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GEOLOGICAL SURVEY

RADIOACTIVITY OF SEDIMENTS IN PARTS OF OKLAHOMA AND KANSAS

Preliminary Report

by

Garland B. Gott

December 1948

Trace Elements Investigations - Report 52

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Sincerely yours,

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RADIOACTIVITY OF SEDIMENTS IN PARTS OF OKLAHOMA AND KANSAS

ABSTRACT

During February 1948 a project was initiated to obtain pertinent data in oil company files relating to the radioactivity of sedimentary rocks in Oklahoma and Kansas as indicated by gamma-ray logs. The location of potential ore-bearing horizons and elimination of unpromising areas, together with calibration of gamma-ray logs, were the primary objectives.

More than 600 gamma-ray logs representative of wells in the central parts of Oklahoma and Kansas, together with the related stratigraphic information, have been examined. Only a few samples from drill holes for which gamma-ray logs were available could be located; these samples have been collected and analyzed to provide basic data for the calibration of gamma-ray logs in terms of equivalent uranium content.

The following tentative conclusions are made on the basis of the preliminary results of this investigation:

(1) Gamma-ray logs, developed primarily for stratigraphic correlations, can easily and profitably be applied to rapid reconnaissance in the search for radioactive deposits in areas where many wells have been gamma-ray logged.

(2) The use of these logs permits a quick preliminary evaluation of the degree of radioactivity in subsurface rocks.

(3) Preliminary results indicate that a semi-quantitative calibration of the radioactivity shown by gamma-ray logs can be made. A tentative calibration of 0.0007 percent equivalent uranium per inch of deflection on gamma-ray logs run at a 10-inch sensitivity scale is suggested by a comparison of radiometric analyses of cores and gamma-ray logs.

(4) Gamma-ray well log data indicate that the highest radioactive zones in the Woodford (Chattanooga) shale are marginal to depositional basins. On the basis of the gamma-ray log calibration, this shale seems to have an average of about 0.006 percent equivalent uranium.

(5) The most radioactive sediments encountered are those of some basal Pennsylvanian deposits in the Peabody field along the Nemaha anticline in south-central Kansas at depths between 2,350 and 2,400 feet. Radiometric measurements of weathered cable-tool samples from old sludge pits show a range from 0.08 to 1.0 percent equivalent uranium. One gamma-ray log of a drill hole located in this field indicates the presence of 0.19 percent equivalent uranium on the basis of the tentative gamma-ray log calibration. Chemical analyses of weathered cable-tool sludge-pit samples indicate that the radioactivity is due largely to radium. The possibility that the uranium has been separated from the radium and carried away in solution during the drilling process or during the subsequent weathering over a period of 25 years seems to be indicated.

(6) Sediments at selected localities near the base of the Pennsylvanian rocks along the Nemaha anticline range from 8 to 30

times more radioactive than does the average Woodford (Chattanooga) shale. This radioactive material is present in the subsurface at six localities along the flanks of the Nemaha anticline between central Kansas and central Oklahoma. This anticline extends from southeastern Nebraska to southern Oklahoma. It was elevated above base level during early Pennsylvanian time and then subjected to rapid erosion prior to later Pennsylvanian overlapping. Although there is no assurance that the association between structure and radioactive material is continuous over this distance, gamma-ray logs indicate that there is at least an intermittent association. An ore body found along the Nemaha anticline would, therefore, have a very good possibility of being of comparatively large areal extent with tonnage in the order of millions of tons.

(7) Orogenic and erosional processes are probably the controlling factors in the localization of the radioactive deposits in the basal Pennsylvanian sediments.

INTRODUCTION

Gamma-ray well logging was initially developed as a method for detecting lithologic differences in the rocks through which many of the older oil wells had penetrated. In many instances these older wells were cased without adequate testing for oil or gas content in the upper sands. In later years, after depletion of the oil from the deeper formations, accurate locations of the cased out potential oil-bearing sands were needed in order to determine perforation points. The gamma-ray well-logging device was developed by well surveys and later licensed to Lane-Wells Company for the purpose of obtaining such information while the casing was still in the hole.

A gamma-ray curve is obtained by measuring the current developed through a gas-filled ionization chamber and, after amplification, recording it at the surface in the form of a continuous graph by means of an automatic pen recorder. Ionization of the inert gas in the chamber is effected by gamma-ray penetration from naturally radioactive rocks, and as the amount of current which flows through the charged system is directly proportional to the gamma radiation, the completed graph represents an indirect measurement of the gamma radiation of the rocks closely adjacent to the drill hole.

The gamma-ray log was later expanded to include a neutron log. The ultimate purpose of the neutron log is to determine the relative porosity of the rocks. To do this the absorption characteristic of hydrogen is utilized. As hydrogen is present in some form in all fluids, a comparative measurement of the amount of hydrogen present in the rocks would serve as a basis for estimating the fluid content. Measurement of the hydrogen content is accomplished by fast neutron bombardment of the rocks adjacent to the drill hole from a neutron source attached to the bottom of the ionization chamber. Where hydrogen is not present in the formation, the neutron is taken into the atomic nucleus by many of the elements present in the rocks. During the process of energy readjustment gamma-rays are emitted. These artificially stimulated gamma-rays are measured in a manner similar to the natural gamma radiations. Where hydrogen is present in the rocks in sufficient quantities, neutrons are slowed down by collision near the source, resulting in a less amount of gamma-ray stimulation near the ionization chamber. The effect registered on the neutron log is a curve of low intensity representing those formations having a high hydrogen content and a curve of high intensity representing those formations that are dry and dense.

