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CHARACTERISTICS OF RADIOACTIVE CARBONACEOUS AND BITUMINOUS SHALES

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ILLUSTRATIONS
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CHARACTERISTICS OF RADIOACTIVE CARBONACEOUS AND BITUMINOUS SHALES

ABSTRACT

The radioactive carbonaceous and bituminous shales of the United States are, for the most part, Paleozoic in age. Relatively thin bedding, fine grain, black color, and marine origin are characteristics of these shales. Although their thickness and composition are usually comparatively uniform, small local lenses of carbonaceous shale are abnormally radioactive in some places. The most common constituents of bituminous and carbonaceous shales are silica, organic matter or carbon, and clay minerals. Pyrite, marcasite, and phosphate are associated with these minerals in some of the radioactive shales. Many, but not all, "black" shales yield oil by destructive distillation.

Among the radioactive oil shales described, the Chattanooga formation of Upper Devonian-Lower Mississippian age in Tennessee is the best known in the United States. This formation is widely distributed in the East and Middle West. The maximum uranium content appears to be in the uppermost part of the Chattanooga, and ranges from 0.002 to 0.013 percent and averages 0.005 percent.

Correlatives of the Chattanooga, such as the New Albany shale of Indiana and Kentucky, the Antrim shale of Michigan, the Sunbury and Ohio shales of Ohio and Kentucky, and the Genesee and Dunkirk shales of New York, are generally less radioactive than the Chatta-

nooga of Tennessee. The bituminous shale in the Woodford chert formation of Oklahoma and Kansas, however, is an exception. The radioactivity of these shale beds is comparable to that of the Chattanooga.

The radioactive carbonaceous shales of Pennsylvanian age include the Erin formation of Alabama; the Bourbon, Fort Scott, Hushpuckney, and Stark shales of Kansas; the Pandora, and the shale over the Checkerboard limestone in the Coffeyville formation of Oklahoma. The formations in Oklahoma and Kansas differ from the Chattanooga of Tennessee in that the Pennsylvanian shale beds are relatively thinner and are separated by greater thicknesses of other strata. The uranium content of these shales ranges from 0.003 to 0.013 percent. Many of the Pennsylvanian shales contain abundant phosphatic nodules that are more radioactive than the shales themselves.

Few radioactive Mesozoic shales have been discovered thus far. A carbonaceous shale in the Upper Triassic Lockatong formation in New Jersey, however, contains 0.016 percent uranium, and two small lenses of carbonaceous shale in the Upper Dakota sandstone of Upper Cretaceous age in Colorado are also abnormally radioactive.

The results of investigations of the radioactive black shales indicate a possible relationship between the uranium and sulfur contents. The ratio of uranium to sulfur in samples of pyritic Chattanooga shale is approximately 1:800. A relation between uranium content and paleogeography also seems probable, as the radioactive con-

tent of the Chattanooga is highest in areas where comparatively small amounts of clastic debris from land areas were deposited. Moreover, deflection in gamma-ray well logs shows that the most radioactive shale beds in the Woodford formation appear to be marginal to the deeper parts of depositional basins.

The uranium content of shales is not clearly related, however, to the organic content, as shown by the low radioactivity of most coals. Oil yield, which is directly proportional to the organic content, is likewise not related to the uranium content, as exemplified by the Green River oil shales.

INTRODUCTION

Measurements of the radioactivity of sedimentary rocks have shown that in general the radioactivity of black carbonaceous and bituminous shales is the greatest of all sedimentary rocks (Russell, 1944, pp. 188-191).

The bituminous, or oil, shales emit a strong petroliferous odor when broken or crushed and yield oil by high-temperature distillation; they are composed largely of the remains of microscopic aquatic organisms, both plant and animal. The carbonaceous shales more nearly resemble coal and consist largely of carbonized remains of land plants.

