Summer 1949

An Investigation of The Radioactivity of Oilwell Drilling Fluid, With Depth, of Wells in The Berland Field of Rooks County

Milford W. Johnston

Fort Hays Kansas State College

Recommended Citation

Johnston, Milford W., "An Investigation of The Radioactivity of Oilwell Drilling Fluid, With Depth, of Wells in The Berland Field of Rooks County" (1949). *Master's Theses*. 426.

DOI: 10.58809/PZGB1346

Available at: https://scholars.fhsu.edu/theses/426

AN INVESTIGATION OF THE RADIOACTIVITY OF OILWELL DRILLING FLUID, WITH DEPTH, OF WELLS IN THE BERLAND FIELD OF ROOKS COUNTY

being

A thesis presented to the Graduate Faculty
of the Fort Hays Kansas State College in
partial fulfillment of the requirements for
the Degree of Master of Science

by

Milford W. Johnston, B.S.
Fort Hays Kansas State College

Date July 27, 1949 Approved Harvey A. Zinszer
Major Professor

F. W. Albertson
Chairman Graduate Council

ACKNOWLEDGMENTS

The author of this thesis wishes to acknowledge all sources of information used in its preparation. He also wishes to express appreciation to Dr. Harvey A. Zinszer, under whose direction this work was carried out, for his helpful suggestions and constructive criticisms. My special thanks are due to Dr. Richard H. Zinszer, director of the research laboratory of the Union Oil Company in Los Angeles, for numerous suggestions.

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INTRODUCTION

In 1936, Runyon and Rankin published the results of an extensive chemical survey on the bromine and iodine content of sub-surface waters of Russell, Ellis and Trego Counties of Kansas (Runyon and Rankin, 10). In 1937, Lippert published the results of an electroscopic survey of the radioactive properties of the subterranean waters of Ellis County of Kansas (Lippert, 7). In 1940, Bell, Goodman and Whitehead reported a survey on the radioactivity of sedimentary rocks and associated petroleum (Bell, Goodman, and Whitehead, 3). In 1943, Frye and Brazil published an extensive report on ground water in the oil-field areas of Ellis and Russell Counties of Kansas (Frye and Brazil, 4). Lastly, W. L. Russell in 1944 reported on the total gamma ray activity of sedimentary rocks as indicated by Geiger Counter determinations (Russell, 11).

In reviewing the foregoing literature and in consideration of the very important place of the state of Kansas in the nation's production of petroleum, it was thought that possibly a contribution might be made to the general subject of geophysical prospecting for oil by the adoption and execution of the problem proposed by the title of this thesis. Since a similar but more scattered study of this problem had been previously made by Lippert with the use of an electroscope, it was considered worth-while to repeat the electroscopic observations together with Geiger-Mueller Counter observations on a new series of wells for samples of both soil and water, and to determine, if possible, a correlation between the readings of these two instruments. Furthermore, instead of taking a few readings of many wells scattered over the county, it was thought wiser to take daily samples of a limited number of wells in the same field.

HISTORY, SOURCE AND NATURE OF RADIOACTIVE EMANATIONS

Early in 1896, J. J. Thomson and others believed that the emission of x-rays by a Crookes tube was connected with the greenish-yellow fluorescence or phosphorescence of the glass walls of the tube. It seemed worthwhile to search for penetrating radiations from substances that are phosphorescent under the action of x-rays or light. Balmain's paint, whose active ingredient is calcium sulfide, phosphoresces for several hours after exposure to light. Several phosphorescent substances were examined for rays which would penetrate black paper, but no certain results were obtained until February 24, 1896, when Henri Becquerel (Becquerel, 2) of France found that an uranium salt which had been exposed to strong sunlight emitted rays which could penetrate black paper and a thin sheet of aluminum and then blacken a photographic plate. However, Becquerel believed that he was observing a phenomenon of phosphorescence. Several days passed with overcast skies and in his impatience Becquerel developed a plate which had been enclosed in a plate-holder on the outside of which a button of uranium salt had been placed. The button and plate-holder had lain in a closed drawer for several days. Yet, on development, the plate under the button was quite as black as if the button had been exposed to direct sunlight. This remarkable result was obtained on March 1, 1896. Becquerel was immediately alert. He dissolved uranium nitrate in the dark. Solution of phosphorescing salt removes its phosphorescence. Becquerel then recrystallized the uranium nitrate in the dark and found that the recrystallized salt emitted penetrating rays. As the weeks went by Becquerel tried various compounds of uranium. Finally, he tried uranium metal and found that it, like the compounds of uranium, emitted penetrating though invisible radiation. Nevertheless, Becquerel still believed that he was observing a phenomenon of phosphorescence. But the persistence of the invisible radiation puzzled him. The phosphorescence of Balmain's paint dies out after a while. On the other hand, the uranium rays persisted with undiminished intensity for a period of months and then of years. Becquerel attributed the persistent rays from uranium and its compounds to the proportion of uranium present. He said that these rays were a property of the element uranium.

Research on the peculiar rays from uranium stagnated during the latter part of 1896 and during the whole of 1897. The concept of phosphorescence seemed to be the stumbling block. Then, in the earlier part of 1898, Marie Curie, working in Paris, and Schmidt in Germany discovered that thorium compounds also emit penetrating, though invisible, rays which persist indefinitely. In the late 1890's uranium was the element of highest atomic weight and thorium was the next highest. It is strange from our present viewpoint that it had not previously occurred to anyone to test thorium for radioactivity, a term used by the Curies, Pierre and Marie, in 1898. However, the discovery of the radioactivity of thorium meant that the radioactivity of uranium was no longer a unique and anomalous property of uranium. Marie Curie stated that radioactivity is a property of the atoms of the radioactive substance. This concept was a distinct advance in the thinking of those days.

It was early noted by Becquerel that the penetrating rays from uranium and its compounds produces ionization in a gas similar to the ionization produced by x-rays. The Curies used the ionization method to measure radioactivity. They found that pitchblende, an ore containing uranium was more radioactive then it should be according to the fraction of uranium present. The Curies proceeded to the decomposition of pitchblende and its separation, by chemical analysis, into its constituent elements, testing each preparation for its radioactivity. They obtained "radiferous" bismuth and barium sulfides, which were both strongly radioactive. Finally, they obtained radiferous bismuth sulfide which was 400 times as radioactive, mass for mass, as uranium. The Curies claimed that they had found a new element, which they called "polonium" in honor of the country of Mme. Curie's birth. However, in 1898 the existence of a new element in small quantities was accepted only if its spark spectrum could be obtained. No such spectrum was presented and the Curies' claim was received with reservation.

The Curies then worked on the radiferous barium chloride which they obtained from the sulfide by chemical means. By fractional precipitation of the chloride from solution in water by alcohol, they found an increasing radioactivity in the precipitate. Finally at the end of 1898 they obtained a fraction possessing a radioactivity of 900 times that of uranium. Since spectroscopic analysis of this fraction showed a new spectrum line, it was conceded that the Curies had discovered a new element. They called this new element radium because of its high radioactivity. After more than three years of the most exacting and tedious effort, Mme. Curie obtained a sample of radium chloride spectroscopically free from barium. The atomic weight of the radium in this sample was found to be 225, which is quite different from 137, the atomic weight of barium.

In 1899 Rutherford, then of McGill University, Canada, turned his attention to the radiations emitted from uranium. He measured the absorption of the rays in aluminum by means of an ionization chamber. He found that the rays from a powdered uranium compound consisted of a soft component with an absorption coefficient $\mu = 1600$ cm^{-1} and a hard component with $\mu = 15$ cm^{-1}. Rutherford called the soft component α-rays and the hard component β-rays. In 1900 Villard of France found exceedingly penetrating rays from a sample of a radium salt and these came to be known as γ-rays.

In 1900 Rutherford announced the isolation of thorium emanation. This is a radioactive gas at ordinary temperatures. Previous to 1900 the persistence of the rays from radioactive substances had been the outstanding property of these substances. But the rays from thorium emanation and, later, from radium emanation were found to die out as time passed. Rutherford also discovered radioactive substances which were deposited from the thorium emanation on solid substances and particularly on negatively charged metals if air was present. The radioactivity of the deposit obtained after long exposure to the thorium emanation decays exponentially with the time after removal from the thorium emanation according to $I = I_0 e^{-\lambda t}$, where I_0 is the activity soon after removal, I is the activity as measured at a time t after the measurement of I_0, and λ is a constant known as the radioactive constant.

After examining various decay and recovery curves, Rutherford and Soddy were led in 1902-03 to announce the theory of radioactive transformations. The true nature of radioactivity had at last been recognized. According to the prevalent opinion held by physicists in early 1895 the atom was indestructible, impenetrable and immutable. The recognition of the electron in 1897 had shattered the concept of impenetrable atoms; Rutherford and Soddy's epochal theory of radioactive transformations shattered the concept of indestructible and immutable atoms.

Previous to 1903 the general public had little interest in radioactivity. Then early in 1903 Pierre Curie and Laborde discovered the heating effect of radium. It seemed at the time that radium provided an inexhaustible source of energy. Most extravagant claims were made for the miraculous powers of radium. Numerous articles appeared in the press and popular journals of the day. It was even suggested in 1903 that by means of the energy of radium the whole earth might be blown up and the end of the world brought about.

The α-rays are very easily absorbed in matter, being unable to penetrate more than a thickness of 0.1 mm of aluminum or of a few centimeters of air. The α-rays possess a very intense ionizing power. Provided that the α-rays can penetrate to a fluorescent screen or photographic plate, the fluorescent or photographic effect of the rays is intense. The β-rays are much less easily absorbed than the α-rays, being able to penetrate a thickness of 1 mm. of aluminum. The ionizing, fluorescent, and photographic effects of γ-rays are much less than those of β-rays. Recent measurement of the heating effect of radium gives a rate of emission of 130 cal/ hr from a gram of radium in equilibrium with its transformation products.

GEOLOGIC HISTORY OF KANSAS

The known geologic history of this area started with the erosion of the Pre-Cambrian basement rocks that occur below the Paleozoic sediments. This surface was submerged below sea level and marine sediments were deposited upon it. Throughout much of Paleozoic time the area was successively submerged and elevated. Marine sediments accumulated during periods when the surface was below sea level, and these sediments were subsequently eroded during periods of emergence. The lower Paleozoic rocks consist for the most part of marine limestone, shale, and sandstone.

An important structural event occurred in this area during post Devonian-Pre-Mississippian time (Moore and Jewett, 8). This consisted of a regional arching of the strata along a northwest-southeast axis and is indicated by the fact that Pre-Mississippian erosion truncated the earlier Paleozoic rocks and stripped off all of the beds down to the Arbuckle limestone. This period of uplift and subsequent erosion is believed to have been followed by marine inundation and resulting deposition of the Mississippian strata over this part of Kansas. The rocks of northwestern Kansas were again uplifted and warped along this same general structural trend at the close of Mississippian time or during early Pennsylvanian time to form the structural feature now recognized as the Central Kansas Uplift. It is this structure that has localized the accumulation of oil produced from these counties. The Mississippian strata believed to have existed across the top of this structure were stripped away by early Pennsylvanian erosion. At some places along the Central Kansas Uplift this early Pennsylvanian erosion cut away the rocks to such a depth as to expose the Pre-Cambrian basement. Coarse clastic deposits accumulated along the flanks of the Uplift as a result of this period of erosion, and it is believed that they may have been contemporaneous with the denudation deposits that were spread out toward the east from the ancestral Rocky Mountains.

The sea again invaded the area and marine deposits accumulated across all of northwestern Kansas during Pennsylvanian time. During the latter part of the Paleozoic, marine conditions were less prevalent and at times sediment accumulated on the surface of the land. Thus marine and nonmarine deposits occur alternately throughout rocks representing upper Pennsylvanian and Permian time. Desiccation and continental type sediments became more prevalent throughout Permian time, indicating an intermittent but progressive withdrawal of the seas.

