	0.0077
B	112819A	Gm	1.47	.006	.0032
C	112837	Gl	6.35	.007	.0052
A-C	. . .	G	11.25	0.007	0.0056
41-45	. . .	Du	9.82	n.a.	n.a.
51-54	112832-112835	Dl	3.85	n.a.	0.0037
Locality C37 (Field no. YB-37)					
[Samplers: T. M. Kehn, M. L. Conant. Analysts (TWC-2898): Mary Joslyn, Jesse Warr, B. A. McCall. Chemical, thorium, and oil-yield analyses, tables 1, 17, 19, and 20. Spectrographic data, fig. 16.]					
2	114182	Gu	6.80	0.010	0.0086
3	114183	Gm	3.03	.006	.0033
4	114184	Gl	7.62	.008	.0057
2-4	. . .	G	17.43	0.008	0.0064
5	114185	Du	11.50	0.004	0.0012
6	114186	Dl	5.11	0.006	0.0034
Locality C38 (Field no. YB038)					
[Sampler: T. M. Kehh. Analysts (TWC-2902): Joan Smith, Carmen Hoy, B. A. McCall.]					
2	114188	Gu	4.97	0.010	0.0080
3	114189	Gm	2.12	.006	.0036
4	114190	Gl	9.08	.008	.0055
3-4	. . .	G	16.17	0.008	0.0060
5	114191	Du	10.52	0.004	0.0008
6	114192	Dl	6.76	0.006	0.0032
Locality C39 (Field no. YB-39)					
[Sampler: T. M. Kehn. Analysts (TWC-2894): Carmen Hoy, Joseph Budinsky, B. A. McCall.]					
2	114194	Gu[1]	7.23	0.008	0.0066
3	114195	Gm	2.18	.006	.0033
4	114196	Gl	6.03	.007	.0043
2-4	. . .	G	15.47	0.007	0.0054
5	114197	Du	9.25	0.001	0.0011
6	114198	Dl	6.04	0.005	0.0029

1/ On basis of both thickness and uranium content, phosphatic zone is probably present in upper 1 or 2 feet of this unit.

Table 91. [illegible]
Chattanooga shale, continued.

Sample			Analyses		
Field no	Laboratory no.	Unit	Thickness, feet	eU, percent	U, percent
		Locality C40 (Field no. YB-40)			
		[Sampler: Lynn Glover. Analysts (TWC-2922): Alice Caemmerer, Carmen Hoy, B. A. McCall.]			
2	114256	Cu	4.16	0.009	0.0079
3	114257	Cm	2.43	.006	.0039
4	114258	Cl	8.15	.007	.0054
2-4	. . .	C	14.74	0.007	0.0058
5	114259	Du	10.72	0.003	0.0011
6	114260	Dl	6.88	0.005	0.0033
		Locality C41 (Field no. YB-41)			
		[Samplers: T. M. Kehn, Julian Soren. Analysts (TWC-2940): Joan Smith, Carmen Hoy, Joseph Budinsky, B. A. McCall.]			
2	114262	Cu	3.91	0.009	0.0074
3	114263	Cm	1.34	.005	.0038
4	114264	Cl	7.77	.007	.0053
2-4	. . .	C	13.02	0.007	0.0058
5	114265	Du	7.88	0.004	0.0010
6	114266	Dl	5.54	0.006	0.0038
		Locality C42 (Field no. YB-42)			
		[Samplers: T. M. Kehn, Julian Soren. Analysts (TWC-2927): Joseph Budinsky, Mary Joslyn, J. H. Goode. Chemical and oil-yield analyses, tables 1, 19, 20. Spectrographic data, fig. 16.]			
2	114268	Cu	6.50	0.009	0.0080
3	114269	Cm	1.86	.006	.0049
4	114270	Cl	9.99	.007	.0052
2-4	. . .	C	18.35	0.008	0.0062
5	114271	Du	9.62	0.003	0.0010
6	114272	Dl	5.02	0.005	0.0032
		Locality C43 (Field no. YB-43)			
		[Samplers: Julian Soren, Stanley Byers. Analysts (TWC-2966): Carmen Hoy, Jesse Warr, Joseph Budinsky, B. A. McCall.]			
12	115877	Cu	3.87	0.008	0.0075
21	115878	Cm	1.30	.006	.0032
31	115879	Cl	6.10	.006	.0052
12-31	. . .	C	11.27	0.007	0.0057
n.s.	. . .	Du	9.49	n.a.	n.a.
n.s.	. . .	Dl	8.42	n.a.	n.a.
		Locality C44 (Field no. YB-44)			
		[Samplers: T. M. Kehn, Julian Soren. Analysts (TWC-2916): Alice Caemmerer, Mary Joslyn, Joan Smith, J. H. Goode. Thorium and oil-yield anabyses, tables 18, 19, 20. Spectrographic data, fig. 16.]			
2	114274	Cu	6.64	0.009	0.0085
3	114275	Cm	1.97	.007	.0048
4	114276	Cl	6.19	.006	.0049
2-4	. . .	C	14.80	0.007	0.0065
5	114277	Du	9.25	0.003	0.0010
6	114278	Dl	5.41	0.005	0.0035