Bituminous shales of Paleozoic age are widespread in the United States, occurring from New York to Alabama in the East and extending westward beyond the Mississippi River. Oil shales of Permian and Tertiary age are extensive in parts of Colorado, Utah, Idaho, Wyoming,

Montana, and California.

Radioactivity tests indicate that those bituminous and carbonaceous shales of Tertiary age, which have been examined thus far, are the least radioactive marine shales, and that their radioactivity is not above the average for sedimentary rocks.

The most notably radioactive shales of the world are those of Cambrian age in Sweden, which are reported to contain a million tons of 0.02 percent uranium (Eklund, 1947, p. 9). This fact and the recent discovery of uranium in lignite in North Dakota warrant continued investigation of carbonaceous rocks as possible sources of uranium.

The characteristics of the known radioactive bituminous and carbonaceous shales in the United States are outlined in this report to serve as a guide in the exploration of similar shale deposits.

Anne B. Keller, Louis C. Conant, and Robert H. Stewart collaborated in the preparation of this report. The manuscript was read critically by Andrew Brown and Arthur P. Butler, Jr., and the latter supervised the general organization of the report. Wilfred C. Carr assisted in drafting one of the illustrations.

URANIUM-BEARING SHALES

The black shales which are of interest at present as possible sources of radioactive material range in age from pre-Cambrian to Cenozoic. In general, the Paleozoic shales are more radioactive than the younger shales (Russell, p. 1945, p. 1486). Whether or not age relationship is any more significant than other factors that

may influence the concentration of radioactive elements in shales is uncertain at present.

Origin and physical characteristics

Abnormally radioactive shales are, for the most part, marine sediments, whereas most shales of continental origin appear to be no more radioactive than the average sedimentary rock. The possibility cannot be eliminated, however, of the future discovery of fresh-water shales having abnormal radioactivity.

In general, uraniferous shales are dark-colored or black fine-grained rocks, some of which seem massive but split into laminae on weathering. The formations are thin compared with other sediments of equivalent age.

The thickness and composition of most, but not all, uranium-bearing shales are remarkably uniform for great distances (McKelvey and Nelson, 1949). Locally, however, small shale lenses are abnormally radioactive (Bernd, Granger, and Sharp, 1949).

Composition

The most common constituents of the radioactive bituminous and carbonaceous shales are silica, organic matter or carbon, and clay minerals. Many shales also contain pyrite or marcasite in the form of lenses, nodules, or disseminated particles; others are phosphatic or contain phosphate nodules or small concretions. Carbonate compounds are usually absent or rare.

may influence the concentration of radioactive elements in shales to appreciable or economic.

Effects on physical characteristics

Chemically radioactive shales are, for the most part, marine deposits, whereas most shales of nonradioactivity appear to be no more radioactive than the average sedimentary rock. The possibility cannot be eliminated, however, of the future discovery of fresh-water shales having economic radioactivity.

In general, radioactive shales are dark-colored or black bituminous shale, some of which have wonderful but evil taste lingering on application. The radiations are this evidenced also other radiations of environment.

The thickness and composition of coal, but not all, uranium bearing shales are remarkably uniform for great distances (McKelvey and Nolan). Locally, however, small shale lenses are abnormally radioactive (Denson, Bentley, and Davis).

Conclusion

The most common constituents of the radioactive bituminous and carbonaceous shales are silica, organic matter, or both, and clay minerals. Many shales also contain crystals or particles in the form of layers, nodules, or disseminated materials; others are phosphatic or contain phosphatic nodules or small concretions. Fossils commonly are usually absent or rare.

The origin of the radioactive elements in bituminous and carbonaceous shales and the minerals with which they are associated are still problematical. No uranium mineral has been found, and it seems probable that the uranium was deposited from solution in the fine-grained or amorphous fraction of the shale (McKelvey and Nelson).