The sensitivity scale of Lane-Wells radioactivity logs varies over a rather wide range from one survey to another and often is changed during the process of logging one well. The operator of the well-logging device chooses a scale which will permit as much of the graph as possible to remain on a six-inch wide strip of graph paper. The sensitivity scale is given on the heading of the log or longitudinally along the curve in terms of inches deflection and simply means that that amount of deflection was obtained by placing a standard sample of known equivalent uranium content against the ionization chamber and adjusting the instrument to the desired relative sensitivity. Thus, the instrument would be ten times more sensitive on a ten-inch sensitivity scale than it would be on a one-inch scale, or stated differently, a deflection at a scale of one inch, which is as great as another deflection at a scale of ten inches, would represent a bed which contained ten times as much equivalent uranium. It is therefore necessary to consider the sensitivity scale of the instrument before making comparisons between individual radioactive logs. For the sake of clarity and consistency, those gamma-ray logs that are discussed in this report have been computed to show the deflection they would have shown had they been run on a ten-inch sensitivity scale. Radiometric analyses of 100 core samples indicate that a one-inch deflection, at a ten-inch sensitivity scale, on a gamma-ray log, represents approximately 0.0007 percent equivalent uranium content. More chemical and radiometric analyses of cores from wells that have been gamma-ray logged may require this figure to be revised. This calibration, therefore, is intended to be used only for the purpose of estimating the degree of radioactivity of the more radioactive beds, as indicated by gamma-ray logs, where samples are not available.

As the gamma-ray logs indicate the relative degree of radioactivity of the rocks adjacent to the drill hole, they are particularly useful as an aid in locating zones which may contain radioactive ores or in eliminating those non-radioactive beds upon which more work need not be done. They also make it possible to form an estimate of the relative radioactivity of the subsurface rocks in areas where such estimates would be impossible to make by surface methods.

For these reasons a project was started in February 1948 for the purpose of collecting from the major oil companies copies of their Lane-Wells radioactivity logs with all available stratigraphic information for the same drill holes for which gamma-ray logs had been obtained. The primary purpose of this investigation was to find locations of potential ore deposits and to determine what beds could be considered as non-radioactive. To date 467 gamma-ray logs from Oklahoma and about 150 from Kansas have been examined. In Oklahoma most of the wells that have been gamma-ray logged are within a 75-mile north-south strip through the central part of the state.

Acknowledgments.—The following oil companies have cooperated

in this investigation by giving copies of radioactive logs as well as stratigraphic and general geological information: Amerada Petroleum Corporation, Atlantic Refining Company, Barnsdall Oil Company, The California Company, Carter Oil Company, Cities Service Oil Company, Continental Oil Company, Gulf Oil Corporation, Magnolia Petroleum Company, Pure Oil Company, Sinclair-Prairie Oil Company, Stanolind Oil and Gas Company, and The Texas Company. Well Surveys and Lane-Wells Company have also given information pertaining to the technique of making radioactive surveys and general information regarding the radioactivity of the sediments in those areas with which they are familiar.

RADIOACTIVITY OF THE SEDIMENTS

General Statement

The Paleozoic rocks from upper Cambrian to Permian are well represented in Oklahoma and Kansas (Plate V). Radioactivity logs have been made through all of this section, with the possible exception of the upper Cambrian and lower Ordovician limestones and dolomites, and the resulting gamma-ray logs indicate that the great mass of rocks penetrated by drill holes are radioactively weak. On the basis of intensity of radioactivity, the Paleozoic rocks of this section can be divided conveniently into three classifications: (1) The slightly radioactive rocks that predominate throughout the stratigraphic section and lithologically include all of the rock types except black shales; (2) the more highly radioactive Woodford (Chattanooga) and other black shales; and (3) some Pennsylvanian sediments adjacent to the Nemaha anticline and Wichita Mountains which are from 6 to 30 times more radioactive than is the Woodford (Chattanooga) black shale. Deposits of the last two classifications are discussed below.

Woodford (Chattanooga) Shale.—The Woodford black shale of early Mississippian or late Devonian age is the most extensive black shale bed of this region. It is underlain by the Hunton limestone of Siluro-Devonian age, overlain by the lower Mississippian Kinderhook group, and varies in thickness from less than 20 feet to more than 400 feet. This black shale bed causes an average deflection on the gamma-ray logs of about 8 inches, but has a known maximum variation ranging between 2.4 and 28 inches deflection at a sensitivity scale of 10 inches.

The area underlain by the Woodford shale is large, and the tonnage involved is tremendous. By using a factor of 0.0007 percent equivalent uranium for one-inch deflection on gamma-ray logs run at a ten-inch sensitivity scale, the following estimates of percentages can be made. The range in percent equivalent uranium of the Woodford shale is from 0.001 to 0.019 percent; the average is 0.006 percent.

The radioactive intensity of the Woodford shale is so consistently above that of other formations in Oklahoma that it serves as an excellent marker for stratigraphic correlations based on gamma-ray logs. Variation in deflection on these logs appears to be related to depositional or ecological factors. Although the amount of gamma-ray log information is inadequate to make this point clear, the areas of highest gamma-ray deflection appear to be marginal to the deeper parts of the depositional basins. Both the thinner Woodford shale between the deeper basins, and the thicker part within the basins cause weaker deflections than does this thin band (see Plates III and IV).

Nelson and Brill _/ have described a similarly high radioactive

_/ Nelson, J. M., and Brill, K. G., Jr.; Radioactivity of the Chattanooga shale east of the Mississippi River and south of the Ohio River; U. S. Geological Survey, Trace Elements Investigations—Report No. 22, August, 1947.

zone in the Chattanooga shale bordering shallow basins along the east side of the Cincinnati Arch. They suggest that this concentration may have been brought about by the removal of the lighter organic fractions, which are associated with uranium, from the crest of the Arch by tidal currents and deposited in the small basins along the flank where the currents were weaker. The organic content of the sediments deeper in the basin was contaminated with coarser clastic material from Appalachia, and these sediments, therefore, have a lower equivalent uranium content.

The above hypothesis applied to explain the conditions on the east flank of the Cincinnati Arch could probably be applied to explain some of the conditions in Central Oklahoma. It is doubtful, however, if the thicker sediments in the deeper basins have been contaminated, as may have been the case on the east side of the Cincinnati Arch, by a type of sediment which would not also have been deposited both within and between the basins.