Table 9--Equivalent uranium and uranium analyses of Chattanooga shale - continued.

Sample			Analyses		
Field no.	Laboratory no.	Unit	Thickness, feet.	eU, percent	U, percent
			Locality C45		
			(Field no. YB-45)		
			[Samplers: T. M. Kehn, Julian Soren. Analysts (TWC-3282, 2967): Joan Smith, Joseph Budinsky, Jesse Marr, Mary Joslyn, J. H. Goode, B. A. McCall.]		
12, 41 . . .	115874-115875	Gz	12.35	0.008	0.0068
Dowelltown member not present.					
			Locality C46		
			(Field no. YB-46)		
			[Samplers: Julian Soren, Stanley Byers. Analysts (TWC-2941): Carmen Hoy, Joan Smith, Mary Joslyn, Joseph Budinsky, B. A. McCall. Thorium analyses, table 17. Spectrographic data, fig. 16.]		
2	115049	Gu	5.18	0.008	0.0084
3	115050	Gm	2.27	.006	.0058
4	115051	Gl	8.95	.007	.0057
2-4 . . .	. . .	G	16.40	0.007	0.0066
5	115052	Du	9.63	0.004	0.0010
6	115053	Dl	6.16	0.005	0.0030
			Locality C47		
			(Field no. WR-47)		
			[Sampler: Lynn Glover. Analysts (TWC-2957): Joseph Budinsky, B. A. McCall, J. H. Goode.]		
12-31 . . .	115780-115783	Gz	10.89	0.009	0.0080
n.s.	. . .	Du	2.96	n.a.	n.a.
Lower unit of Dowelltown member notpresent.					
			Locality C48		
			(Field no. WR-48)		
			[Sampler: Lynn Glover. Analysts (TWC-2949): Mary Joslyn, Joseph Budinsky, B. A. McCall. Chemical and oil yield analyses, tables 1, 19, 20. Spectrographic data, fig. 16.]		
2-4	115061-115063	Gz	15.07	0.008	0.0069
5	115064	Du	2.05	0.004	0.0016
Lower unit of Dowelltown member not present.					
			Locality C49		
			(Field no. WR-49)		
			[Sampler: Lynn Glover. Analysts (TWC-2896): Mary Joslyn, Audrey Smith, J. H. Goode. Chemical, thorium, and oil-yield analyses, tables 1, 17, 19, 20. Spectroggaphic data, fig. 16.]		
11	114280	Gz[1]	4.00	0.005	0.0029
21	114281	Gup	4.00	.006	.0038
31	114282	Gu	5.40	.010	.0092
32	114283	Gm	1.72	.008	.0061
33	114284	Gl	2.85	.008	.0062
11-33 . . .	. . .	G	17.97	0.007	0.0058
41	114285	Du	6.46	0.004	0.0011
Lower unit of Dowelltown member not present.					
1/ Uncertain correlation. See text, p.					