The sea withdrew completely from the area by the close of Paleozoic time and the surface was eroded, uplifted, and warped. Erosion proceeded throughout much of Triassic and Jurassic time and it was over this eroded land surface that the Cretaceous deposits were spread.

The contact between the Cretaceous and Permian rocks, where it can be observed in adjacent areas, is characterized by a weathered zone at the top of the Permian. This zone is several feet thick, gray in color, and transgresses the bedding planes, indicating a relatively long period of weathering. At many places a zone of pebbles or cobbles consist of quartzite and igneous rocks and probably represent the first phase of continental deposition. This zone may be equivalent to the gravel that occurs at approximately the same stratigraphic position northeastward from Kansas. It has been observed in Kansas at the base of the Cheyenne, Kiowa, and Dakota where these formations immediately overlie the Permian.

During much of early Cretaceous time Ellis and Russell counties were still above sea level, whereas marine deposits were accumulating to the south and southwest. As the early Cretaceous sea encroached northward, clastic sediments accumulated at and near the shore line as beach deposits, deltas, and off-shore bars. These deposits, in addition to near-shore channel and flood-plain deposits, constitute the Cheyenne sandstone. In central Kansas they probably accumulated during a period of stable sea level or when the shore line was moving slowly northward, and the Kiowa shale, which overlies and overlaps the Cheyenne, represents the sediments deposited under marine conditions as the sea more rapidly advanced and inundated this region.

The close of early Cretaceous time is marked by the withdrawal of the sea. It was not a continuous retreat but was marked by minor readvances, and left interbedded marine and continental beds. Also it seems that the earth movements that occurred elsewhere at the close of Lower Cretaceous time may not have affected this area, because the Dakota formation, which is generally considered Upper Cretaceous in age, conformably overlies the Kiowa shale and is transitional with it. The Dakota formation is composed of continental and littoral beds deposited in channels, flood plains, beaches, lagoons and bars. Sand accumulated in stream channels or on beaches and bars, and clay, silt, and carbonaceous material were deposited on flood plains and in lagoons. The channel sandstones in general trend northeast, and the more evenly bedded bodies of sand that are believed to represent bar or beach deposits generally trend north or north-northwest. Thus the sandstones in the Dakota formation are elongate lenticular sand bodies interspersed through the clay and silt. This explains the fact that in some places one of two near-by wells will encounter several beds of sandstone and the others few or none. Also it can readily be seen why two near-by wells drilled into the Dakota sandstones yield water of different quality or water under a different hydrostatic head, and yet other wells more widely separated may have similar characteristics. This lattice work of lenticular sandstones is in part interconnecting, however, as shown by exposure where one lenticular sand body rests upon another.

Continental conditions existing throughout Dakota time again gave way to marine conditions and the upper part of the Dakota contains a larger percentage of even-bedded sand and silt suggesting beach or bar deposits. The sea completely transgressed the area for the last time and the Graneros shale and overlying marine formations of upper Cretaceous age were deposited.

Since the withdrawal of the Cretaceous sea this area has been continuously above sea level. It was subject to erosion during most of Tertiary time and was covered by a thin veneer of clastic sediments during the Pliocene. These sediments represent material eroded from the highlands to the west and transported to western Kansas by eastward flowing streams.

During the Pleistocene the major streams crossing this area from west to east cut wide valleys and spread a thick layer of gravel and silt over their valley floors. It was at this stage of valley development during the early Pleistocene that major changes occurred in the drainage pattern of central Kansas (Frye, Leonard and Hibbard, 5). Wilson valley in western Ellsworth county, which formerly had carried the Saline river drainage into the Smoky Hill valley, was abandoned. Also, the McPherson valley, which carried this western drainage southward to its junction with the Arkansas valley, was abandoned, and the major drainage way was established to the eastward across the flint hills in the position of the present Kansas river valley. Several minor periods of valley cutting followed and gave rise to the series of terraces now to be seen along the major valleys of this area. The present valleys of the major steams are quite narrow and are cut below the level of the lowest Pleistocene terrace.

DISTRIBUTION OF PRODUCING AREAS. A glance at the index map (Fig. 1) reveals three main petroleum areas: one in southeastern Kansas, one about midway or a little west of the center, and one, the Hugoton gas field, in the southwest corner of the State. These divisions correspond rather closely to what are commonly called "the old eastern Kansas fields," the "western Kansas" or

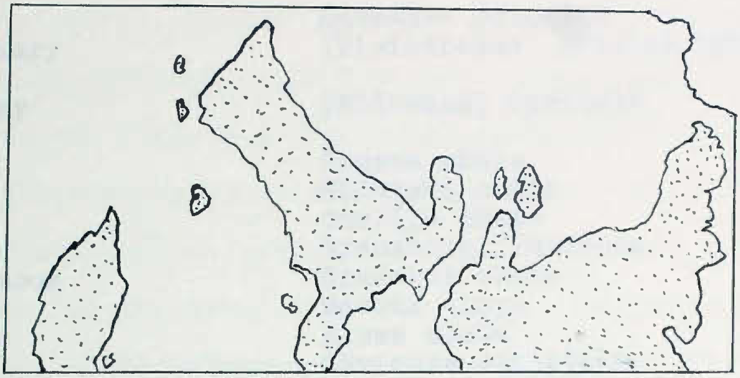

Fig. 1 Map of Kansas Showing Petroleum Areas.

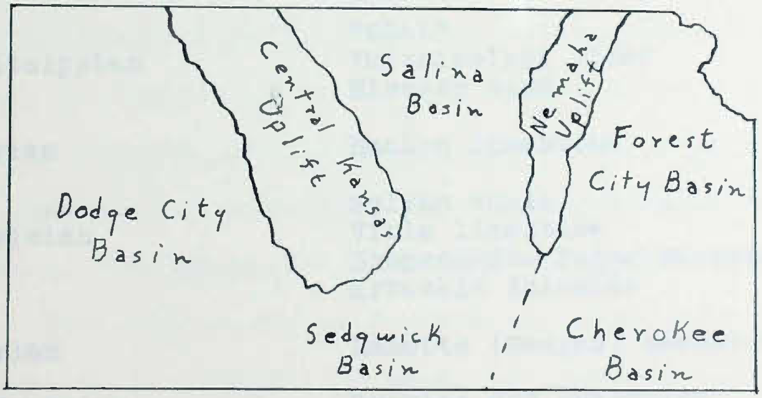

Fig. 2 Major Structural Features of Kansas Geology.

Geologic System	Some Subdivisions
Quaternary	Recent-- Alluvium (Pleistocene) Glacial sediments
Tertiary	(Pliocene) Ogallala
Cretaceous	Pierre shale Niobrara chalk Carlile shale Greenhorn limestone Graneros shale Dakota clays Kiowa shale Cheyenne sandstone
Permian	Stone Corral dolomite Herington Limestone
Pennsylvanian	Tarkio limestone Topeka limestone Oread limestone Lansing-Kansas City Burgess sand Sooy (basal) conglomerate
Mississippian	"Chat" "Mississippi lime" Misener sand
Silurian	Hunton limestone
Ordovician	Sylvan shale Viola limestone Simpson-St. Peter sandstone Arbuckle dolomite
Cambrian	Lamotte (Reagan) sandstone
Pre-Cambrian	Granite and quartzite

Fig. 3. Generalized Geologic Column Showing Rock Units Commonly Used by Drillers and Petroleum Engineers.

"Central Kansas uplift area," and the Hugoton field. The eastern half of the easternmost area, including Chautauqua, Montgomery, Labette, Wilson, Neosho, Crawford, Woodson, Allen, Bourbon, Anderson, Linn, Franklin, Miami, Douglas, and Johnson Counties are noted mainly for their water-flooding activities at the present time. It was in these counties that production began in Kansas and flourished around the turn of the century. They are now noted for their shallow "stripper" production. The remaining counties of eastern Kansas have somewhat larger per-well average production from considerably greater depths. Two features, the rather important shoestring sand production of Greenwood County and the more important production of the El Dorado field, are worthy of note.

Production within the area of the Central Kansas uplift, or "western Kansas," has featured the State's oil activity for the last 10 or 15 years. It is in this area that spectacular production has been discovered with such fields as the Trapp, Silica, Kraft-Prusa, and Bemis-Shutts.

Development of the Hugoton gas area was not pushed until pipe line facilities made possible the distribution and sale of substantial amounts of natural gas to distant areas of larger population and to industrial centers.

GEOLOGY. Oil or gas has been found in Kansas at the top of the Pre-Cambrian or basement complex and in at least a dozen stratigraphic subdivisions from there up to the Cretaceous.

Rocks of several ages are included among the sedimentary sequences overlying the Pre-Cambrian in Kansas. Of the six main divisions of these sediments which are recognized (Moore and Jewett, 8), five, excluding the topmost division, contain rock layers that produce oil or gas. In ascending order, these are:

1. The Cambrian-Ordovician rocks, mainly dolomite and limestone. This division includes the Lamotte sandstone, the Arbuckle dolomite, the Simpson formation, and the Viola limestone or dolomite, all of which are well-known oil-producing zones at various points in the State.

2. The Silurian-Devonian rocks, which are mainly dolomite and limestones. The "Hunton lime," an oil-producing unit of some importance, occurs in this division.

3. The Mississippian rocks, mainly limestones, some of which have produced substantial amounts of oil.

4. The Pennsylvanian-Permian rocks. The lower rocks of this division consist mainly of limestones with some shale, and produce an important amount of oil. The upper, or Permian, part produces 75 per cent of the natural gas of the State but no oil. It is composed principally of red, sandy, and shaly beds which because of their characteristic color are commonly referred to as the

"Permian Red Beds."

5. The Cretaceous rocks, consist mainly of sandstone, shale, and chalky limestone. One small gas pool, the Goodland, near the town of that name in Sherman County comprises the total production of the State from The Cretaceous to date.

The major rock units and some of the minor but better-known units that are recognized by drillers and oil geologists are indicated in Figure 3.

Oil and gas production in Kansas is definitely related to several broad features of the structural geology. These features consist of wide, shallow basins, separated by low arches or up-warped areas, called uplifts. Two pronounced uplifts, the Central Kansas and the Nemaha, are recognized. The basins are the Forest City of northeastern Kansas, the Cherokee of the southeastern part of the State, the Salina of north-central Kansas, the Sedgwick south of the Salina, and the Dodge City in southwestern Kansas. The relationships among these several major structural features are shown in Figure 2.