Another hypothesis which should be considered in explaining the concentration of radioactive elements along margins of depositional basins is that these elements are directly related to the ecological factors controlling the plant and animal life existing during the time of Woodford shale deposition. It is possible that some species of life capable of extracting uranium from sea water were restricted to the shallow water adjacent to the tidal zone. Further encroachment of the sea would inundate the interbasinal highs and bring about conditions unfavorable for the continued life of the species in their former habitat. Under these conditions, a greater concentration of radioactive elements would be present at the base of the formation due to an initial progressive shore line as well as in interformational zones near the depositional margins caused by fluctuations between a progressive and regressive sea. To some extent this idea can be substantiated by making a comparison of Plates II and III.

Sylvan Shale.—The Sylvan shale of Ordovician age is present in the subsurface throughout that part of Oklahoma covered by this report. Normally it overlies the Viola limestone and underlies the Hunton limestone. However, the overlying Hunton has, in some places, been removed by erosion and in those places the Sylvan shale directly underlies the Woodford shale. The Sylvan shale is a smooth, even textured, greenish-gray shale with thicknesses commonly ranging between 90 and 125 feet. Usually it causes deflections on the gamma-ray logs of 2.5 to 6 inches. In no place, where both formations are present in the same drill hole, has it been observed to exceed the Woodford shale in radioactive intensity.

<u>Other black shales</u>.—In central and south-central Oklahoma there is a rather highly radioactive zone at about the top of the Mississippian Caney shale (Plate IV). The zone is 10 to 20 feet thick and causes a gamma-ray curve to be registered comparable to those curves representing the Woodford shale. Correlations based on gamma-ray logs indicate that the Caney shale is present in the deeper part of the depositional basin in Seminole and adjoining counties. Although there is inadequate information available concerning the area south of the Seminole district, the same stratigraphic unit probably extends southward around the east end of the Arbuckle Mountains.

Some black marine shale beds of Pennsylvanian age cause deflections corresponding in magnitude to average deflections caused by the Woodford shale. In Oklahoma these Pennsylvanian shales often contain radioactive nodules at the outcrop and it is more than probable that these nodules cause at least part of the gamma-ray peaks in the subsurface. These shales are, however, generally thinner and their radioactivity is more erratic than that of the Woodford. They, therefore, offer a much less desirable source for radioactive elements.

Representatives of Lane-Wells Company have stated that the Heebner shale in Kansas, a member of the Oread limestone of the Shawnee group, causes a deflection equally as high as that caused by the Woodford shale. The writer has examined only three gamma-ray curves that are definitely known to represent the Heebner shale (figures 7, 8, and 9). These curves showed the Heebner shale to be from 5 to 20 feet thick and caused deflections of 6.6, 3.8, and 6.3 inches computed to a 10-inch sensitivity scale. More data pertaining to the Heebner shale is needed before any conclusion regarding its radioactivity can be made.

In the same wells, the Douglas shale group, which is separated from the Heebner shale by the Toronto limestone member, causes deflections of 5.6, 3.8, and 6.3 inches. The Douglas shale is from 45 to 70 feet thick in these three wells.

<u>Radioactive Pennsylvanian Sediments near the Nemaha Anticline and the Wichita Mountains</u>.—Unusually high deflections on gamma-ray logs were caused by some Pennsylvanian beds along the buried Nemaha anticline in both Oklahoma and Kansas and along the northeast flank of the Wichita Mountains in Oklahoma.

In Sec. 8, T. 8 N., R. 20 W., just northeast of the buried Wichita Mountains, the Gulf-Garland No. 1 well (figure 2) penetrated rather highly radioactive arkosic beds of Pennsylvanian age between depths of 5,400 and 6,150 feet. The maximum deflection on the gamma-ray log is 49 inches or about six times the normal Woodford shale deflection. The presence of arkosic material in these sediments indicates that they were deposited at a time when the igneous core of the Wichita Mountains was exposed and suggests that the radioactive material was derived from that source.

By using the calibration of .0007 percent equivalent uranium for one-inch deflection on gamma-ray logs at a ten-inch sensitivity scale, but keeping in mind that this calibration may not be completely reliable, the maximum equivalent uranium content indicated in the

Gulf-Durland well is about 0.033 percent. The arkosic facies of these beds are present along the northeast flank of the Wichita-Amarillo uplift for 200 miles to the northwest, but no further information pertaining to their radioactivity is known to the writer. It should be noted, however, that the helium produced in the Amarillo district is localized over this same structural feature and stratigraphically within and immediately above the granite arkose.

One of the most interesting gamma-ray logs examined is the one of the Cities Service-Trosper Park No. 24 well located near the crest of the faulted Nemaha anticline in the Oklahoma City field. This drill hole, located in NE ¼ NE ¼ SW ¼ sec. 12, T. 11 N., R. 3 W. (figure 3), penetrated a highly radioactive zone between depths of 4,000 and 4,600 feet. The maximum deflection on the gamma-ray log is 88.5 inches computed to a 10-inch sensitivity scale with an average deflection of about 42.5 inches for the total 600-foot thickness. Again using the gamma-ray log calibration discussed above, the average equivalent uranium for this 600-foot zone is estimated to be between 0.05 and 0.06 percent. The highly radioactive zone begins at about the base of the Hoover sand and continues downward through the Greed limestone and 500 feet into the Tonkawa formation. Since the gamma-ray log did not extend below 4,600 feet, the total thickness of the radioactive zone is not known. This radioactive zone is located almost directly above a pre-Cherokee (Pennsylvanian) fault of about 2,200 feet displacement (figure 1). Gamma-ray logs of closely adjacent wells on either side of the fault plane, indicated that only normally radioactive rocks were present at these localities. The period of greatest movement along this underlying fault probably occurred during early Pennsylvanian time, but prior to Cherokee deposition. After truncation of the anticline and Cherokee deposition, recurrent faulting slightly displaced the Cherokee sediments and perhaps caused extensive fracturing in the later Pennsylvanian sediments.