Table 91

Field no.	Laboratory no.	Unit	Thickness, feet	Oil, percent	U, percent
Locality C50 (Field no. WR-50)					
[Sampler: Lynn Glover. Analysts (TWC-2960): Jesse Warr, Carmen Hoy, J. H. Goode. Chemical, thorium, and oil yield analyses, tables 1, 17, 19, 20. Spectrographic data, fig. 16.]					
12-13	115770-115771	Gu	10.21	0.009	0.0078
21	115772	Gm	1.87	.007	.0057
31-32	115773-115774	Gl	8.76	.008	.0060
12-32 . . .	. . .	G	21.04	0.008	0.0070
41-42	115775-115776	Du	11.01	0.004	0.0008
51-52	115777-115778	Dl	2.84	0.006	0.0043
Locality C51 (Field no. YB-51)					
[Sampler: T. M. Kehn. Analysts (TWC-2999): Carmen Hoy, Joseph Budinsky, B. A. McCall. Thorium analyses, table 17. Spectrographic data, fig. 16.]					
12-13	117624-117625	Gu[1]	10.07	0.008	0.0057
21	117626	Gm	2.74	.006	.0038
31	117627	Gl	4.02	.006	.0039
12-31 . . .	. . .	G	16.89	0.007	0.0050
41	. . .	Du	3.53	n.a.	n.a.
51	117629	Dl	3.86	n.a.	0.0010
Locality C52 (Field no. YB-52)					
[Sampler: T. M. Kehn. Analysts (TWC-3035): Joseph Bydinsky, J. H. Goode, B. A. McCall.]					
11	117731	Gup	1.88	0.005	0.0038
12-13 . . .	117732-117733	Gu	9.37	.009	.0069
21	117734	Gm	3.14	.006	.0037
31	117735	Gl	5.34	.006	.0047
11-31 . . .	. . .	G	19.73	0.008	0.0055
41	. . .	Du	6.91	n.a.	n.a.
51-52 . . .	117738-117739	Dl	6.15	n.a.	0.0015
Locality C53 (Field no. NV-53)					
[Samplers: T. M. Kehn, Julian Soren. Analysts (TWC-2990): Carmen Hoy, Joseph Budinsky, B. A. McCall, J. H. Goode.]					
12-14 . . .	115862-115864	Gz	13.36	0.007	0.0053
41	. . .	Dz	4.06	n.a.	n.a.
Locality C54 (Field no. NV-54)					
[Samplers; T. M. Kehn, Julian Soren. Analysts (TWC-2956): Joseph Budinsky, B. A. McCall, J. H. Goode.]					
12-13	115785-115786	Gz	11.58	0.008	0.0060
41	. . .	Dz	13.49	n.a.	n.a.

[1] Upper 1 to 2 feet of this sample is phosphatic unit (Gup).

Table 91.—Equivalent [illegible] of Chattanooga shale — continued.

Sample			Analyses		
Field no.	Laboratory no.	Unit	Thickness, feet.	eU, percent	U, percent
Locality C55 (Field no. NV-55)					
/Samplers: T. M. Kehn, Julian Soren. Analysts (TWC-2989): Carmen Hoy, Joseph Budinsky, J. H. Goode, B. A. McCall./					
12-13 . . .	115888-115889	Cz	10.62	0.007	0.0056
n.s.	. . .	Du	6.57	n.a.	n.a.
n.s.	. . .	Dl	9.35	n.a.	n.a.
Locality C56 (Field no. NV-56)					
/Sampler: T. M. Kehn. Analysts (TWC-2917): Joan Smith, Alice Caemmerer, J. H. Goode. Chemical, thorium, and oil-yield analyses, tables 1, 17, 19, 20. Spectrographic data, fig. 16./					
2-3	115055-115056	Cz	9.67	0.007	0.0056
4-6	115057-115059	Dz	13.15	0.003	0.0009
Locality C57 (Field no. NV-57)					
/Sampler: T. M. Kehn. Analysts (TWC-2997): Carmen Hoy, Joseph Budinsky, J. H. Goode, B. A. McCall./					
12-13	115883-115884	Cz	11.23	0.007	0.0052
n.s.	. . .	Dz	10.69	n.a.	n.a.
Locality C58 (Field no. NV-58)					
/Sampler: T. M. Kehn. Analysts (TWC-6272): Joseph Budinsky, Jesse Warr, Joan Smith, B. A. McCall, J. H. Goode./					
12-14 . . .	115867-115869	Cz	16.62	0.006	0.0044
41-43 . . .	115870-115892	Dz	12.34	n.a.	0.0012
Locality C59 (Field no. NV-59)					
/Sampler: T. M. Kehn. Analysts (TWC-2996): Carmen Hoy, Joseph Budinsky, J. H. Goode./					
12-14 . . .	115792-115794	Cz	16.67	0.006	0.0040
n.s.	. . .	Dz	3.31	n.a.	n.a.
Locality C60 (Field no. NV-60)					
/Samplers: T. M. Kehn, Andrew Brown. Analyst (TWC-6269): Joseph Budinsky./					
11a-11b . . .	115889-115890	Czp	3.95	n.a.	0.0038
12-15	115891-115894	Cz	10.02	n.a.	.0061
11a-15 . .	. . .	C	13.97	n.a.	0.0055
51-52	115895-115896	Dz	3.67	n.a.	0.0020
Locality C61 (Field no. NV-61)					
/Sampler: T. M. Kehn. Analysts (TWC-3060): Joseph Budinsky, Carmen Hoy, B. A. McCall, J. H. Goode./					
12-15 . . .	116550-116553	Cz	15.57	0.007	0.0052
41	116554	Dz	5.89	0.003	0.0011