Oil was first discovered in Kansas in the southern part of what is now referred to as the Forest City basin. It was extended southward into the Cherokee, then westward into Butler County where fields located on the southern part of the Nemaha uplift were found. The next

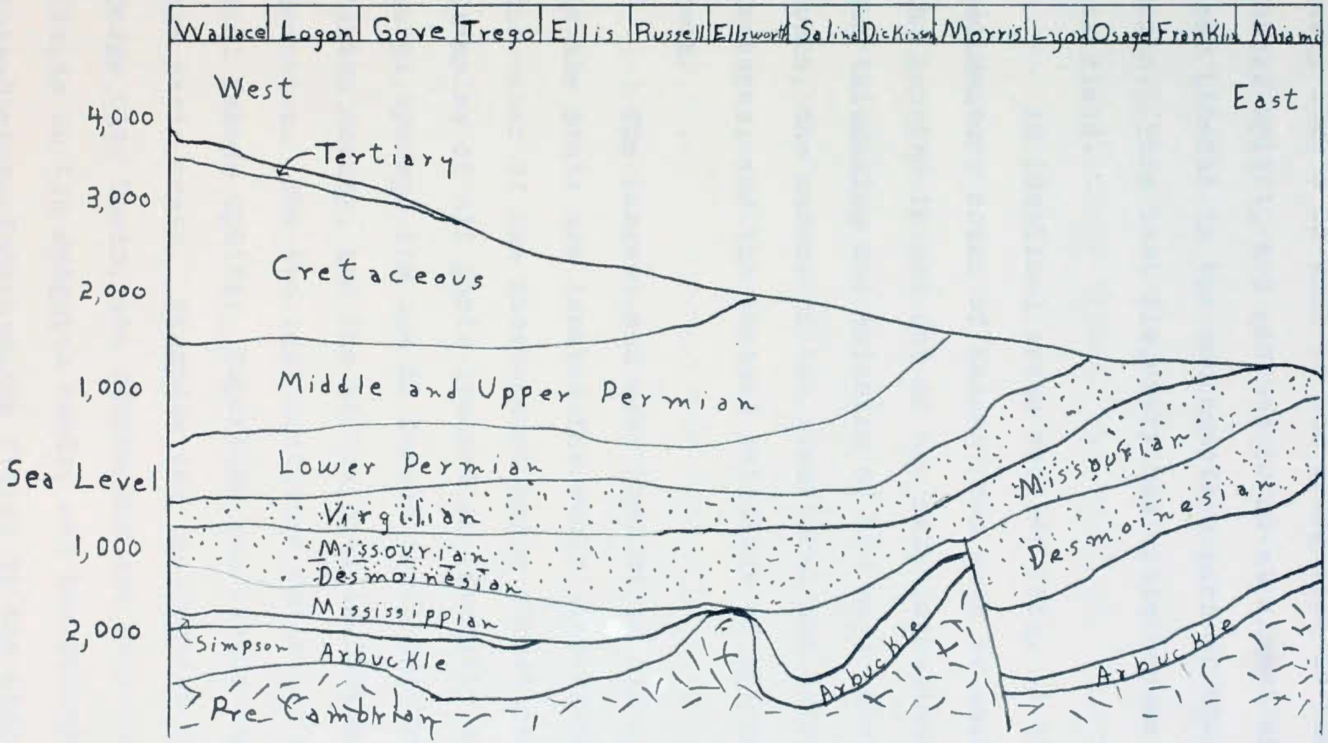

Fig. 4 Generalized Cross Section of Kansas Rocks

important discovery of oil was in Russell County in the early 1920's on what is now recognized as the Central Kansas uplift, and gas was found at almost the same time near Liberal in the southwestern part of the Dodge City basin. This last discovery has since become the Hugoton gas field.

An idealized cross section (Fig. 4) through the sedimentary rocks of Kansas from west to east clearly shows the lensing in and out of the many formations and sequences, the thickening and thinning of the major divisions of the rocks, the nature of the structural and deformational features, and the contact relations of the unconformable beds.

The largest and most productive oil and gas pools in the State are located favorably with respect to one or the other of the above-named major structural features. Examples of oil pools located on favorable structure or large upwarps are the El Dorado pool, the Trapp pool in Barton County, and the Silica pool in Barton and Rice Counties. The two last mentioned pools are on the Central Kansas uplift. Important gas fields seem to favor the basin areas. Examples are the Hugoton field in the Dodge City basin, the Cunningham and Medicine Lodge fields in the Sedgwick basin, and the formerly important Iola-Chanute-Independence fields in the Cherokee basin of southeast Kansas.

Deposits of oil or gas in Kansas, referred to as pools or fields, are by liquid or gaseous hydrocarbons being trapped in porous rocks beneath the surface. Two kinds of traps, structural and depositional, account for Kansas petroleum production. Most structural traps, called "structures," are dome- or ridge- like folds in the rocks, caused by lateral compression. Such structures are called anticlines, domes, or terraces, and they have widths of from a few hundred feet to several miles. The anticlines may have lengths many times their widths. Anticlinal structures not underlain by porous, oil-bearing rocks, are, of course, barren, but it is almost axiomatic in Kansas that--other conditions being favorable--good local structures, such as anticlines, have offered the most attractive conditions for the accumulation of oil.

Depositional traps, common in Kansas, result mainly from a condition of porosity wherein a porous area of a given oil or gas "sand" grades in all lateral directions to a less porous or impervious condition. Porosity in an oil-bearing rock to allow migration and accumulation of oil or gas, and their controlled escape when tapped by drill holes, is a most essential condition to the formation of oil pools. It is next in importance to the presence of liquid and gaseous hydrocarbons somewhere in the same or in a nearby sequence of sedimentary rocks. The Cunningham gas pool in Pratt and Kingman Counties is an example of a depositional trap. The Lansing-Kansas City formations of Middle Pennsylvanian age have been hosts to notable accumulations of oil and gas in areas where the rocks are porous but without attractive structure.

The Hugoton gas field, which with its extensions into Oklahoma and the Texas Panhandle is now regarded as the largest known gas reserve in the world, is essentially a stratigraphic trap. The relatively porous, dolomitic marine strata which occur in the main part of the field and on the down-dip or east side, grade laterally to fine-grained, rather dense, less porous continental strata up the dip to the west (Moore and Jewett, 8). Thus a trap has been formed.

Another and somewhat different type of depositional or stratigraphic trap is represented by the so-called "shoestring" sands of Butler, Greenwood, and other eastern Kansas counties. Original deposits consisting of channel-fillings of narrow offshore bars or spits of pervious sediments which grade laterally into impervious shales or other denser rocks, have permitted important accumulations of oil in the form of long, narrow lenses or "shoestrings."

It seems unlikely that any new, major structural features will be revealed, or that any new Kansas oil pools will be discovered to challenge the El Dorado or the Trapp pools in productivity. However, it is almost a certainty that many new pools will be discovered, and that exploration and production methods will be greatly improved to offset in part the decline in productivity of many of the fields in the State.

SELECTION OF OIL-WELLS; COLLECTION OF SAMPLES

No county in western Kansas received more intensive study and attention during 1946 than Rooks County. This is revealed not so much by the total number of completions as by the widely scattered operations. The number of new oil wells brought in during the year was 35 and the number of dry holes drilled was 32. Among the dry holes 14 are classed as ordinary wildcats and the rest as extension wildcat tests and dry pool wells.

Perhaps no field in Kansas has continued to present such interesting possibilities as Rooks County's Berland field. Its latest surprise was the completion of Nadel and Gussman's Ouderkirk in the SE NW of 7-10S-19W for a maximum rating.

It was in the above field that the present study was made. Three new locations for wells were chosen. They are:

Well #1	S7	T10S	R19W	(by Birmingham)
Well #2	S13	T10S	R20W	(by Sohio)
Well #3	S18	T10S	R19W	(by Sinclair)

The drilling mud was carefully collected in one-gallon jugs from the three wells mentioned above. The samples were taken every day at approximate 8 o'clock in the morning, while the wells were being drilled. The

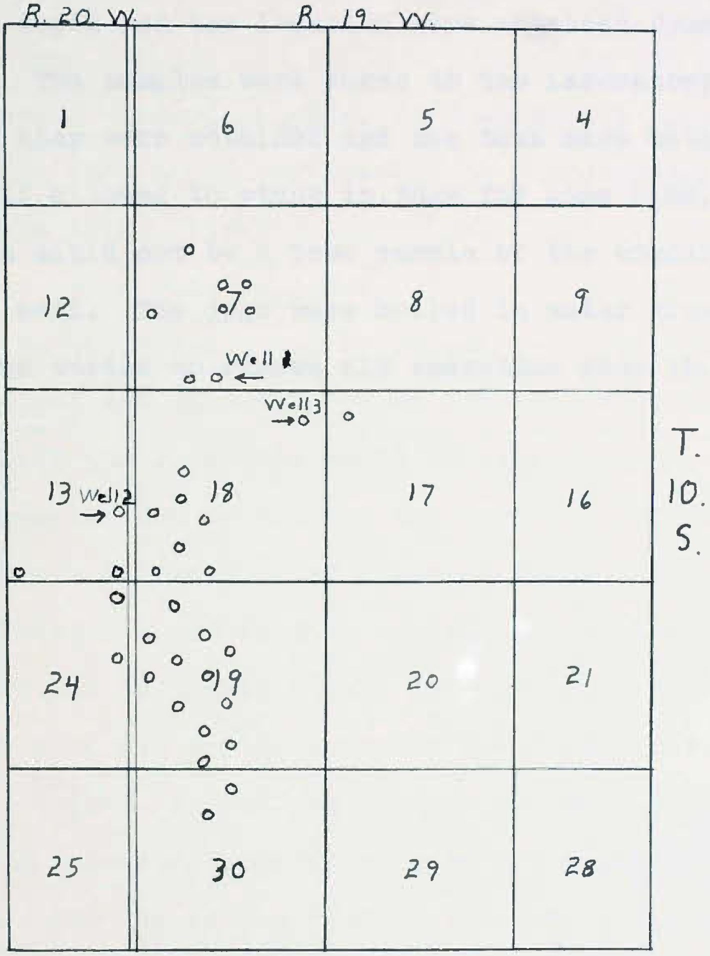

Fig. 5 Map of Berland Oil Field

drilling mud was allowed to run freely into the jugs as it came out of the well. With each sample of drilling mud, the depth and the location were obtained from the workers. The samples were taken to the laboratory the same day they were obtained and the test made within 2 hours. If allowed to stand in jugs for some time, the emanation would not be a true sample of the emanation from the well. The jugs were boiled in water after each sample was tested to remove all emanation from it.

CONSTRUCTION AND CALIBRATION OF THE ELECTROSCOPE

The electroscope proper was made up of two parts, the emanation chamber and the box containing the leaf. The emanation chamber, E, Fig. 6, comprised a circular cylindrical can, seven centimeters in diameter and 13 centimeters long. Its lid was fitted tightly. Two small brass stop-cocks were soldered into the sides of the can, so that the emanation could be pumped into the chamber. One stop-cock was near the bottom and the other near the top, so that the emanation could circulate within the can. The rectangular box containing the leaf was 10x10x15 centimeters. It was made of tin with the bottom soldered fast and with the lid fitting tightly. Two windows were cut in the box to enable one to see the leaf. These apertures were 8x8 centimeters and about two centimeters from the bottom. A hole was made in the side of the box, so that an insulated charging contact, C, could be inserted. The top of the box and the lid of the emanation chamber were soldered together. A hole passing through the center of both was fitted with a metal cylinder about two centimeters in diameter and about one centimeter long.

The rod, R, that extended into the emanation chamber was a thin copper wire, necessarily small compared with the size of the metal cylinder. The smaller the wire and leaf system, the smaller the capacity of the electroscope and the more sensitive it will be. The rod extended into the emanation chamber 11 centimeters and through the metal cylinder far enough so that a copper plate could be soldered onto the lower end. This copper plate was five millimeters wide and long enough to extend down past the windows in the box. The copper plate having been fastened to the rod, the latter was inserted into the cylinder above and held in place by a cork. Melted sulphur was poured into the other end of the cylinder. In melting the sulphur, care was used not to get it too hot or to burn it. The melted sulphur was a clear amber liquid (if it takes on a waxy appearance due to overheating it should be discarded). After the sulphur in the cylinder cooled for several hours, the cork was removed and the other end of the cylinder filled with melted sulphur. The sulphur served as an excellent insulator.

For the charging contact a small copper wire was used. It was bent so that it touched the insulated rod at one position and the case in the opposite position. The contact wire was insulated and fastened in the hole in the side of the box with melted sulphur. The sulphur insulators were kept free from dirt and moisture at all times. In case they became dirty they were cleaned by removing the dirty part with a knife. If the insulators collected moisture, they were renewed.

The front window consisted of a piece of ordinary glass of single thickness. Small tin clamps were soldered onto the box to hold the window in place. A contact plug was soldered on the side of the electroscope so that it could be connected to the ground. The back window was made of paper. A plastic protractor was used for the scale, S, which was fastened to the paper with paraffin and the whole assembly was then placed in melted paraffin before being stuck over the opening. The melted paraffin served a two-fold purpose; first, it made the paper transparent; and, second, it served as an adhesive for fastening the paper to the box.