The location of the radioactive zone directly above the fault plane and the uniformly high gamma-ray deflections transgressing lithologic boundaries indicate that the radioactive material in these beds may be genetically related to the faulting. If this assumption is valid, the following hypotheses can be advanced. (1) The radioactive material originated within an igneous source and was deposited later than the time of faulting. It ascended the fault zone in hydrothermal solutions and was precipitated along fracture and shear zones resulting from the faulting. (2) The radioactive material was deposited from meteoric solutions descending a highly fractured zone and carrying radioactive elements derived from black marine Pennsylvanian shales higher in the section.

Farther north along the east flank of the Nemaha anticline (figure 4) in sec. 24, T. 27 N., R. 5 E, a zone in the Gulf-McComb No. 5 well between 2,915 and 2,845 feet, and another zone between 2,925 and 2,970 feet caused deflections of 40 and 55 inches respectively (estimated 0.028 and 0.038 percent equivalent uranium). The position of these zones within the stratigraphic section is not known except that they are in the lower Pennsylvanian. The well was completed in 1923 and no samples are available.

Thirty-two miles west of the Gulf-McComb No. 8 well and on the west flank of the anticline in [illegible] sec. 16, T. 27 N., R. 1 W., the gamma-ray log of the C. E. Johnson-School Land No. 1 well shows a 53-inch deflection representing one zone in the Pennsylvanian. The estimated percent of equivalent uranium for this deflection is 0.037. No stratigraphic data pertaining to this well is, at present, available to the writer.

Still further north, on the east side of the Nemaha anticline, in Cowley County, Kansas, [illegible], sec. 8, T. 33 S., R. 7 E., the Dillworth and Miller-Dillworth No. 2 fee well (figure 5) penetrated a highly radioactive zone between depths of 2,670 and 2,710 feet. The deflection caused by this zone was about 200 inches at a sensitivity scale of 10 inches, and the estimated percentage of equivalent uranium is 0.07 percent. According to the thickness of the Permian and Pennsylvanian as given by the State Geological Survey of Kansas _/ for this vicinity, the radioactive zone represented

_/ Jewett, John Mark, and Abernathy, George E., Oil and gas in eastern Kansas; State Geological Survey of Kansas, Bull. 57, pp. 94-95, 1945.

on this log should be within the basal part of the Pennsylvanian. It is perhaps significant that the Dexter helium field is located only two miles to the southwest of this well. The Wabaunsee and Shawnee groups of Pennsylvanian age have produced helium in the Dexter field between the depths of 325 and 1,200 feet _/.

_/ Dobbin, C. E., Geology of Natural Gases Rich in Helium, Geology of Natural Gas, p. 1035, 1935.

Northwest of the Ellsworth No. 2 well and high on the west flank of the Nemaha anticline in the Peabody field, Marion County, Kansas, in NE¼NE¼, sec. 8, T. 22 S., R. 4E., the C. H. Colpitt-Spier No. 1 well (figure 6) penetrated a very highly radioactive zone in basal Pennsylvanian sediments. Between depths of 2,350 and 2,366 feet the gamma-ray curve reached a maximum deflection of [illegible] inches, computed to a 10-inch sensitivity scale. An equivalent uranium content of approximately 0.18 percent is indicated by this deflection. Between 2,100 feet and the top of the above-mentioned zone, three other gamma-ray peaks occur with deflections varying from 135 to 150 inches. Samples collected from old sludge pits of this and adjacent wells drilled 25 to 30 years ago contained an equivalent uranium content ranging from 0.08 to 1.0 percent and an uranium content determined by chemical analyses of four samples of .003 percent. These wells were distributed over an east-west distance of one mile (figure 11). In addition, remnants of drill sludge and cuttings from at least one well five miles north of this area were also highly radio-active.

Radiometric and chemical analyses indicate that most of the radioactivity from these samples is due to radium. However, the presence of so much radium suggests that uranium might also have been present before or shortly after the cuttings were brought up by the drill. During the process of drilling or during the time when the cuttings were subjected to surface weathering, the uranium may have been taken into solution and carried away by water.

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During the examination of some cable-tool samples from wells located south of the Peabody field and closely adjacent to the Nemaha anticline, small amounts of a canary yellow, amorphous to finely granular mineral were found coating shale fragments. This mineral, which was separated from shale by leaching with cold water, was found by chemical analyses to contain from 0.001 to 0.01 percent uranium and 5.8 percent iron in combination with sulfate radical. It is thought that this yellow mineral represents the residue after evaporation of the water from the wet samples. It could hardly be expected that such a highly soluble mineral could withstand the drilling process without having been taken into solution, and this may be the reason for the presence of radium without uranium in the Peabody field.

The Peabody field was discovered in 1919 and was largely drilled out before the custom of collecting reliable subsurface information was begun. Consequently the identification of the formation from which this radioactive material originally came is open to question. All available evidence, however, indicates that the most radioactive zone is basal [illegible] and is at the unconformity between the Pennsylvanian and the underlying Mississippian chert. This indicates that the radioactive material was deposited upon an erosional surface representing all of pre-Cherokee Pennsylvanian time. During this hiatus the Nemaha anticline was elevated above base level, and locally, the Mississippian, Devonian, Ordovician, and Cambrian beds were removed by erosion. The source of the radioactive sediments could, therefore, have been a wide range of both sedimentary and igneous rocks. On the basis of present information, however, it is more probable that the material was either concentrated through the erosion and redeposition of (1) the Chattanooga shale, or (2) uraniferous deposits in the igneous core of the Nemaha

Table 1

Radioactivity of Selected Pennsylvanian Beds

Represented on gamma-ray logs Figure	Maximum deflection in inches on gamma-ray log at 10-inch sensitivity scale	Estimated percent equivalent uranium Column II X 0.0007	Thickness of radioactive zone Feet	Age
2	48	0.033	Three zones totaling 350 feet	Basal Pennsylvanian
3	88.5	0.062	600 +	Oread-Tonkawa (lower Shawnee and Douglas)
4	55	0.038	Two zones totaling 75 feet	Lower Pennsylvanian
5	100 ±	0.07	20	Marmaton ?
6	262.5	0.18	17	Marmaton ?

anticline.