Plant remains are the most abundant of the recognizable organic constituents and comprise aquatic spores and spore cases. Fish, brachiopods, and conodonts are also present in many carbonaceous or bituminous shales. The fact that many of the most radioactive shales possess a high organic content suggests a relationship between the radioactive elements and organic material. The non-marine coals and oil shales, however, contain larger proportions of organic matter than most of the marine oil shales, but are among the least radioactive rocks that have been tested. Russell (1945, pp. 1480-1481) points out that "certain types of organic matter are not associated with high radioactivity," and that "different organisms and different chemical environments could easily alter the types of organic matter and the amounts of the radioactive elements precipitated."

"Preliminary experiments...have shown that certain clay minerals in sedimenting out of colloidal dispersion will adsorb large portions of uranium and thorium salts in solution or suspension...It is evident also that the adsorption of organic matter may influence this co-precipitation" (Evans, 1945, p. 15). The problem of adsorption in relation to phosphate is discussed by McKelvey (see chapter on Phosphoria formation).

A bituminous or oil shale contains little or no liquid oil that can be removed by ordinary petroleum solvents, but will yield oil by destructive distillation. The oil yield increases with the organic content and, in the uranium-bearing oil shales, ranges from 2 to 35 gallons per shorton of rock. However, the radioactivity bears little or no relation to the oil yield.

Descriptions of oil shale formations

The oil shale formations described below include (1) The Chattanooga formation and its correlatives of Upper Devonian-Lower Mississippian age in the East, Southeast, and the Middle West; (2) the Eocene Green River shales of Colorado, Utah, and Wyoming; and (3) the Miocene Modelo formation in southern California.

The Phosphoria oil shale formation of Permian age is not included here, as it is discussed in connection with the chapter entitled "Relation of uranium and phosphate in the Phosphoria formation."

Chattanooga formation

The Chattanooga formation and its correlatives of Upper Devonian and Lower Mississippian age underlie much of Tennessee, southern Kentucky, northern Alabama, Ohio, Indiana, Illinois, and parts of Georgia, Virginia, Mississippi, Missouri, Oklahoma, and Arkansas (see fig. 1).

The Chattanooga is here discussed in more detail than other shale formations, as it is the best known of the radioactive shales

in the United States.

Paleogeography.--The Chattanooga shale and its correlatives accumulated in a widespread interior sea covering vast areas of North America. The sea lay west of the ancient landmass of Appalachia and was apparently bounded on the south and southwest by the landmasses of Ozarkia and Llanoria. Configurations of its shorelines and the positions of probable island and shoal areas are mostly unknown. The Nashville dome in Tennessee and the Jessamine dome in Kentucky apparently were persistently high areas in the interior sea. In general the shale is thinner in Tennessee and thicker to the north and northeast. Some of the difference in thickness probably reflects the distance from a land area which supplied the sediment, although locally it results from the fact that some areas received no sediments at certain times, probably because they were out of water.

Structure.--On the east and west flanks of the Nashville and Jessamine domes the Chattanooga and equivalent formations dip away from the crest at low angles. Westward the shale strata disappear under the Eastern Interior Coal Basin in Indiana and Illinois. East of the Nashville dome the shale underlies much of the Eastern Highland Rim Plateau and the Cumberland Plateau at depths of 300 to 2,000 feet. It is essentially flat-lying in this area but is warped locally into numerous gentle folds. In the folded area of eastern Tennessee, the shale is exposed as long parallel bands and dips at moderate to steep angles. In Alabama the Chattanooga is largely concealed by younger strata but is exposed along limbs of folds in the northeast

[illegible]

[illegible]

part of the State.

Paleontology.--In addition to abundant plant remains, marine organisms of Upper Devonian age include Lingula-like brachiopods, conodonts, and a few fish remains. Conodonts are microscopic plate-like or toothlike parts of an undetermined type of animal, are of great diversity, and have proved to be good stratigraphic markers (Conant, 1949, p. 7).

Stratigraphy.--The Chattanooga formation in east-central Tennessee is about 35 feet thick and consists chiefly of alternating beds of shale and gray claystone or siltstone. The black shale beds are nearly massive when fresh but are fissile when weathered. The different beds are practically identical in appearance, though they can be differentiated in part by their conodonts.