The next step was to mount the leaf, L. Using Dutch foil, the leaf was made about one millimeter wide and four centimeters long. The supporting metal strip was cleaned with ether or alcohol and wiped with a clean, lint-free cloth. A very small amount of soft beeswax was spread over the upper end of the support, down to the transverse scratch in the metal which serves as the hinging line for the leaf. The foil was cut between sheets of greasefree paper with a pair of sharp scissors. One must not press down too hard on the guiding ruler or the foil will stick to the paper. The top paper was carefully removed and the waxed end of the support strip was placed on one end of the foil. Only a touch was needed to make them stick together. The foil was carefully inverted and gently pressed into the wax in order to insure good electrical contact and to define the hinging line of the foil. Gold foil is the best foil for leaves, but it is very difficult to cut and mount. Aluminium foil does not serve so well because it is rigid and does not swing freely, (but goes in jerks across the scale). The electroscope was rebuilt several times before it proved satisfactory. A rubber band (Hoag and Korff, 6) was used to charge the electroscope. The rubber band was stretched, then touched to the charging rod and slowly moved along until the deflection was of the desired amount. If the deflection was too great, the corner of a small piece of paper was flicked across the charging rod. Each movement of the paper removes only a small amount of electricity and the leaf may be brought down very close to the desired position.

A point-o-lite lamp was used to illuminate the scale. The source of illumination was kept constant and about 20 centimeters from the scale. The reading telescope was placed at the other end of the table, a distance of three meters from the electroscope. The telescope was adjusted until only the edge of the leaf was sharply in focus. The same irregularity on leaf edge was used as a reference mark in all the work. The divisions in the eyepiece of the telescope were made parallel to the edge of the leaf at the center of the scale. Care was taken to avoid parallax. The other apparatus comprised glass cylinder, thermometers, rubber bank, voltmeter, wires and a source of direct current varying from 0 to 200 volts.

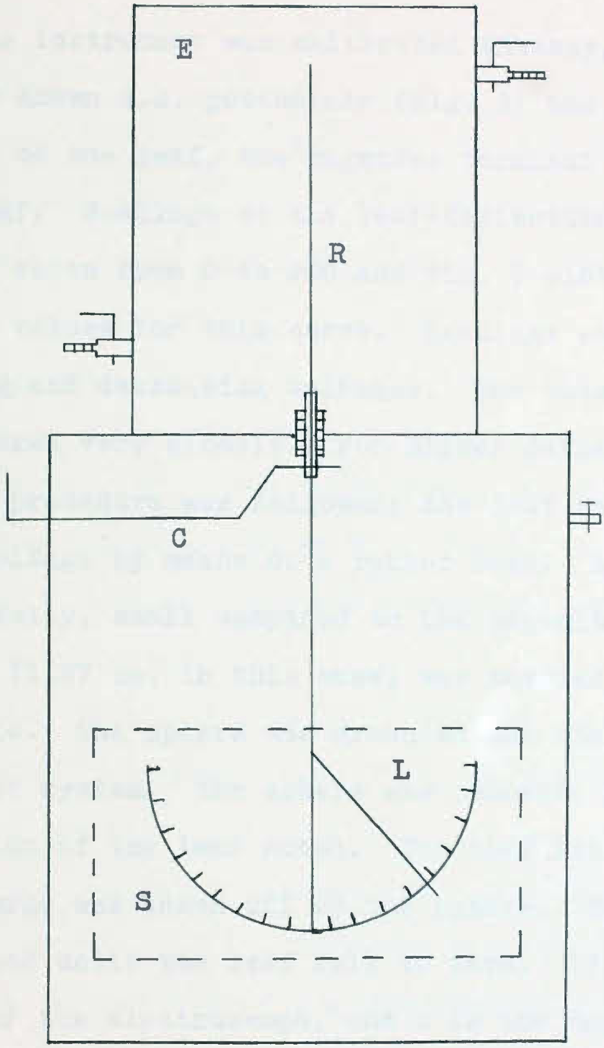

Fig. 6 Electroscope and Emanation Can

CALIBRATION OF ELECTROSCOPE

The instrument was calibrated (Ramsey, 9) by connecting it to known d.c. potentials (Fig. 9) and noting the deflections of the leaf, the negative terminal being connected to the leaf. Readings of the leaf-deflection were taken every few volts from 0 to 200 and Fig. 7 plotted. Table I gives the values for this curve. Readings were taken for increasing and decreasing voltages. The sets of deflections checked very closely. For higher deflections the following procedure was followed: the leaf was charged to maximum voltage by means of a rubber band. A sphere of small capacity, small compared to the capacity of the electroscope, (1.27 cm. in this case) was mounted on an insulated handle. The sphere was grounded and then touched to the charged system. The sphere was removed, grounded and the position of the leaf noted. The leaf fell because part of the charge was taken off by the sphere. This operation was repeated until the leaf fell to zero. If C is the capacity of the electroscope, and c is the capacity of the sphere; Q, the quantities of electricity on the electroscope; V_1, V_2 are the 1st., 2nd., ---potential of the leaf; d_1, d_2 are 1st., 2nd.,---deflection of leaf,

Then

$$Q_1 = CV_1 = (C + c)\, V_2$$

$$Q_2 = CV_2 = (C + c)V_3$$

$$Q_n = CV_n = (C + c)V_{n + 1}$$

$$\frac{C + c}{C} = \frac{V_1}{V_2} = \frac{V_2}{V_3} = \frac{V_n}{V_{n + 1}}$$

The last three or four deflections were on the part of the scale already calibrated, that is, the potentials were less than 200 volts. V_n and V_{n+1} were found by comparing with d_n and d_{n+1} on the calibrated curve, Fig. 7. Since, $V/V_{n+1} = V_{n-1}/V_n$ then, V_{n-1} was calculated. V_{n-1} being known, then V_{n-2} was calculated. In like manner all the V's were determined up to V_o. These results are given in Table II. Knowing V and its corresponding deflection, d, Fig. 8 was plotted.

In the same equation if c is known, that is, if c is a spherical condenser, then C can be obtained. The capacity of the spherical condenser, c, is equal to the radius of the sphere in centimeters. C is the capacity of the "leaf" system plus the charging system. Knowing the sum, the capacity of the "leaf" was obtained by getting a ratio of the two capacities, $C + c$ and c, by an operation similar to the above. The value of C is given in Table II. Several leaves were made and mounted before the tests were made. Each leaf was calibrated and the capacity of the electroscope determined everytime a change was made.

To standardize the electroscope, one of two methods was available. In the first, a standard solution is boiled, and the expelled gas collected over mercury. The gas is then dried and introduced into the electroscope, after which the ionization current or leak of the electroscope is noted. Other samples can be compared with the first by putting them through the same process and comparing the leaks. The Bureau of Standards at Washington is prepared to standardize radium solutions by comparing them with a standard in their possession.

If no standard solution is at hand the electroscope may be standardized by using Duane's empirical formula:

where

$$e = \frac{i_0}{2.49 \times 10^6 \, (1 - 0.517 \, S/V)} \text{ Curies}$$

$$e = \frac{i_{max.}}{6.31 \times 10^6 \, (1 - 0.572 \, S/V)} \text{ Curies}$$

e = amount of emanation in the electroscope.

i_0 = initial current expressed in e.s.u.

$i_{max.}$ = maximum current (current at the end of three hours) expressed in e.s.u.

S = inside surface of ionization chamber of electroscope in $cm.^2$

V = volume of ionization chamber in $cm.^3$ This equation applies to a cylindrical ionization chamber with a central rod.

The ionization current, i, is measured by knowing the capacity, C, of the electroscope; the change of potential, dV, of the insulated leaf system, in the time, t; according to the equation $i = \frac{C \, dV}{t}$.

TABLE I

DIRECT CURRENT CALIBRATION VALUES

Voltage	Deflection
0	0
22.5	0
46	.5
69	1.5
91	3.0
112	4.5
133	5.6
155	7.0
178	8.5
200	9.5
178	8.5
155	7.0
133	5.6
112	4.5
91	3.0
69	1.5
46	.5
22.5	0
0	0

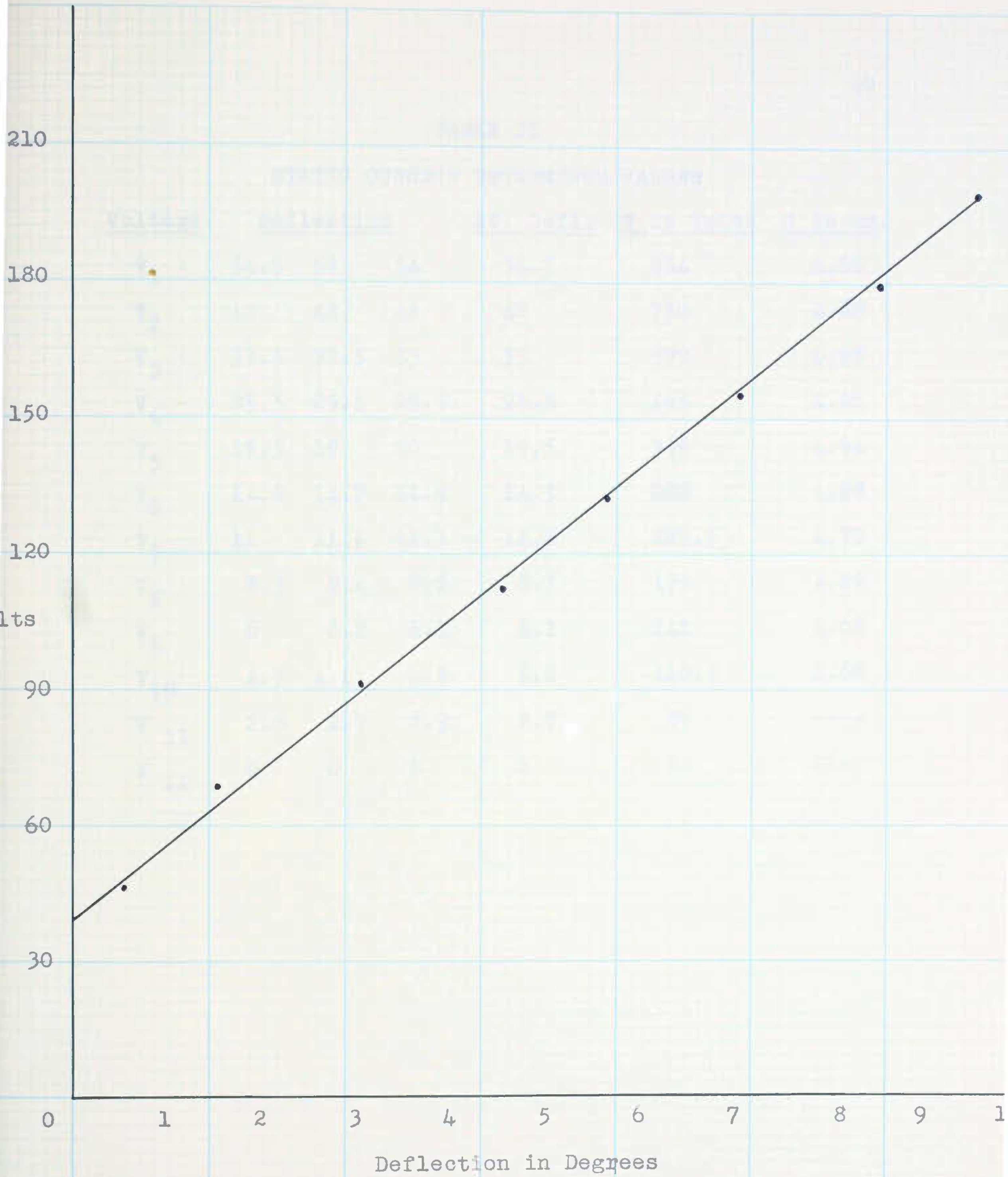

Fig. 7. Direct Current Deflection Curve

TABLE II

STATIC CURRENT DETERMINED VALUES

Voltage	Deflection			Av. Defl.	V in Volts	C in cm.
V_1	54.5	55	54	54.5	954	4.66
V_2	42	42	42	42	750	4.68
V_3	33.5	32.5	33	33	590	4.68
V_4	25.5	25.5	25.5	25.5	465	4.66
V_5	19.5	19	20	19.5	366	4.64
V_6	14.2	14.7	14.6	14.5	288	4.68
V_7	11	11.5	11.1	11.2	227.5	4.70
V_8	8.3	8.4	8.2	8.3	179	4.69
V_9	6	6.2	6.1	6.1	141	4.66
V_{10}	4.3	4.1	4.2	4.2	110.5	4.68
V_{11}	2.8	2.7	2.9	2.8	87	----
V_{12}	0	0	0	0	--	----