The radioactive intensity of the lower Pennsylvanian beds discussed above and represented by figures 2-6, inclusive, are from 6 to 30 times greater than that of the average Woodford shale. The minimum estimated range of equivalent uranium content is from 0.03 to 0.18 percent. This abnormally high radioactive concentration indicates that some condition or set of conditions was present which resulted in the concentration of radioactive elements in localized areas. Information pertaining to the stratigraphy and radioactivity of the rocks in the vicinity of these abnormally high gamma-ray peaks is inadequate for analysis of the factors which caused the localization of the radioactive elements. Nevertheless, the few known facts listed below suggest that the concentration of the radioactive elements is closely related to the orogenic and erosional processes of early Pennsylvanian time.

(1) The more highly radioactive zones are all of Pennsylvanian age.

(2) The sediments with which the radioactive elements are associated are younger than the orogeny which resulted in the formation of the Nemaha anticline and the Wichita Mountains.

(3) The radioactive sediments were, in part, derived from the eroded cores of these major structural features.

(4) So far as is known, the radioactive sediments were, with the exception of those beds represented in figure 3, deposited shortly after an erosional interval.

(5) Figure 3 differs from the other gamma-ray logs in that it may represent a primary deposit associated with a fault zone, and, therefore, of possible igneous origin, while the other gamma-ray curves represent sedimentary beds.

RELATION OF RADIOACTIVE MATERIAL TO UNCONFORMITIES

There is some indication that radioactive materials are concentrated locally along old, erosional surfaces. This is well illustrated by figures 7, 8, 9, and 10, where somewhat highly radioactive sediments lie on the unconformity at the top of the Arbuckle dolomite. Examples of this type are numerous and probably represent detrital material in which the radioactive elements have been concentrated by mechanical and chemical weathering of the older rocks.

REGIONAL AND STRUCTURAL HISTORY

The major structural features of Oklahoma and Kansas are: (1) The Arbuckle-Wichita-Amarillo uplift extending northwestward through southern and western Oklahoma into the Texas panhandle with the deep Anadarko basin containing an estimated 24,000 feet of sediments on the northeast flank. (2) The Nemaha anticline extending northward and northeastward from the Arbuckle Mountains, bisecting the states of both Oklahoma and Kansas. (3) The Ouachita Mountains in southeastern Oklahoma. (4) The southwestern flank of the Ozark dome in northeastern Oklahoma and southeastern Kansas. (5) The Central Kansas uplift extending from central Kansas northwestward into Nebraska.

Since gamma-ray log data are available only in the first two structural provinces, the last three mentioned have not been considered in this report.

From Cambrian to early Pennsylvanian time, southern and most of western Oklahoma was probably included withinthe large geosyncline which extended from southern Oklahoma to western Texas. There was relatively uninterrupted deposition throughout this geosyncline, although deposition to the north and east must have been repeatedly interrupted, resulting in several important unconformities of which the one at the base of the Woodford shale probably represents the greatest time interval.

The first major orogenic movement within the geosyncline is thought to have occurred during post-Mississippian and pre-Cherokee (Desse) time, although the initial movement may have started as early as late Mississippian time. During this early Pennsylvanian orogeny, the Arbuckle-Wichita Mountain chain, with the accompanying Anadarko Basin, was formed. Movement continued along the Wichita-Amarillo uplift throughout most of the Pennsylvanian and on into the Permian. Erosion of the land mass elevated above base level resulted in thick deposits of arkosic material being deposited along the flanks of the uplift. This indicates that large areas of the igneous core were at various times denuded of their protective sediments.

Simultaneously with the events of early Pennsylvanian time, along the Arbuckle-Wichita-Amarillo uplift, the Nemaha anticline to the north was elevated above base level and pre-Cherokee erosion locally removed all of the earlier sediments and exposed the granite core. The crest of the anticline was completely inundated by the Lansing sea and presumably remained under water throughout the remaining part of Pennsylvanian time, although intermittent movement continued throughout that era.

CONCLUSIONS

Approximately 600 gamma-ray logs distributed over several thousand square miles from southern Oklahoma to central Kansas have been examined.

Although this is an inadequate number of radioactivity logs for delineation of possible ore deposits, they do point toward specific areas where more detailed work might profitably be carried out. The available evidence indicates that two and possibly three types of higher than normal radioactive deposits are found in Oklahoma and southern Kansas.

The first of these types is represented by the black marine shales, of which the Woodford shale is the most notable example. Concentration of radioactive elements in these shales may have been controlled by the bio-chemical environment of the sea in which the sediments were deposited. Generally, the radioactivity of these beds is more consistent than in the other types, although the order of magnitude is only about 0.006 percent uranium equivalent.

The second type includes the more highly radioactive basal Pennsylvanian sediments flanking the Wichita Mountains and the Nemaha anticline. On the basis of gamma-ray logs these sediments are estimated to have an equivalent uranium content ranging between 0.03 and 0.18 percent. At least some of these sediments were derived from an igneous source, and it is reasonable to suppose that the radioactive elements were derived either from the same source or from the erosion of a radioactive sedimentary bed such as the Woodford shale. It seems probable that the concentration of radioactive elements could have been brought about through the normal weathering and erosional processes. In those places where the radioactive source rocks were near enough, the heavier radioactive elements could have been concentrated mechanically. Later, radioactive solutions derived from this zone of mechanical concentration could have been carried downward by circulating ground water to form a secondarily enriched zone.