A layer of fine- to coarse-grained sandstone, commonly an inch or less thick, is present at the base of the Chattanooga at most places. It contains assorted conodonts and waterworn fragments of shells and bones.

A conspicuous gray siltstone zone in the middle and lower part of the section in east-central Tennessee is as much as 9 feet thick in places but is absent near the north and south borders of the State. It consists of interbedded black shale and medium-gray siltstone or claystone, the gray beds predominating. A thin bed of bentonite, about one-half inch to 2 inches thick, is a good stratigraphic marker in this area (Hass, 1948, p. 816) and is everywhere within 2 feet of the top of the siltstone zone.

Phosphate nodules, 1 to 12 inches in diameter, are abundant near the top of the Chattanooga in the northern part of Tennessee.

Composition.--The bituminous shale zones are composed of minute grains of quartz, clay, and organic matter. Pyrite and marcasite are distributed unevenly through the shale as small crystals, as crystalline aggregates in thin layers along bedding planes, or locally as nodules. The organic material, probably chiefly plant spores and plankton, constitutes approximately 16 percent of the shale and is disseminated through the rock. The rock yields about 9.5 gallons of oil per short ton (Battelle, 1949, p. 95).

Radioactivity.--The bituminous shale and gray siltstone units in Tennessee are relatively persistent and uniform, and the radioactivity is relatively uniform in any given part of the formation throughout a considerable area.

The uranium content of the Chattanooga shale ranges from 0.001 to 0.035 percent. The higher figure was obtained from a sample of an almost pure bitumen vein in the shale which was collected by J. M. Nelson of the U. S. Geological Survey.

Normally the maximum content of uranium appears to be in the uppermost part of the formation, although nearly as much is present in the next lower bituminous shale zone (see fig. 2). The average uranium content of samples from east-central Tennessee is probably about as tabulated below (Conant, 1949, p. 8).

Name	Approximate thickness (feet)	Average uranium content (percent)
Maury shale	2	0.002*
Chattanooga shale		
Uppermost black shale	7	0.008
Upper silty zone	2	0.005
Middle black shale zone	8	0.007*
Main gray claystone zone	7	0.003*
Lowermost black shale	7	0.004*

* Estimated average, not actually calculated

The radioactive elements in the Chattanooga shale belong to the uranium, thorium, and potassium families. No uranium mineral has been identified as yet, but the uranium is believed to be in an acid soluble form in the fine-grained or amorphous fraction of the rock (McKelvey and Nelson).

It has also been suggested that clays may have withdrawn the uranium from sea water by a base-exchange mechanism (Fredericksen, 1948, pp. 184-185) or by adsorption (Hoogterling and Sisco, 1948, pp. 357-360).

Early studies of the Chattanooga shale indicated a marked relationship between radioactivity and organic content, thereby suggesting that marine plants may have withdrawn uranium from seawater and concentrated it in their tissues before their death and subsequent preservation in sea-bottom muds.

Analysis of a small sample of highly pyritic Chattanooga shale showed a higher uranium content than that of other shale samples from the same vicinity (Carbide and Carbon, 1949, pp. 5, 12). Although the uranium is not contained in the pyrite or marcasite, a definite though not invariable relationship between the uranium and

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sulphides has been noted, the ratio of uranium to sulfur in analyses of samples from 25 widely scattered localities being on the order of 1:800.

Oil shales correlative with the Chattanooga

Several oil shales in the eastern and middle western parts of the United States (fig. 1) of Upper Devonian and lower Mississippian age are correlated in part with the Chattanooga formation, although the exact correlations with the various units of the Chattanooga shale are still uncertain. Most of these shales appear to be less radioactive than the Chattanooga of Tennessee. This may be due to one or more of the following factors:

(1) The other formations may be similar to the less radioactive parts of the Chattanooga shale.