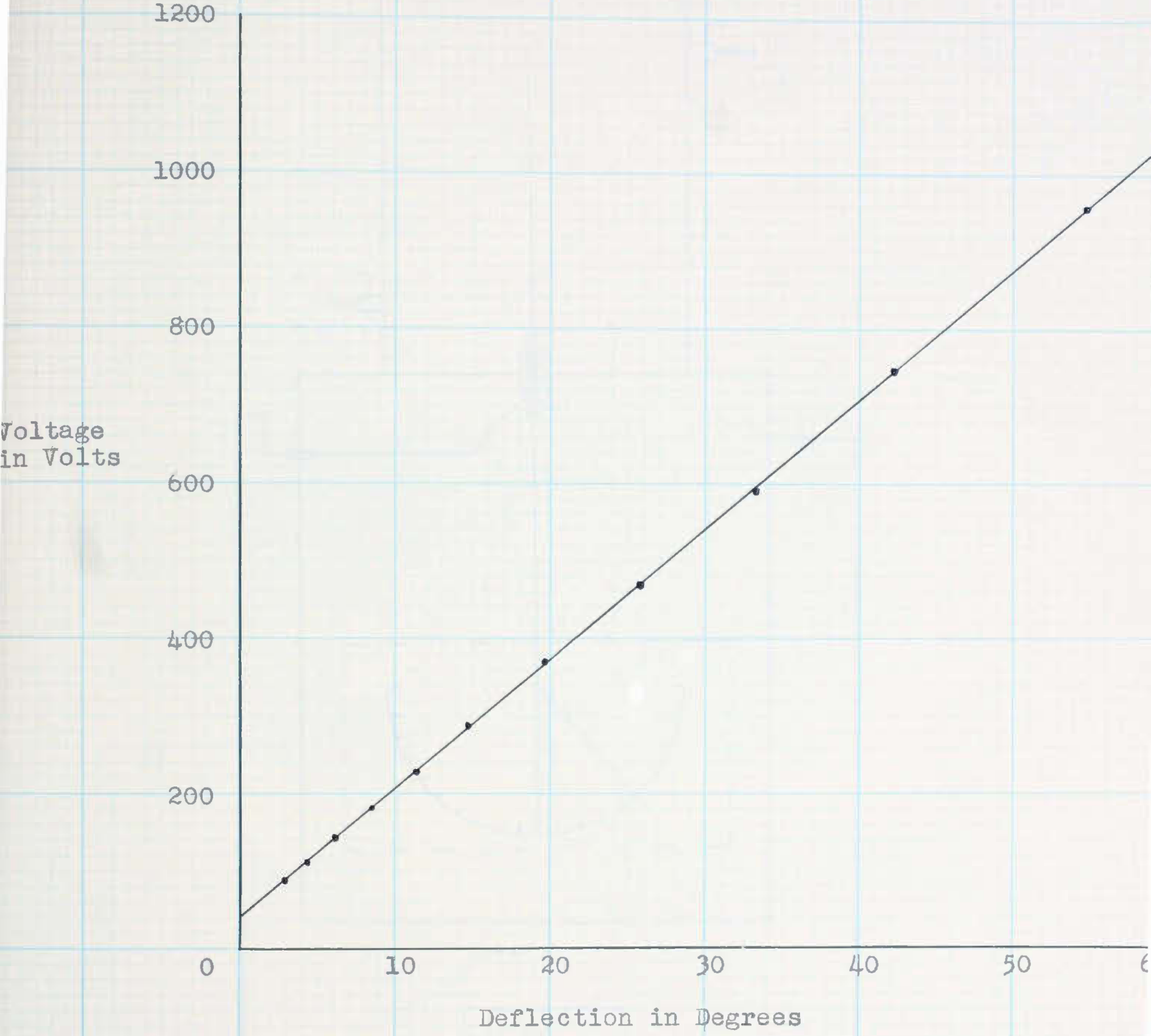

Fig. 8. Static Current Deflection Curve

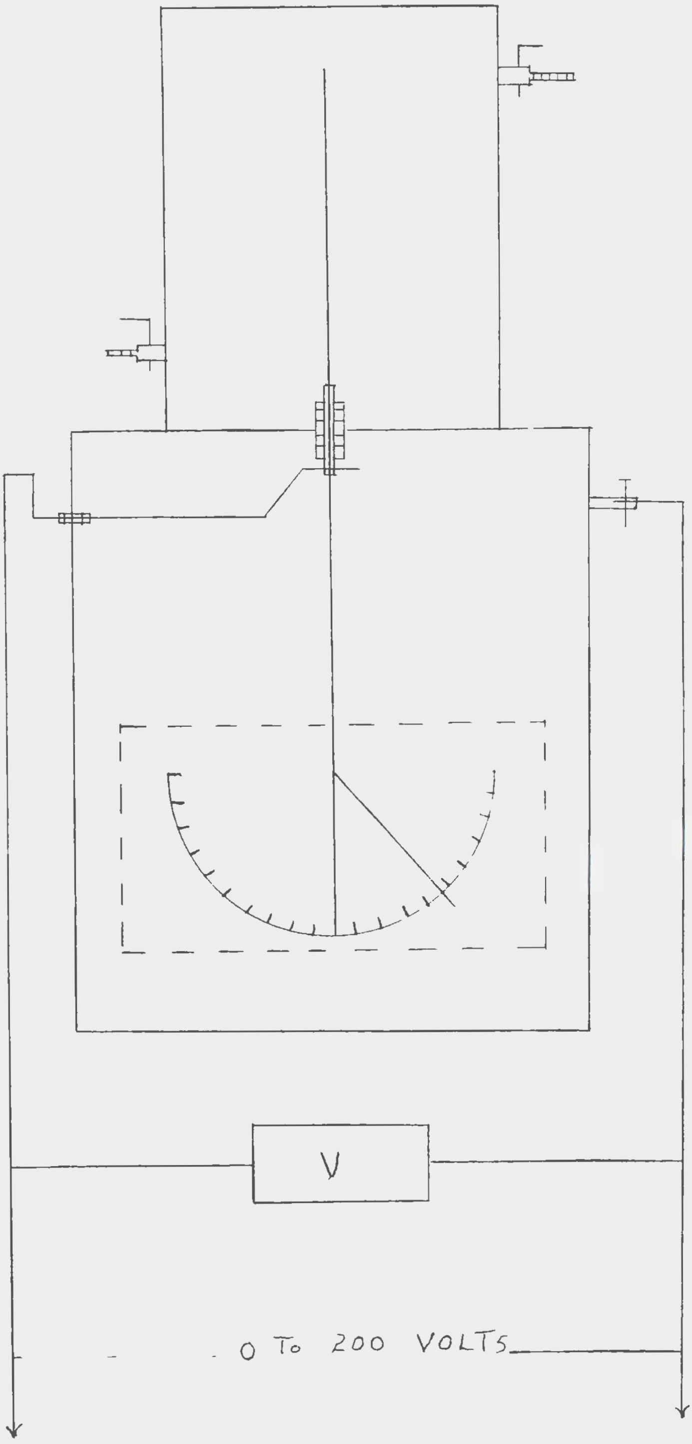

Fig. 9 Connection of Apparatus for Calibration of Leaf

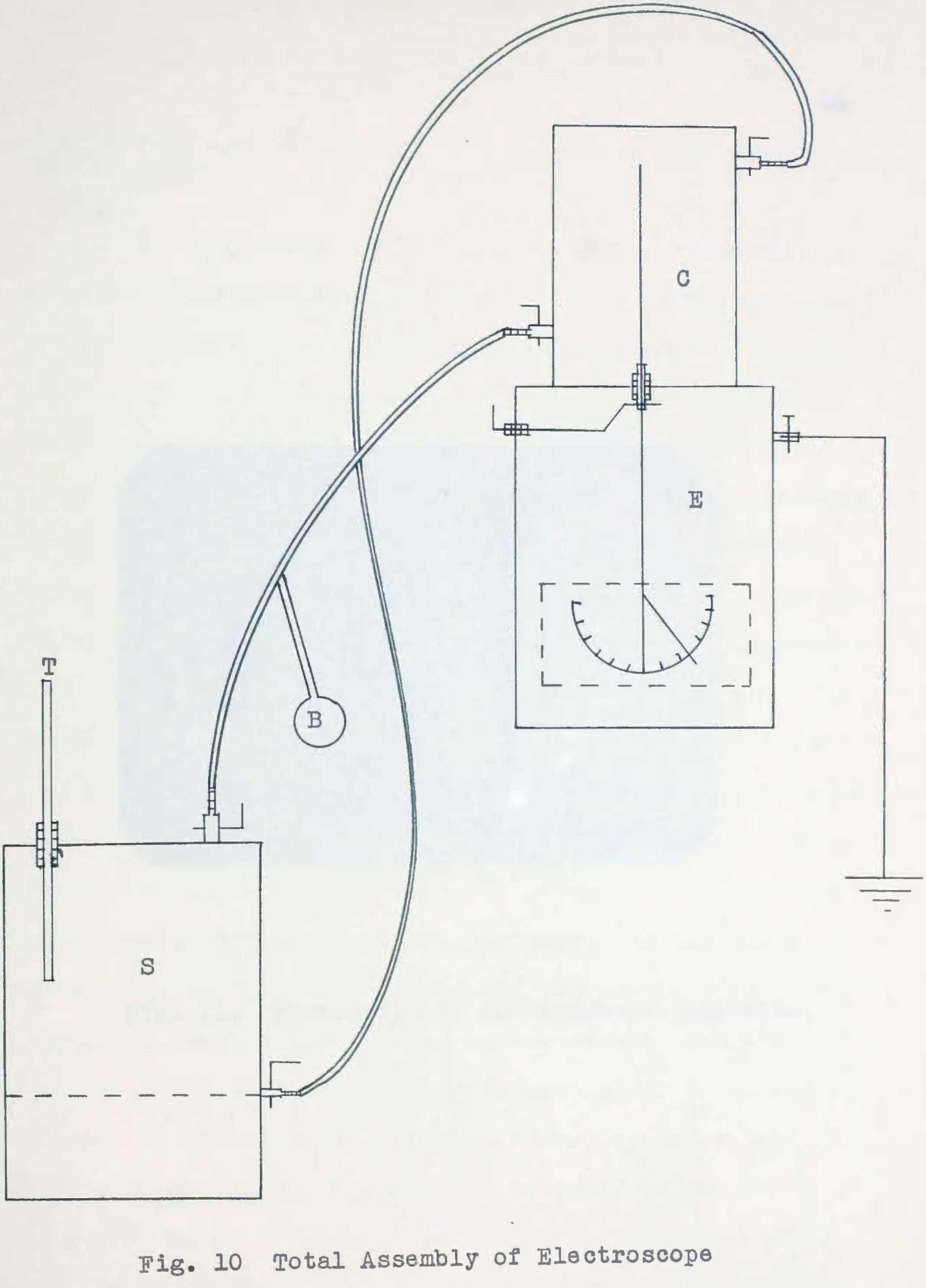

Fig. 10 Total Assembly of Electroscope

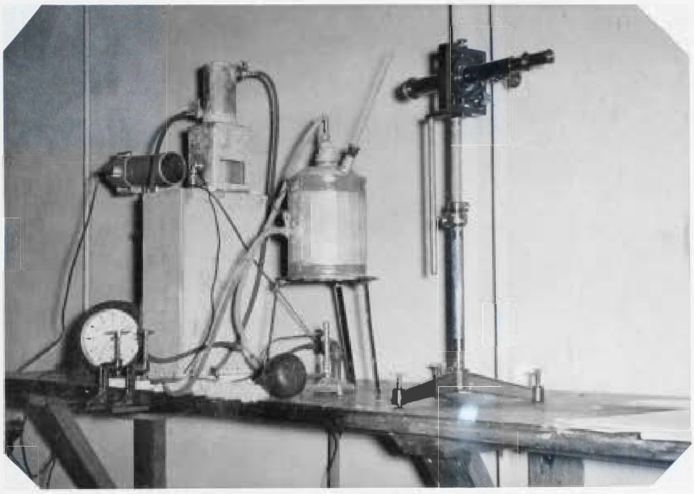

Fig. 11. Photograph of Electroscope Assembled.