Whether these basal Pennsylvanian deposits were localized along the anticlinal flanks at the time of deposition of the sediments by a combination of orogenic and erosional processes, or whether the deposits were formed later through the medium of circulating ground water cannot be determined with the present information. Regardless of the specific manner of transportation and deposition of these deposits, however, their close association with the major structural features is too consistent to be regarded as a coincidence and strongly suggests that the localization of the radioactive material was structurally controlled. The relatively high radium concentration with a negligible uranium content in weathered cable-tool samples from the Peabody field, Kansas, indicates that the uranium was in soluble form and was removed during the drilling process or later through the action of meteoric water.

A third type of deposit is inferred by figure 3. The relationship between the radioactive zone and the fault plane indicates the possibility of a primary deposit. However, in the absence of more positive data, further speculation would be useless.

Information from gamma-ray logs further indicates that radioactive material has been concentrated in places along old erosional surface This relationship suggests that the lighter minerals were removed by erosion and the heavier radioactive elements left behind in the residue.

ECONOMIC BEARING

More subsurface information is necessary before the radioactive beds discussed above can be properly evaluated in regard to their economic importance and their possible stratigraphic, structural and historical relationships. Information pertaining to the source, manner of transportation and deposition, and their possible relationship to helium is desirable. To obtain this information it is recommended that the following areas be studied in detail:

(1) Southeastern Kansas, particularly in the vicinity of the Nemaha anticline.

(2) The northeast flank of the Wichita Mountains in Oklahoma.

Arrangements have been made to obtain drill samples from the Kansas Geological Survey. If necessary, similar arrangements can probably be made with the Kansas Geological Society and the major oil companies.

The estimated time necessary to carry out this project is three man-years.

APPENDIX

Analyses of Miscellaneous Samples from the Peabody Field

Five samples submitted by Garland Gott 5 August 1948, Lot No. 466. The samples were collected near abandoned oil wells of the Peabody Oil Field in Kansas, and are believed to be 20 to 25 year old cuttings of cable-tool drillings.

Chemical Analysis

Sample No.	%eU	% U	% Loss on Ignition	pH
3659	0.097	0.003	20.9	2.8
3660	0.090	0.003	34.4	6.5
3661	0.113	0.001	38.0	2.5
3662	0.097	0.003	15.5	7.3
3663	0.064	0.003	24.1	8.0

Petrographic Examination by whom?

Sample No. 3659: Predominately composed of volatile hydrocarbons, limonite, gypsum and clay. The hydrocarbons give a waxy texture to the sample and cause it to repel water. The waxy material is easily removed by moderate heating.

Sample No. 3660: Predominantly a soft, oil impregnated clay material containing encrustations of gypsum, substantial amounts of small detrital quartz particles, minor amounts of feldspar, gypsum and calcite, and rare particles of white mica. The ash obtained by igniting the sample at 300-400°C is composed of kaolinite clay containing the detrital particles mentioned above. Recent plant debris is present in the specimen.

Sample No. 3661: Predominantly a limonite stained clay impregnated with wax-like hydrocarbons which are easily removed by moderate heating. The clay is an intimate mixture of kaolinite and illite with a lesser amount of montmorillonite-type clay. Substantial amounts of gypsum are present, and rarely detrital particles of zircon and a sphene are observed.

Sample No. 3662: A chocolate-brown earthy material containing moderate amounts of hydrocarbons. Small olive-grey rock particles and some flattened (probably originally veinlets) pieces of chalcedony are present. The specimen is composed essentially of montro-

<u>Sample No. 3662</u>: nite clay mixed with kaolinite clay and containing crystals of gypsum. Particles of chalcedony, steatite rock (soapstone), and some hydrocarbons are also present.

<u>Sample No. 3663</u>: An earthy brown, extremely porous and absorbent material composed predominantly of nontronite clay (probably mixed with kaolinite) and containing minor quantities of gypsum and calcite and minute particles of barite and celestite.

Discussion

Samples of a similar nature had been analysed in the Washington laboratory. The radioactivity measurements indicated a few tenths of a percent equivalent uranium, but no uranium was found chemically. A check for thorium showed this element to be also absent. The effect of potassium, if present, could be neglected because of its slight effect (100% KCl ≈ 0.03% eU). Radium was therefore suspected.

Facilities were not available to determine radium in the conventional manner. However, measurement of the radioactivity of the sample before and after ignition gives the magnitude of the radium concentration.

In figure 1 is shown the variation of the radioactivity (sample No. 3661) with time. To determine the radium concentration the difference in activity of the sample before ignition and five hours after ignition was compared to a standard radium ore treated in the same manner as the sample.

It was found that the Ra on sample No. 3661 was found to be about 1.3 x 10^{-9} g/g on the "dry" basis. On an "as received" basis, this would correspond to about 0.8 x 10^{-9} g/g Ra. This amount of radium should have been in equilibrium with about 0.23% U on an "as received" basis or 0.37% U on a "dry" basis.

The presence of radium without uranium at a depth from which these samples were supposed to have originated is impossible. Either the uranium was leached out during the drilling or during the 20 to 25 years during which the samples were exposed, or else the samples containing radium did not come from the wells. Radioactivity logs of the wells however, indicate highly radioactive zones.

Radioactivity logs of the oil wells in the Peabody Oil Field, studied by Garland Gott, showed high activity in certain zones below 1500 ft. (below sea level). Analyses of the samples of cuttings from this area showed about 10^{-9} g/g Ra, but practically no uranium (see Report TDC-9).