(2) The other shales may include more clastic material or carbonates, both of which are noticeably absent from shales possessing abnormal radioactivity. The presence of calcium in the New Albany shale may account for its relatively low radioactivity.

(3) The shale may have accumulated more rapidly, thereby diluting the uranium precipitates, whatever their nature.

New Albany shale.--The New Albany shale occurs on the west flank of the Cincinnati arch in Indiana and north-central Kentucky. The formation ranges in thickness from 50 to 140 feet and, in general, resembles the Chattanooga shale. Pyrite is well distributed throughout the New Albany. According to Reeves (1922, p. 1070) and Campbell (1946,

p. 875), lime concretions are abundant, and Campbell also mentions the presence of sandstone and limestone lenses in the bulk of the shale. The topmost part of the New Albany shale contains phosphatic nodules. This formation in Indiana yields from 6 to 14 gallons of oil per ton of rock.

The data available at present suggest that the New Albany in Indiana is less radioactive than its equivalent in Tennessee and Kentucky but is more radioactive than correlatives in Ohio, Illinois, and Missouri. Parts of the New Albany contain about 0.006 percent uranium (Nelson and Stratton, 1949, pp. 7-8). The relatively high calcium carbonate content of this formation may explain the weaker radioactivity of the New Albany shale compared with the Chattanooga of east-central Tennessee.

Antrim shale.--The Antrim shale of the Lower Peninsula of Michigan is considered to be of early Upper Devonian age (Cooper, 1942, p. 1745). It is similar to part of the Chattanooga shales, and marcasite nodules occur in some layers. According to available data, the Antrim is less radioactive than the topmost unit of the Chattanooga of Tennessee or of the New Albany formation (Slaughter and Clabaugh, 1944, Secs. 8-113 and 114; Sears, 1945, pp. 10-12).

Woodford shale.--The bituminous shale in the Woodford chert, which is widespread in Oklahoma and Kansas, has been doubtfully assigned to the Devonian and is considered by Gott (1948, p. 6) to be of late Devonian or early Mississippian age and possibly may be

correlated with the Chattanooga. It ranges in thickness from less than 20 to more than 400 feet. Alternating beds of chert and dark fissile shale are the chief constituents, and dark gray to black nodules are abundant locally in the shale or along partings between shales and chert. The beds yield shale oil, and tests show that they are consistently higher in radioactivity than other formations in Oklahoma. They contain an average of 0.007 percent uranium and range from 0.003 to 0.010 percent (Slaughter and Clabaugh, 1945, pp. 11-12). The most radioactive parts of the formation seem to be marginal to the deeper parts of depositional basins, as shown by deflection in gamma-ray logs of drill holes (Gott, 1948, p. 7).

Miscellaneous oil shales equivalent in whole or in part to the Chattanooga.—The formations listed below are similar to the Chattanooga in general characteristics, but where they have been examined their radioactivity is relatively low.

Formation	State
Cleveland shale	Ohio
Sunbury shale	Ohio, Kentucky
Ohio shale	Ohio, Kentucky
Genessee shale	New York
Dunkirk shale	New York

CARBONACEOUS SHALES

In this group are included the carbonaceous or "black" shales that do not yield oil on distillation but contain abundant carbonized plant matter, chiefly land plants. Some of the most favorable carbonaceous shales that have been examined for radioactivity are discussed

briefly here.

Pennsylvanian black shales

Erin shale

The Erin shale, which is probably of early Pennsylvanian age, occurs in Clay County, eastern Alabama. It is a black pyrite-bearing shale or slate which weathers to a gray color. Tests throughout a stratigraphic thickness of 510 feet indicate that in most of the formation the radioactivity is no more than the average for sedimentary rocks, although samples from a relatively rich zone, 3.5 feet thick, contain 0.009 percent uranium (Butler and Chesterman, 1945, pp. 21-22). No relation can be discerned between the more radioactive part of the formation and any other recognizable feature that might explain localization of radioactivity.