CONSTRUCTION AND PRINCIPLES OF OPERATION OF THE GEIGER-MUELLER COUNTER

The Geiger-Mueller counter, or tube counter is an instrument for detecting the alpha, beta, and gamma rays. In its simplest form it consists of a metal tube with insulating plugs at either end, which support a thin wire passing down the center. The cathode is the metal tube and the anode is the wire (usually made of steel, aluminum, or tungsten, and from .1 to .5 millimeters in diameter) placed on the axis of the cylinder. In order to avoid the use of very high voltages, the counter is generally filled with air or some other gas at reduced pressure (from 2 to 10 cm. of mercury). Then between the wire and the metal tube a voltage is applied. This voltage must be just less than enough to break down the wire-to-cylinder gap. When an ionizing particle, for instance a beta ray, enters the space between the wire and the cylinder, the electrons produced in the gas will be speeded toward the wire with increasing kinetic energy and, in the strong electric field near the wire, obtain sufficient energy to ionize the gas, producing more electrons. The current builds up to a sudden surge of currents--in other words, an incipient spark. If the voltage is close but not too close to the sparking voltage the surge will die out very quickly. As each β-particle enters the chamber a surge will occur. By counting the surges the number of β-particles entering the chamber can be found.

The radioactive counter used in this study was a model LS64 Geiger-Mueller counter purchased from El Tronics, Inc. of Philadelphia. This model LS64 Geiger-Mueller laboratory set is a complete instrument for use with Geiger-Mueller counter tubes in making precise laboratory measurements of radiation intensities. It is a complete scaling type instrument with built-in impulse register (recording clock). It uses the famous, simple, positive and reliable Higinbotham scaling circuit (used under license agreement with the U.S. Atomic Energy Commission). It is a complete compact light weight instrument constructed on a single 13" x 17" chassis with 8 3/4" x 19" rack type front panel and mounted on a single deck rack type steel cabinet.

The following circuit components are all combined in one single assembly to form the complete model LS64 laboratory set.

(1) Scale of 64 scaling circuits (Higinbotham).
(2) Regulated high voltage power supply for Geiger-Mueller tube.
(3) Recorder circuit for operation of impulse register.
(4) Impulse register, zero reset type, counts to 9999 before recycling.
(5) Preamplifier stage.
(6) Bias and high voltage power supplies for scaling circuit, amplifier and recorder stages.

TUBES: A total of 20 tubes of the following types are used:

5 - Type 6H6
7 - Type 6SN7
1 - Type 6J6
1 - Type 5U4G
1 - Type 6V6GT
2 - Type 6A G5
1 - Type 2X2
1 - Type VR105
1 - Type VR150

EXTENSION AMPLIFIER: When using self-quenching counter tubes, the counter tube is connected to the input circuit of the instrument by means of the length of coaxial cable. When externally quenched counter tubes are used, it is necessary to connect same to the input of the preamplifier stage which is furnished as an extension unit at the end of a cable which plugs into the instrument. This permits the necessary short connecting lead between the counter tube and the grid of the first amplifier stage and still permits the counter tube to be conveniently moved about.

SECOND AMPLIFIER STAGE: The second amplifier stage which is built in the instrument itself is for the purpose of amplifying the pulses delivered either directly from the self-quenching counter tube itself or from the extension amplifier stage.

SCALING CIRCUIT: The scaling circuit consists of 6 stages to the scale of 64 using the simple, reliable, fool-proof Higinbotham circuit. Diode coupling tubes between the stages permit pulses of only 1 polarity to reach each succeeding scaler stage. A switch is provided on front panel for starting, stopping and resetting the scaling circuit. An AC receptacle is provided on the rear of the chassis for connection of a timing clock so that elapsed time of measurement can be determined. This receptacle is energized with 115 volts 60 cycles when the control switch is placed in the count position, and is de-energized when the switch is placed in the off position. Neon interpolation lamps on front panel determine the progress of the count through the scaling circuit. In addition to providing interpolation of measurement these lamps also indicate proper operation of the scaling circuits.

RECORDER CIRCUIT: A recorder circuit for operation of impulse register from the output of the scaling circuit is incorporated within the instrument. This is a specially designed stage having characteristics most suitable for the size and shape of the output pulses and the characteristics of the built-in impulse register.

IMPULSE REGISTER: A rugged electro-mechanical impulse register (recording clock) is permanently built in the instrument and is conveniently located on front panel. This register has a reset wheel so that it can be set to 0 before each measurement and counts up to 9999 before recycling. This particular register is capable of many million counts at relatively high speeds without any difficulty whatever. The maximum counting speed of the register used is approximately 16 evenly spaced pulses per second. The overall speed of the complete instrument is greatly increased by the incorporation of sufficient scaling stages.

REGULATION HIGH VOLTAGE POWER SUPPLY: A regulated high voltage power supply is incorporated in the instrument to provide an accurate and constant high potential to the counter tube to eliminate any error in measurements due to changes in counting rate caused by voltage variations on the counter tube itself. This power supply is electronically regulated to within 1% or less throughout line voltage fluctuations of 95 to 125 volts. The voltage range, controllable by front panel adjustment, is approximately 700 to 1500 volts.

CONTROLS: The following front panel controls are provided with functions as indicated.

(1) Main power switch
(2) High voltage switch
(3) Count-stop-reset switch
(4) High voltage adjust
(5) Impulse register reset.

INDICATING LAMPS AND INSTRUMENTS: The following instruments and indicator lamps are neatly and symmetrically arranged on front panel:

(1) High voltage voltmeter 0-1.5 K.V. D.C.
(2) Interpolation and count lamps numbered 1, 2, 4, 8, 16, and 32.
(3) Main power pilot light
(4) High voltage pilot light
(5) Count indicator pilot light

EXTERNAL CONNECTIONS: Terminations are provided for connection of the following external equipment:

(1) Oscilloscope
(2) Synchronous clock (for elapsed counting time)
(3) Counter tubes
(4) Extension amplifier

PLACING THE INSTRUMENT IN OPERATION: After making certain that all switches are in the off position, that the high voltage control knob is in the extreme low position, and that the impulse register is set to 0, the instrument is ready to be set up for making a measurement.

Next the counter tube was connected to the input circuit. A self-quenching counter tube was used, and the cathode (cylinder) of counter tube was connected to the shielded lead of the coaxial input cable, while the anode (center wire) was connected to center wire of the coaxial cable. The main power switch was turned on and at least one minute was allowed for all tubes to reach the proper operating temperature.

The high voltage switch was turned on and after allowing a few seconds for tubes in this circuit to reach the proper operating temperature, as evidenced by the reading on front panel voltmeter, the high voltage applied to counter tube was adjusted to the proper value by means of a control knob.

The control switch was placed in the count position. After measurements have been taken over the desired period of time, the control switch was set in OFF position and the reading of total count indicated on impulse register was taken. To this reading the sum of the numbers adjacent to each lighted Neon indicator lamp was added. This procedure furnishes the total count including interpolation counts still remaining within the scaling circuits.

After the total count was tabulated, the operating switch was turned to RESET position and released. This should deionize all of the Neon interpolation lamps. If all lights do not deionize first time, the switch was pushed to reset position several times.

OPERATING NOTES: The maximum reliable speed of the impulse register was approximately 16 evenly spaced pulses per second. When operated from the scaling circuit to the 64:1 ratio, the maximum speed was increased to 1024 evenly spaced pulses per second. However, the pulses created by radioactive substances are spurious and random in nature and often come in fast groups. In determining the maximum counting speed possible on randomly spaced pulses, it was necessary to base the speed on the time interval between the two most closely spaced pulses which occurred during any count period. Statistics indicate that a recording clock capable of measuring counting 16 evenly spaced pulses per second would be capable of counting only 1 to 2 pulses per second when the pulses are spurious and random in nature. Consequently, if great accuracy is desired, the instrument should be operated at speeds not exceeding 100 per second in the input circuit. Greater speeds can be used at a sacrifice in accuracy.

The sample cup which was used with the Dip Type counter was made out of a test tube 1.7 x 13 cm., which was mounted in a cylindrical can 8 x 14 cm., filled with paraffin (Bale, Haven and LeFeure, 1). The cup had a clearance of 1 mm. Centering was not too stringent; for an error of 1% the sample cup must be within 0.25 mm. of its proper center. By using equal volumes of solution and by raising the cup to the same point, the same geometric conditions was obtained for each sample and the resulting counts per minute were proportional to the radioactivity of the sample. A lead shield 0.23x24x47 cm. was constructed around the counter to reduce the background counts.

The procedure for cleaning the counter was to wipe the counter with a piece of absorbent tissue, rinse with distilled water, and again wipe the counter with absorbent tissue. The process was repeated once more to remove all traces of activity.

TABLE III

INFORMATION ON SPECIAL DIPPING TYPE COUNTER TUBE

Overall Dimensions (Inches)	7 x 3/4
Cathode Dimensions (Inches)	Aquadag 3 x 5/8
Glass Wall Thickness	$25 mg/cm^2$
Counter Filling	Argon-Ether
Approx. Threshold Voltage	830 volts
Operating Voltage (D.C.)	980 volts
Plateau Length	250 volts
Plateau Slope per 100 volts	5%
Deadtime in Micro-Seconds	80
Life in Counts	5×10^8 to 10^9

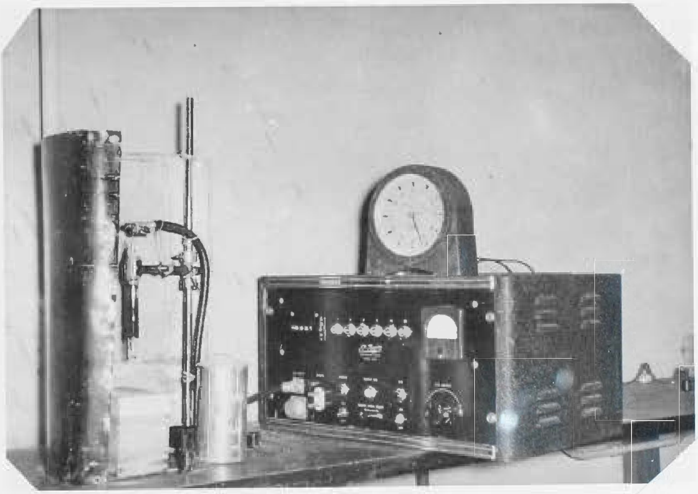

Fig. 12. Photograph of Geiger-Mueller Counter.

LABORATORY PROCEDURE

PROCEDURE BY ELECTROSCOPE: After the electroscope was calibrated and standardized, the next step was to find the volumes of air and water in the shaking can Fig. 13. To do this the can was filled with water, then it was drained out at the lower stopcock and weighed and measured, pains being taken to have the water run out to the same level each time. This procedure was repeated several times and the average taken for the volume of air in the shaking can. The volume was found to be 2.2416 liters. Next, the volume of water in the shaking can was determined. The can was filled above the level of the lower stopcock, placed on a level surface and allowed to drain until the water was level with the stopcock. Then the water remaining in the can was weighed and measured. This volume averaged 1.4998 liters. The volume of the pump, tubes and connections was determined by measurements and also by filling them with water and finding the volume of water contained by them. This volume was found to be 345.6 cubic centimeters. The volume and surface of the ionization chamber were determined by measurements and calculations. The surface, S, was 37513 square centimeters and the volume, V, was found to be 533.5 cubic centimeters.