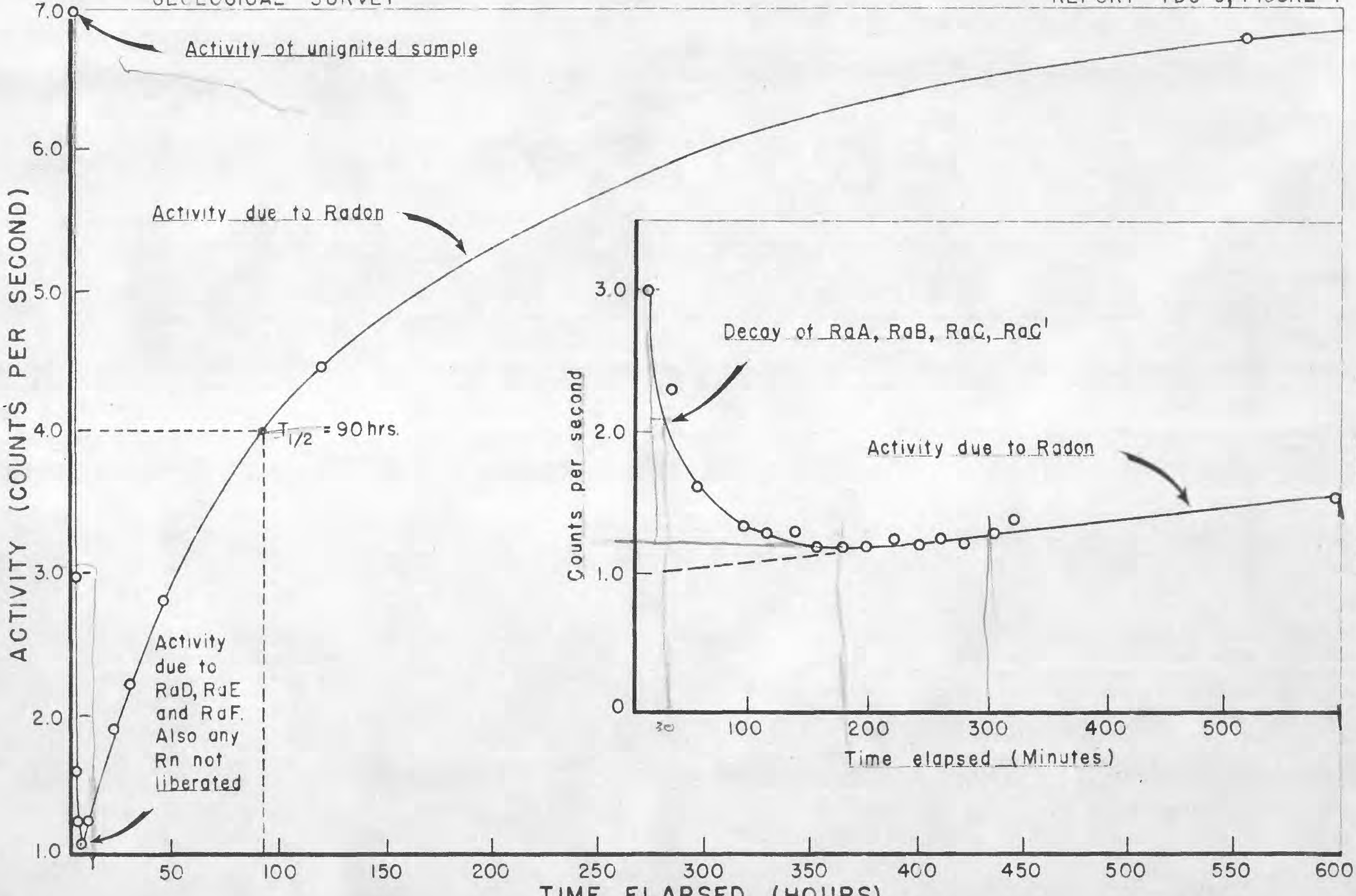
The following samples, Lot No. 466, were submitted by Garland Gott, in order to determine the presence of any uranium in this area:

One hundred and forty (140) samples, No. 5851-5990, from the rotary drilled Berry and Wells-Jolliffe No. 1 Well, submitted 20 October 1949.

Eight (8) samples, No. 5790-5797, consisting of sludge samples from the above well, and oil and water samples from adjoining wells, submitted 15 October 1948.

Eleven (11) radioactive samples from the Peabody Oil Field, submitted 15 October 1948.

Tables II, III, IV show the analyses of the above samples.



DECAY AND RECOVERY CURVE OF RADON AND ITS PRODUCTS

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TABLE I

Radiometric analysis of samples from the Berry-Sollis-Jolliffe No. 1 Rotary Drilled Well

Sample No.	Depth - Feet	eU	Sample No.	Depth - Feet	eU
5851	1805-1810	0.001	5890	2000-2005	0.002
5852	1810-1815	0.001	5891	2005-2010	0.001
5853	1815-1820	0.002	5892	2010-2015	0.001
5854	1820-1825	0.002	5893	2015-2020	0.001
5855	1825-1830	0.002	5894	2020-2025	0.001
5856	1830-1835	0.002	5895	2025-2030	0.000
5857	1835-1840	0.002	5896	2030-2035	0.001
5858	1840-1845	0.002	5897	2035-2040	0.002
5859	1845-1850	0.001	5898	2040-2045	0.001
5860	1850-1855	0.002	5899	2045-2050	0.001
5861	1855-1860	0.001	5900	2050-2055	0.002
5862	1860-1865	0.001	5901	2055-2060	0.002
5863	1865-1870	0.000	5902	2060-2065	0.001
5864	1870-1875	0.001	5903	2065-2070	0.001
5865	1875-1880	0.001	5904	2070-2075	0.002
5866	1880-1885	0.001	5905	2075-2080	0.003
5867	1885-1890	0.001	5906	2080-2085	0.002
5868	1890-1895	0.000	5907	2085-2090	0.001
5869	1895-1900	0.002	5908	2090-2095	0.001
5870	1900-1905	0.002	5909	2095-2100	0.002
5871	1905-1910	0.002	5910	2100-2105	0.002
5872	1910-1915	0.002	5911	2105-2110	0.001
5873	1915-1920	0.001	5912	2110-	0.002
5874	1920-1925	0.001	5913	2110-	0.001
5875	1925-1930	0.001	5914	2110-2115	0.002
5876	1930-1935	0.000	5915	2115-2120	0.001
5877	1935-1940	0.000	5916	2120-2125	0.002
5878	1940-1945	0.001	5917	2125-2130	0.002
5879	1945-1950	0.000	5918	2130-2135	0.001
5880	1950-1955	0.001	5919	2135-2140	0.001
5881	1955-1960	0.001	5920	2140-2145	0.002
5882	1960-1965	0.000	5921	2145-2150	0.002
5883	1965-1970	0.001	5922	2150-2155	0.002
5884	1970-1975	0.000	5923	2155-2160	0.001
5885	1975-1980	0.001	5924	2160-2165	0.001
5886	1980-1985	0.001	5925	2165-2170	0.001
5887	1985-1990	0.001	5926	2170-2175	0.002
5888	1990-1995	0.002	5927	2175-2180	0.002
5889	1995-2000	0.001	5928	2180-2185	0.001

TABLE I CONT'D.