Pennsylvanian shales of Oklahoma and Kansas

Radioactive carbonaceous shales of Pennsylvanian age are present at the surface in northeastern Oklahoma and southeastern Kansas and occur at considerable depth along the buried Nemaha anticline and on the northeast flank of the Wichita Mountains. The shale beds in this area range from 0.2 to more than 12 feet, averaging 3 feet, in thickness. The thin beds of black fissile shale are separated by limestone strata and are commonly underlain by thin coal beds. The general character and considerable stratigraphic range of the shales are shown in figure 3.

Small phosphatic nodules and concretions are abundant in many of the shale beds. The nodules are fine-grained, hard, usually black

or brown, and locally contain pyrite or marcasite. Some nodules are nearly round with a maximum diameter of two inches; others are flat and irregular in shape with a maximum diameter of three inches. Their occurrence in the shale is erratic, and their radioactivity varies. The nodules are commonly more radioactive than the surrounding shale (Slaughter and Clabaugh, 1945, p. 16). The carbonaceous shale over the Checkerboard limestone in the Coffeyville formation of Oklahoma appears to be the most favorable for abundance and radioactivity of nodules. At one locality in Tulsa County, the shale is estimated to contain about five percent nodules; the average uranium content by chemical analysis of the nodules is 0.030 percent, but the average for 5.7 feet of the shale is about 0.003 percent (Slaughter and Clabaugh, 1945, p. 17) (see fig. 4). Radioactive black shales and phosphate nodules have not been studied in sufficient detail to determine why the nodules are much more radioactive than the shale. It is apparent, however, that phosphate has an affinity for uranium in this environment similar to the affinity found in phosphate deposits.

The light-colored clayey shale and adjacent coal have a very small uranium content.

Recent studies of gamma-ray well logs suggest that abnormally radioactive zones occur above fault planes and along ancient erosion surfaces in this area (Gott, 1948, p. 17). Whether or not concentration of radioactive material is genetically related to faulting or to deposition following erosion intervals has not been determined.

The results of radioactivity tests of other Pennsylvanian black shales are given in the following table.

Formation	State	Percent uranium	
		Shale	Nodules
Bandera	Oklahoma	low	.016
Bourbon	Kansas	.013	.032
Fort Scott	Kansas	.005	.017
Mushpuckney	Kansas	.010	
Labette	Oklahoma	low	.022
Stark	Kansas	.008	.021

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Upper Triassic

A radioactive shale of Upper Triassic age was recently discovered in the Lockatong formation in New Jersey (fig. 1). The Lockatong is the middle formation of the Newark group, which is exposed in a broad band extending northeasterly across the central part of the State. The Lockatong formation ranges in thickness from 1700 to approximately 2600 feet and consists of carbonaceous shales, dark-red shales, hard massive argillite, and a few thin layers of calcareous shales. Pyrite is abundant in some of the massive dark shale.

Samples collected at Woodsville, New Jersey, east of Sourland Mountain, include one containing 0.016 percent uranium. The samples obtained probably come from the middle part of the formation, although considerable faulting and soil cover make the stratigraphic position difficult to determine.

The results of qualitatively tasting different Pennsylvanian black shales are given in the following table.

Formation	Shale	Texture
Conemaugh	Calcareous	Fine
Pottsville	Ferrous	Medium
Allegheny	Ferrous	Medium
Pottsville	Calcareous	Fine
Glade	Siliceous	Coarse

- - - -

Short Stories

A radioactive shale of Upper Triassic age was recently discovered in the Lockatong Formation in New Jersey (Fig. 1). The Lockatong is the middle formation of the Newark group, which is exposed in a broad band extending southwestward across the central part of the State. The Lockatong formation ranges in thickness from 1700 to approximately 2000 feet and consists of argillaceous shales, dark-red sandstones, some massive argillite, and a few thin layers of calcareous shales. Pyrite is abundant in some of the massive dark shale.