The electroscope was set on a box near one end of

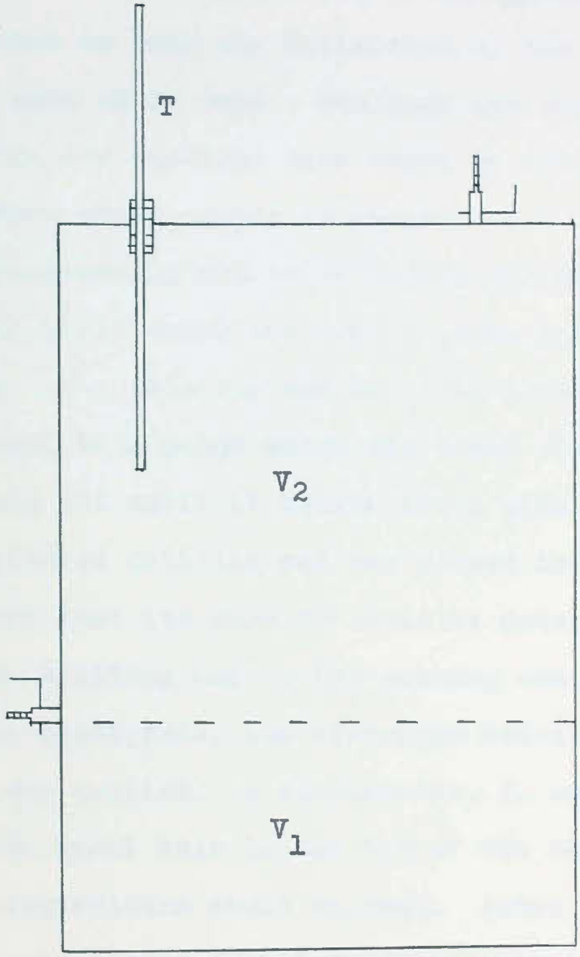

Fig. 13 Shaking Can

a long table and connected to ground. The lamp was placed back of the electroscope so that the scale was illuminated. At the other end of the table the telescope was adjusted to read the deflection of the leaf, when readings were to be made. The lamp was lit several minutes before the readings were taken so that the air.currents, due to heat, would remain constant.

The drilling mud to be tested was screened to remove the cotton hulls which are used to seal the sides of the well-hole. The drilling mud was then poured into the shaking can, to a point above the lower stopcock and allowed to drain out until it became level with it. Also, some of the filtered drilling mud was placed in a deep glass cylinder so that its density could be determined.

The drilling mud in the shaking can was heated to 55 degrees centigrade, the stopcocks being closed before the heat was applied. A thermometer, T, was inserted through the small hole in the top of the shaking can, so that the temperature could be read. After heating the drilling mud, it was agitated for two minutes, then cooled to room temperature in running water. The cooling of the emanation gas before being placed in the electroscope, eliminated two errors; first, it took most of the moisture out of the gas; and second, it cooled the gas to room temperature, thus avoiding spurious ionization effects.

Had the gas been placed in the electroscope while hot, it would have had greater ionizing power than the same gas at a lower temperature. After the gas was cooled to room temperature it was pumped through the emanation chamber for two minutes, so that it became well mixed with the air in the tubes and emanation chamber.

A complete set of ionization observation for a given sample of gas required three hours for completion and involved two sets of readings of ten-minute periods, one at the beginning of the three-hour period, the other at the close. The leaf was charged to near maximum deflection and the charging contact was grounded through the case of the electroscope. The deflection of the leaf was noted, as was also the time. At the end of ten minutes the deflection was again noted and recorded. After the first set of readings was completed the leaf was grounded and the gas was allowed to stand in the emanation chamber for three hours at the end of which, readings were again taken and recorded. The leaf was charged to about the same potential each time. The room was darkened so that the light intensity would remain constant, and the other physical conditions of the room were kept as nearly constant as possible.

The temperature of the gas was taken when it was placed in the emanation chamber. After the two sets of readings were taken, air was pumped through the emanation chamber for thirty minutes to remove the gas. The electroscope was allowed to stand for two hours before the next sample of drilling mud was tested. The natural leak of the electroscope (which was very small) was taken before each set of readings, and was subtracted from the leak due to the gas in the electroscope.

To find the amount of emanation in the emanation chamber, the deflections were substituted in the equations given under "Calibration of Electroscope." Hence, to calculate the amount of emanation per liter of drilling mud, the following formula was used.

$$E = \frac{1}{V_1} \frac{(V_2 + \alpha V_1)}{V_2} \frac{(V_2 + V_3 + V_4)}{V_4} e$$

Where V_1 = Volume of drilling mud in shaking can, expressed in liters.

V_2 = Volume of air in shaking can, expressed in liters.

V_3 = Volume of bulb, pump, and connection tubes.

V_4 = Volume of ionization chamber.

α = Absorption coefficient of water for radium emanation (taken from Fig. 14).

e = Amount of emanation in V_4.

E = Amount of emanation per liter of drilling mud.

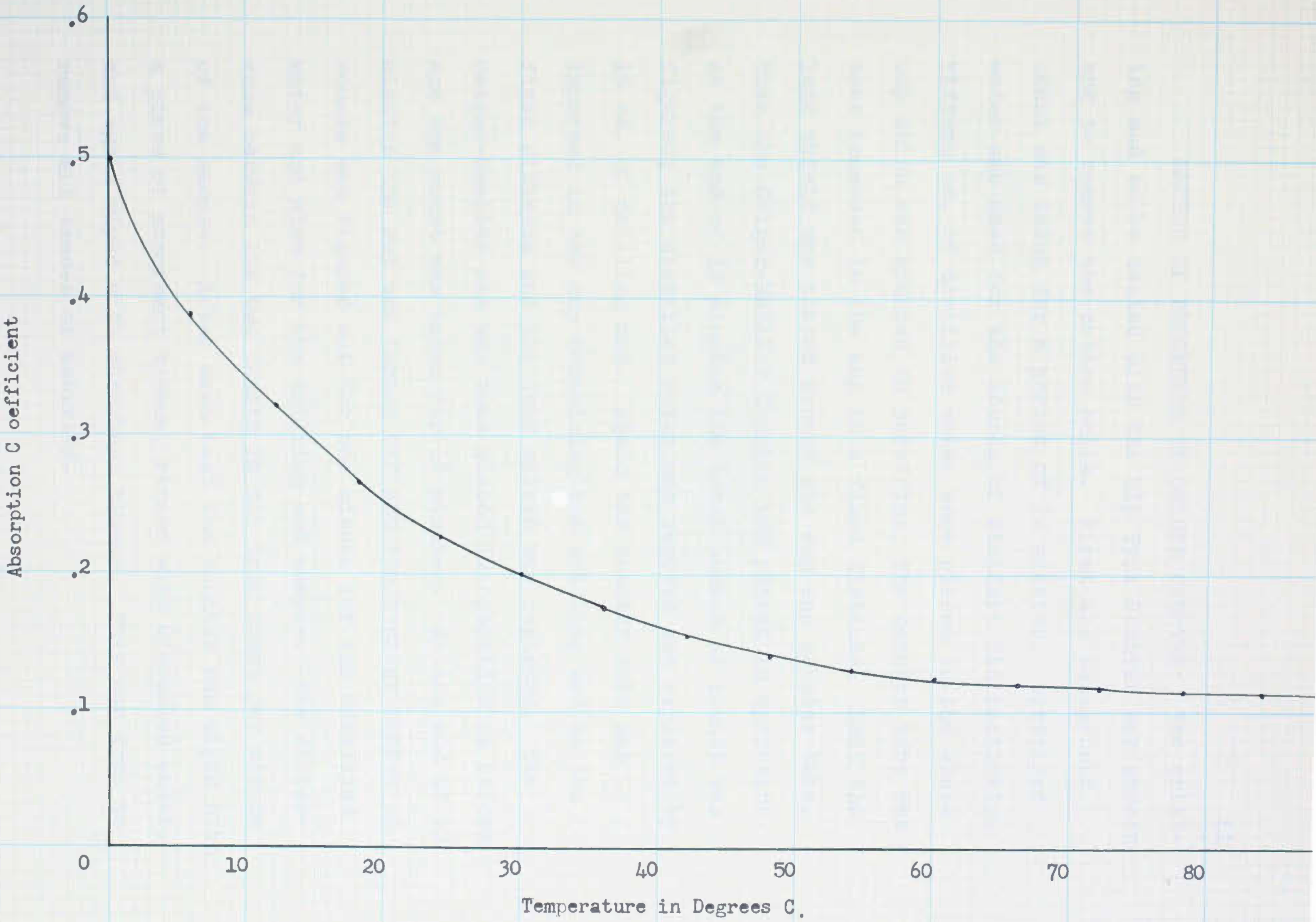

Fig. 14. Absorption C oefficient Curve (After Ramsey)

METHOD OF PROCEDURE BY GEIGER COUNTER: The drilling mud to be tested with the Dip Type Counter was screenend to remove the cotton hulls. First the background count was taken for a period of 12 minutes. Distilled water was used for the source of standard radioactivity. Fifteen cc. of distilled water were placed in the glass cup which was mounted in paraffin. The counter tube was then immersed in the cup to a fixed distance. Next the lead shield was placed around the cup and counter tube. Then the Geiger-Mueller Counter was placed in operation. At the end of 12 minutes the total number of counts was figured; the distilled water was removed and replaced by 15 cc. of drilling mud. Again the counter tube was immersed in the cup containing the drilling mud to the fixed distance and the lead shield was replaced. The Geiger-Mueller set was then placed in operation as before and the count was taken for 12 minutes. At the end of 12 minutes the set was turned off and the average number of counts was figured out for one minute for the distilled water and also for the drilling mud sample. The difference between the two counts is the true count per minute of the sample. After each test the counter was wiped with a piece of absorbent tissue, rinsed with distilled water, and again wiped with absorbent tissue. This was done to remove all traces of activity.

TABLE IV

Electroscope Data - Well 1

Sample	Date June	dV Volts	$i_o \times 10^{-4}$ e.s.u.	$e \times 10^{-10}$ Curies	α	$E_o \times 10^{-12}$ Curies/liter
1	20	16	3.98	2.62	.218	1169
2	21	8	2.07	1.31	.190	585
3	22	8	2.07	1.31	.206	580
4	23	6	1.55	0.98	.190	431
5	24	8	2.07	1.31	.180	571
6	25	14	3.62	2.22	.200	907
7	26	14	3.62	2.22	.190	906
8	27	15	3.88	2.46	.210	973
9	28	13	3.66	2.13	.200	841
10	29	10	2.59	1.64	.190	720
11	30	12	3.10	1.97	.200	776

A SAMPLE CALCULATION

WELL I SAMPLE I

Volts 16

$$i_o = \frac{CdV}{t}$$

$$= \frac{4.66 \text{ x } 16}{600 \text{ x } 300} = 3.98 \text{ x } 10^{-4}$$

$$e = \frac{i_o}{2.49 \text{ x } 10^6 \; (1-0.517 \; s/v)}$$

$$= \frac{3.98 \text{ x } 10^{-4}}{2.49 \text{ x } 10^6 \; \left(1-0.517 \text{ x } \frac{375.3}{533.4}\right)}$$

$$= 2.62 \text{ x } 10^{-10}$$

$$E_o = \left(\frac{1}{V_1}\right) \left(\frac{V_2 + \alpha V_1}{V_2}\right) \left(\frac{V_2 + V_3 + V_4}{V_4}\right) (e)$$

$$= \left(\frac{1}{1.4998}\right) \left(\frac{2.2413 + .218 \cdot 1.4998}{2.2413}\right) \left(\frac{2.2413 + .3456 + .5334}{.5334}\right) \left(2.62 \text{ x } 10^{-10}\right)$$

$$= 1169 \text{ x } 10^{-12} \text{ Curies/l.}$$

TABLE V

Electroscope Data - Well 1

Sample	Date June	dV_{max} Volts	$i_{max} \times 10^{-4}$ e.s.u.	$e \times 10^{-10}$ Curies	α	$E_{max} \times 10^{-12}$ Curies/liter
1	20	38	9.85	2.60	.211	1190
2	21	21	5.45	1.44	.195	599
3	22	21	5.45	1.44	.180	643
4	23	13	3.36	0.89	.210	433
5	24	19	4.90	1.30	.190	585
6	25	33	8.51	2.26	.190	913
7	26	34	8.77	2.33	.195	942
8	27	35.5	9.16	2.44	.190	984
9	28	31	8.00	2.12	.210	858
10	29	27	7.00	1.85	.210	757
11	30	29	7.51	1.99	.190	802