Sample No.	Depth - Feet	eU	Sample No.	Depth - Feet	eU
5929	2185-2190	0.001	5959	2335-2340	0.002
5930	2190-2195	0.000	5960	2340-2345	0.001
5931	2195-2200	0.002	5961	2345-2350	0.001
5932	2200-2205	0.002	5962	2350-2355	0.001
5933	2205-2210	0.002	5963	2355-2360	0.002
5934	2210-2215	0.002	5964	2360-2365	0.001
5935	2215-2220	0.002	5965	2365-2370	0.002
5936	2220-2225	0.002	5966	2370-2375	0.002
5937	2225-2230	0.001	5967	2375-2380	0.002
5938	2230-2235	0.002	5968	2380-2385	0.002
5939	2235-2240	0.003	5969	2385-2390	0.002
5940	2240-2245	0.002	5970	2390-2395	0.003
5941	2245-2250	0.002	5971	2395-2400	0.003
5942	2250-2255	0.003	5972	2400-2405	0.002
5943	2255-2260	0.002	5973	2405-2410	0.002
5944	2260-2265	0.002	5974	2410-2415	0.002
5945	2265-2270	0.002	5975	2415-2420	0.002
5946	2270-2275	0.001	5976	2420-2425	0.001
5947	2275-2280	0.001	5977	2425-2430	0.001
5948	2280-2285	0.000	5978	2430-2435	0.002
5949	2285-2290	0.001	5979	2435-2440	0.002
5950	2290-2295	0.002	5980	2440-2445	0.003
5951	2295-2300	0.001	5981	2445-2450	0.003
5952	2300-2305	0.002	5982	2450-2455	0.002
5953	2305-2310	0.001	5983	2455-2460	0.002
5954	2310-2315	0.002	5984	2460-2465	0.002
5955	2315-2320	0.003	5985	2465-2470	0.002
5956	2320-2325	0.002	5986	2470-2475	0.002
5957	2325-2330	0.001	5987	2475-2480	0.002
5958	2330-2335	0.001	5988	2480-2485 1/2	0.001
			5989	2485 1/2	0.000
			5990	1800-1805	0.002

Note: Field No's. are identical with "Depth - Feet" numbers.

TABLE II

Analyses of Sludge from the Berry and Eells-Jolliffe No. 1 Well, and Water and Oil samples from Adjoining Wells.

Field No.	Serial No.	Source	Liquid Portion ppm U	Solid Portion % U	Solid Portion %eU
GG-16	5790	Crude Oil, Golpitt Well	0.002	-	-
GG-17	5791	Sludge from outlet at 2374 ft. B & E-Jolliffe No. 1	0.003	< 0.001	0.002
GG-18	5792	Crude Oil, B & E Reconditioned Well	0.005	-	-
GG-19	5793	Water from storage tank, Gopitt Well	0.002	-	-
GG-20	5794	Sludge from intake at 2365 ft. B & E-Jolliffe No. 1	0.004	< 0.001	0.002
GG-21	5795	Sludge from outlet at 2275 ft. B & E-Jolliffe No. 1	0.007	< 0.001	0.001
GG-22	5796	Water from B & E Reconditioned Well	0.009	-	-
GG-23	5797	Sludge from outlet at 2485 ft. B & E-Jolliffe No. 1	0.005	< 0.001	0.002

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TABLE III

Analyses of Radioactive Samples Obtained near Wells of the Peabody Oil Field
(Results on "ignited" basis)

Field No.	Sample No.	Source	% Loss on Ignition	%eU	%U	Ra x 10^{-9} g/g	Calculated %
GG-28	5802	Hot well farthest east, cuttings	25.0	0.20	0.000	1.4	0.4
GG-29	5803	Oil soaked sample 50' from Colpitt derrick	39.6	0.091	0.001	0.7	0.2
GG-30	5804	A. Fine portion of sample 20' from Colpitt derrick	19.6	0.63	0.000	4.9	1.4
		B. Same as above-coarse portion of sample	24.8	0.32	0.001	2.6	0.7
GG-31	5805	Near Colpit derrick	63.4	0.077	0.001	0.6	0.2
GG-33	5807	From old pit - Spier well	49.6	0.10	0.000	0.8	0.2
GG-34	5808	South of B & B Rotary well	38.4	0.55	0.001	4.5	1.3
GG-25	5799	Taken from center of pit 6" deep 50' from well. Not representative sample.	18.0	0.023		0.1	0.03
GG-26	5800	Same as above. Top 4" from center of pit. Not representative sample.	17.6	0.021		0.1	0.03
GG-27	5801	Same as above. From pit. Not representative sample.	17.2	0.027		0.1	0.03
GG-32	5806	B & B - Spier 14. Rotary well oil soaked crust between sludge pit and well		("as received" basis) 0.001			
GG-24	5798	Same as above, from bottom of sludge pit		0.001			
GG-35	5809	Augusta Field, Magnolia Foster 14		0.001			

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TABLE III CONT'D.

The radium was determined from the difference in radioactivity between the ignited sample and unignited sample.

The calculated % U is the uranium which would normally be present with the radium under equilibrium conditions.