Shale collected at Wyckoff, New Jersey, west of Hohokus Brook, yielded two counts during 0.05 percent uranium. The samples obtained probably came from the middle part of the formation, although considerable faulting and soil cover make the stratigraphic position difficult to determine.

Upper Cretaceous

Two small lenses of ferruginous carbonaceous shale in the upper Dakota sandstone in Turkey Creek Canyon, Morrison-Golden area, Jefferson County, Colorado, were examined. Two samples from these lenses contain 0.006 and 0.035 percent uranium, respectively (Herzog, Granger, and Cheryl).

SLIGHTLY RADIOACTIVE SHALES

Phosphoria oil shale

The Phosphoria oil shales of Permian age in Idaho, Montana, and Wyoming are marine sediments which are of interest for their phosphate content and abnormal radioactivity. For a detailed description of this formation, see the chapter titled "Relation of uranium and phosphate in the Phosphoria formation."

Green River oil shales

The Green River formation of Eocene age is widely distributed in parts of Colorado, Utah, and Wyoming (fig. 1). It consists of alternating beds of oil shales, siltstone, and, locally, limestone. The Green River shale differs from the oil shales described above in that it is of lacustrine rather than marine origin, and calcite is the predominant mineral constituent (Bradley, 1929, pp. 121-131). The organic content is as much as 36 percent, which is more than that of the Chattanooga.

The members of the Green River formation are, in ascending order:

Parachute Creek
Long's shale
Tipton tongue
Tower sandstone lentil

The Laney shale is the principal oil-bearing member occurring in the Green River and Uinta Basins and includes a black shale that weathers to a conspicuous bluish white and a light- to dark-brown shale that weathers buff. The bituminous shale, containing 19 percent organic matter, yields about 35 gallons of oil per short ton (Battelle, 1949, p. 93). Part of the Tipton tongue is a low-grade papery oil shale with a yield of less than 10 gallons per ton. The few tests that have been made of the Green River oil shale at the outcrop show that the radioactivity of the formation is about normal for sedimentary rocks (Chesterman and Main, 1947, pp. 14-15). Radioactivity measurements made in the Geological Survey laboratory on samples from the Bureau of Mines Experimental Mine at Rifle, Colorado, show that the equivalent uranium content ranges from less than 0.001 to 0.003 percent and confirm the outcrop tests. This formation is, therefore, unfavorable as a source of uranium.

Modelo oil shale

The Modelo formation of middle Miocene age occurs in Los Angeles and Ventura Counties, California (fig. 1). The lower Modelo consists of bituminous and siliceous organic shales, and an oolitic phosphate bed occurs near its base in the Santa Monica Mountains. At points where it has been tested at the surface, this oil shale is low in radioactivity (Chesterman and Main, 1947, p. 16)

SUMMARY

The known radioactive black shales of the United States possess several characteristics that may serve as guides in finding other radioactive black shales. These characteristics are reviewed briefly below.

Thin-bedded fine-grained black shales of marine origin, including many oil shales, are commonly more radioactive than thick-bedded coarser rocks. Black shales of continental origin, such as the Green River oil shales, are not abnormally radioactive, whereas marine black shales that are products of slow deposition over long periods of time generally contain significant amounts of radioactive elements. The radioactive content is apparently related to the paleogeography, as it is highest in areas which received only small amounts of clastic debris from the land. In some formations the most radioactive parts seem to be marginal to the deeper parts of the depositional basins (Gott, 1948, p. 7), as illustrated by the Woodford.

The uranium content of carbonaceous and bituminous shales is not clearly related to the organic content. Coal, for example, is highly carbonaceous but rarely exhibits abnormal radioactivity. However, lignite with relatively high uranium content has recently been discovered in the Eocene Sentinel Butte (?) formation of North Dakota.

The oil yield of shales, which is proportional to the organic content, is not proportional to the radioactive elements. Although uranium is not found in the sulfide minerals of the carbonaceous or

bituminous shales, it is present in the Chattanooga shale in an almost direct ratio to the sulphur, a ratio of about 1:500.

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