Table 9:--Equivalent uranium and uranium analyses of Chattanooga shale - continued.

Sample			Analyses		
Field no.	Laboratory no.	Unit	Thickness, feet.	eU, percent	U, percent
		Locality C62 (Field no. NV-62)			
[Sampler: T. M. Kohn. Analysts (TWC-3061): Joseph Budinsky, Carmen Hoy, B. A. McCall.]					
12-13 . . .	115765-115766	Cz	8.71	0.007	0.0060
41-42 . . .	. . .	Dz	8.05	n.a.	n.a.
		Locality C63 (Field No. NV-63)			
[Sampler: T. M. Kohn. Analysts (TWC-3053): Joseph Budinsky, Carmen Hoy, B. A. McCall.]					
12-13 . . .	116924-116925	Cz	10.00	0.007	0.0058
n.s.	. . .	Dz	8.09	n.a.	n.a.
		Locality C64 (Field no. AL-64)			
[Sampler: Lynn Glover. Analysts (TWC-3021): Joseph Budinsky, Carmen Hoy, B. A. McCall. Chemical, thorium, and oil-yield analyses, tables 1, 17, 19, 20. Spectrographic data, fig. 16.]					
12-14 . . .	120217-120219	Cz	11.95	0.007	0.0044
15-16 . . .	120220-120221	Dz?	7.40	0.004	0.0019
		Locality C65 (Field no. AL-65)			
[Sampler: Lynn Glover. Analysts (TWC-3035): Carmen Hoy, B. A. McCall.]					
12-17 . . .	120191-120196	Cz	20.12	0.007	0.0057
18-19 . . .	120197-120198	Dz?	7.07	0.004	0.0024
		Locality C66 (Field no. AL-66)			
[Samplers: T. M. Kohn. Lynn Glover. Analysts (TWC-3059): Carmen Hoy, Joseph Budinsky, B. A. McCall.]					
12-18 . . .	120207-120213	Cz	33.60	0.007	0.0054
19-20 . . .	120214-120215	Dz?	8.95	0.003	0.0016
		Locality C67 (Field no. PC-1)			
[Samplers: L. C. Conant, T. M. Kohn. M. L. Conant. Analysts (TWC-3279): Joan Smith, Joseph Budinsky.]					
A	122137	Gu	4.92	n.a.	0.0082
B	122138	Gm	2.43	n.a.	.0046
C	122139	Gl	7.80	n.a.	.0062
A-C	. . .	G	15.15	n.a.	0.0066
n.s.	. . .	Du	9.76	n.a.	n.a.
n.s.	. . .	Dl	6.09	n.a.	n.a.

Table 9.— [illegible] — continued

Sample			Analyses		
Field no.	Laboratory no.	Unit	Thickness, feet	eU, percent	U, percent
Locality C68 (Field no. PC-2)					
/Samplers: L. C. Conant, T. M. Kehn, M. L. Conant. Analysts (TWC-3279): Joan Smith, Joseph Budinsky./					
A	122140	Cu	4.73	n.a.	0.0081
B	122141	Cm	2.49	n.a.	.0036
C	122142	Cl	7.45	n.a.	.0057
A-C . . .	. . .	C	14.78	n.a.	0.0061
n.s.	. . .	Du	9.81	n.a.	n.a.
n.s.	. . .	Dl	5.69	n.a.	n.a.
Locality C69 (Field no. PC-3)					
/Samplers: M. L. Conant, L. C. Conant, T. M. Kehn. Analysts (TWC-3279): Joan Smith, Joseph Budinsky./					
A	122143	Cu	5.16	n.a.	0.0084
B	122144	Cm	2.45	n.a.	.0042
C	122145	Cl	7.32	n.a.	.0065
A-C . . .	. . .	C	14.73	n.a.	0.0068
n.s.	. . .	Du	10.98	n.a.	n.a.
n.s.	. . .	Dl	4.49	n.a.	n.a.
Locality C77 (Field no. LC-102)					
/Sampler: Andrew Brown. Analysts (TWC-2646): Blanche Ingram, Audrey Pietsch, B. A. McCall., Oil-yield analyses, table 20./					
12-14 . . .	1132-134	Cu	5.84	0.009	0.0073
21-22 . . .	1135-136	Cm	2.50	0.007	.0042
31-34 . . .	1137-140	Cl	7.10	.007	.0054
12-34 . .	. . .	C	15.45	0.008	0.0058
41-45 . . .	141-145	Du	10.36	0.003	0.0012
51-53 . . .	146-148	Dl	5.74	0.005	0.0026
Locality C93 (Field no. LC-103)					
/Sampler: Andrew Brown. Analysts (TWC-2571, 2845): Blanche Ingram, Mary Joslyn. Joseph Budinsky, Carmen Hoy, B. A. McCall. Oil-yield analyses, table 20./					
12-14 . . .	984-986	Cu	6.20	0.009	0.0077
21	987	Cm	1.50	.006	.0040
31-33 . . .	988-990	Cl	7.00	.009	.0060
12-33 . .	. . .	C	14.70	0.008	0.0065
41-44 . . .	991-994	Du	9.00	0.004	0.0011
51-54 . . .	995-998	Dl	6.40	0.006	0.0032
Locality C94 (Field no. LC-105)					
/Sampler, Andrew Brown. Analysts (TWC-2845): Mary Joslyn, Joseph Budinsky, Blanche Ingram, Carmen Hoy, B. A. McCall. Oil-yield analyses, table 20./					
12-15 . . .	1925-1928	Cu	5.00	0.010	0.0076
21	1929	Cm	1.35	.006	.0038
31-35 . . .	1930-1934	Cl	7.65	.007	.0050
12-35 . .	. . .	C	14.00	0.006	0.0058
41-45 . . .	1935-1939	Du	9.60	0.004	0.0010
51-53 . . .	1940-1942	Dl	5.85	0.006	0.0034

Table 9:—Equivalent uranium and uranium analyses of Chattanooga shale – continued.

Sample			Analyses		
Field no.	Laboratory no.	Unit	Thickness, feet	eU, percent	U, percent
		Locality C211 (Field no. LC-113)			
[Samplers: W. H. Hass, Andrew Brown. Analysts (TWC-2571): Blanche Ingram, B. A. McCall. Oil-yield analyses, table 20.]					
12-14	5270-5272	Gu	5.70	0.010	0.0066
15	5273	Gm	1.00	0.010	.0053
16-18	5274-5276	Gl	4.80	.008	.0059
12-18 . . .	. . .	G	11.50	0.009	0.0062
41-45	5277-5281	Du	8.40	0.004	0.0009
51	5282	Dl	2.00	0.005	0.0024
		Locality C212 (Field no. 10M-1)			
[Sampler: L. C. Conant. Analysts (TWC-2950): Mary Joslyn, Joseph Budinsky.]					
1-5	339-343	Gu	7.50	n.a.	0.0080
6	344	Gm	2.00	n.a.	.0034
7-9	345-347	Gl	5.50	n.a.	.0051
1-9	. . .	G	15.00	n.a.	0.0063
n.s. [1] . . .	. . .	Dz	8.00	n.a.	n.a.
		Locality C301 (Field name Tom Brown no. 1)			
[Sampler: T. M. Kehn. Analysts					