TABLE VI

Calculated Results for Electroscope Data - Well 1

Sample	Date June	Depth in feet	$E_0 \times 10^{-12}$ curies/l	$E_{max} \times 10^{-12}$ curies/l	Av. E x 10^{-12} curies/l
1	20	806	1169	1190	1179.5
2	21	1877	585	599	592
3	22	2206	580	643	611.5
4	23	2505	431	433	432
5	24	2742	571	585	578
6	25	2981	907	913	910
7	26	3279	906	942	924
8	27	3398	973	984	978.5
9	28	3517	841	858	849.5
10	29	3635	720	757	738.5
11	30	3754	776	802	789

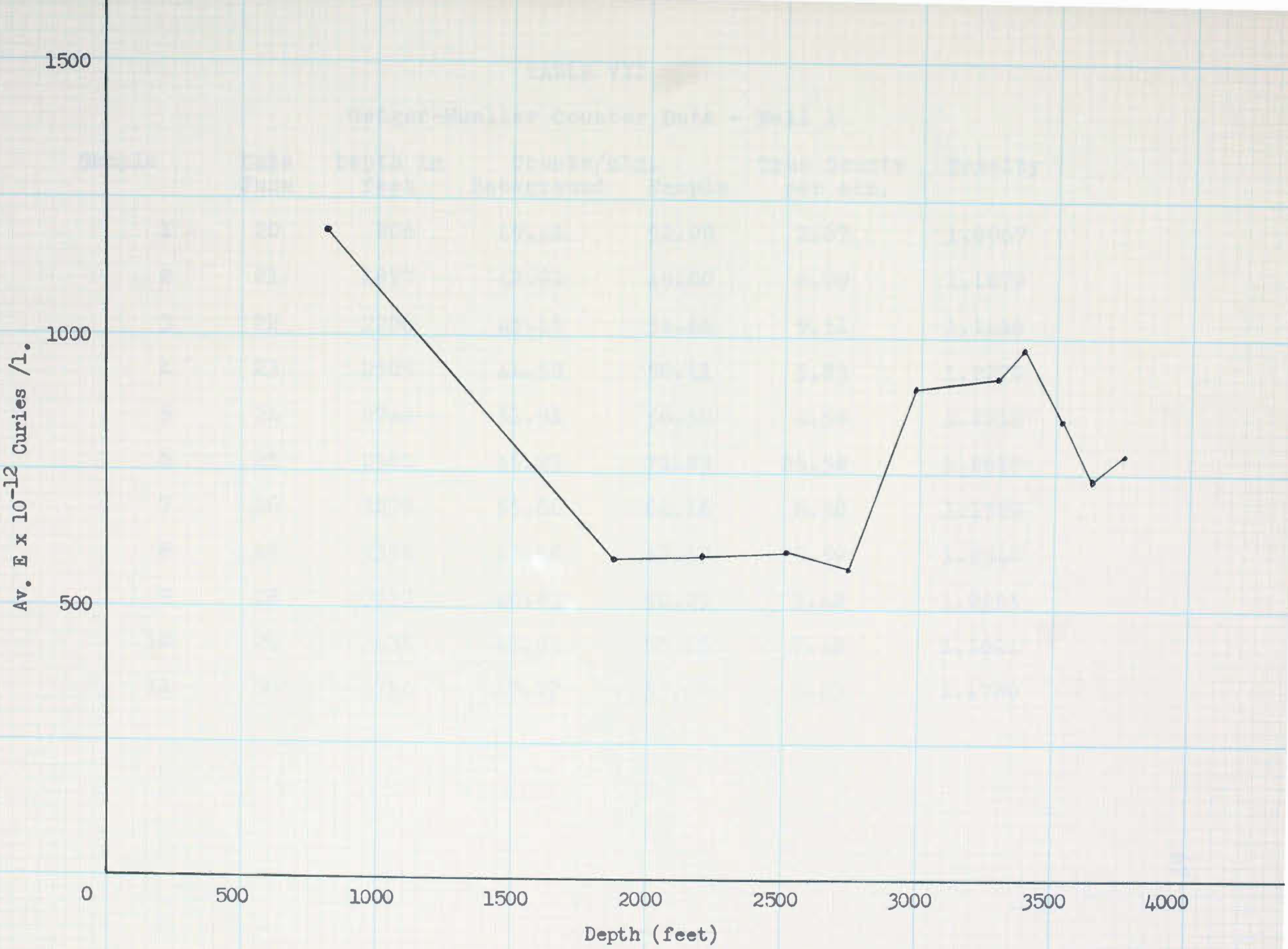

Fig. 15. Radioactivity Curve - Well 1

TABLE VII

Geiger-Mueller Counter Data - Well 1

Sample	Date June	Depth in feet	Counts/min. Background	Counts/min. Sample	True Counts per min.	Density
1	20	806	49.41	52.08	2.67	1.0967
2	21	1877	42.91	49.00	6.09	1.1079
3	22	2206	45.15	54.66	9.51	1.1416
4	23	2505	44.58	50.41	5.83	1.2270
5	24	2742	51.91	56.50	4.59	1.2212
6	25	2981	45.25	71.83	26.58	1.2617
7	26	3279	55.66	64.16	8.50	1.1789
8	27	3398	43.58	47.17	3.59	1.2340
9	28	3517	46.83	50.25	3.42	1.2565
10	29	3635	45.83	55.25	9.42	1.1624
11	30	3754	47.17	53.00	5.83	1.1780

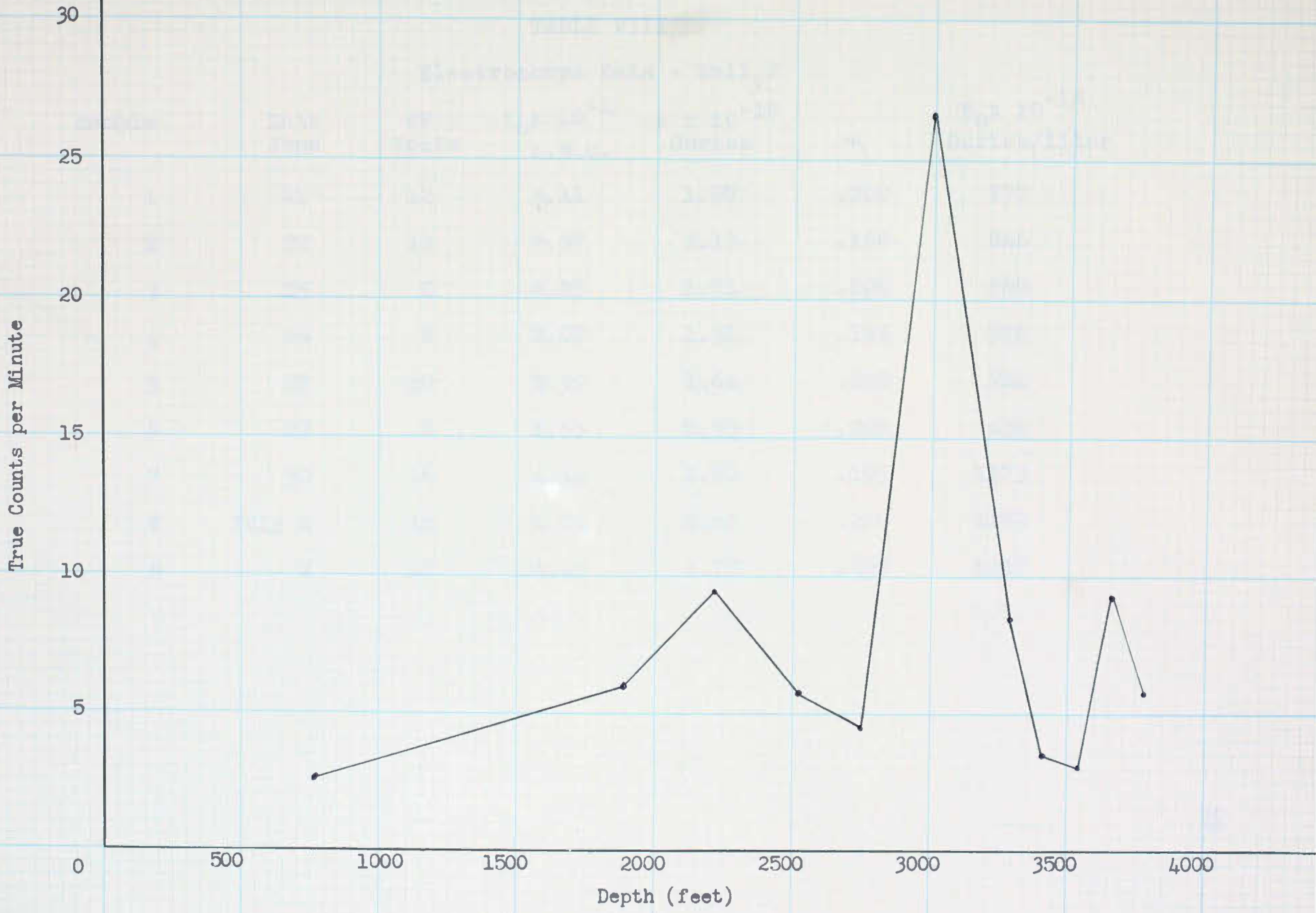

Fig. 16. Radioactivity Curve - Well 1

TABLE VIII

Electroscope Data - Well 2

Sample	Date June	dV Volts	i_o x 10^{-4} e.s.u.	e x 10^{-10} Curies	α	E_o x 10^{-12} Curies/liter
1	21	12	3.11	1.97	.200	777
2	22	13	3.37	2.13	.190	846
3	25	8	2.07	1.31	.200	580
4	26	8	2.07	1.31	.195	576
5	27	10	2.59	1.64	.200	724
6	29	6	1.55	0.93	.202	434
7	30	16	4.14	2.62	.195	1173
8	July 1	16	4.14	2.62	.210	1183
9	2	17	4.40	2.78	.200	1227

TABLE IX

Electroscope Data - Well 2

Sample	Date June	dV_{max} Volts	$i_{max} \times 10^{-4}$ e.s.u.	$e \times 10^{-10}$ Curies	α	$E_{max} \times 10^{-12}$ Curies/liter
1	21	29	7.51	1.99	.210	802
2	22	31	8.04	2.13	.195	857
3	25	21	5.94	1.45	.195	676
4	26	21	5.94	1.45	.200	678
5	27	27	7.00	1.86	.180	825
6	29	18	4.66	1.24	.190	553
7	30	41	10.60	2.82	.210	1236
8	July 1	40	10.30	2.75	.210	1245
9	2	42	10.90	2.89	.185	1292

TABLE X

Calculated Results for Electroscope Data - Well 2

Sample	Date June	Depth in feet	$E_0 \times 10^{-12}$ curies/l	$E_{max} \times 10^{-12}$ curies/l	Av. $E \times 10^{-12}$ curies/l
1	21	506	777	802	789.5
2	22	1058	846	857	851.5
3	25	1695	580	676	628
4	26	2433	576	678	627
5	27	2887	724	825	774.5
6	29	3396	434	553	493.5
7	30	3563	1173	1236	1204.5
8	July 1	3717	1183	1245	1214
9	2	3870	1227	1292	1269.5

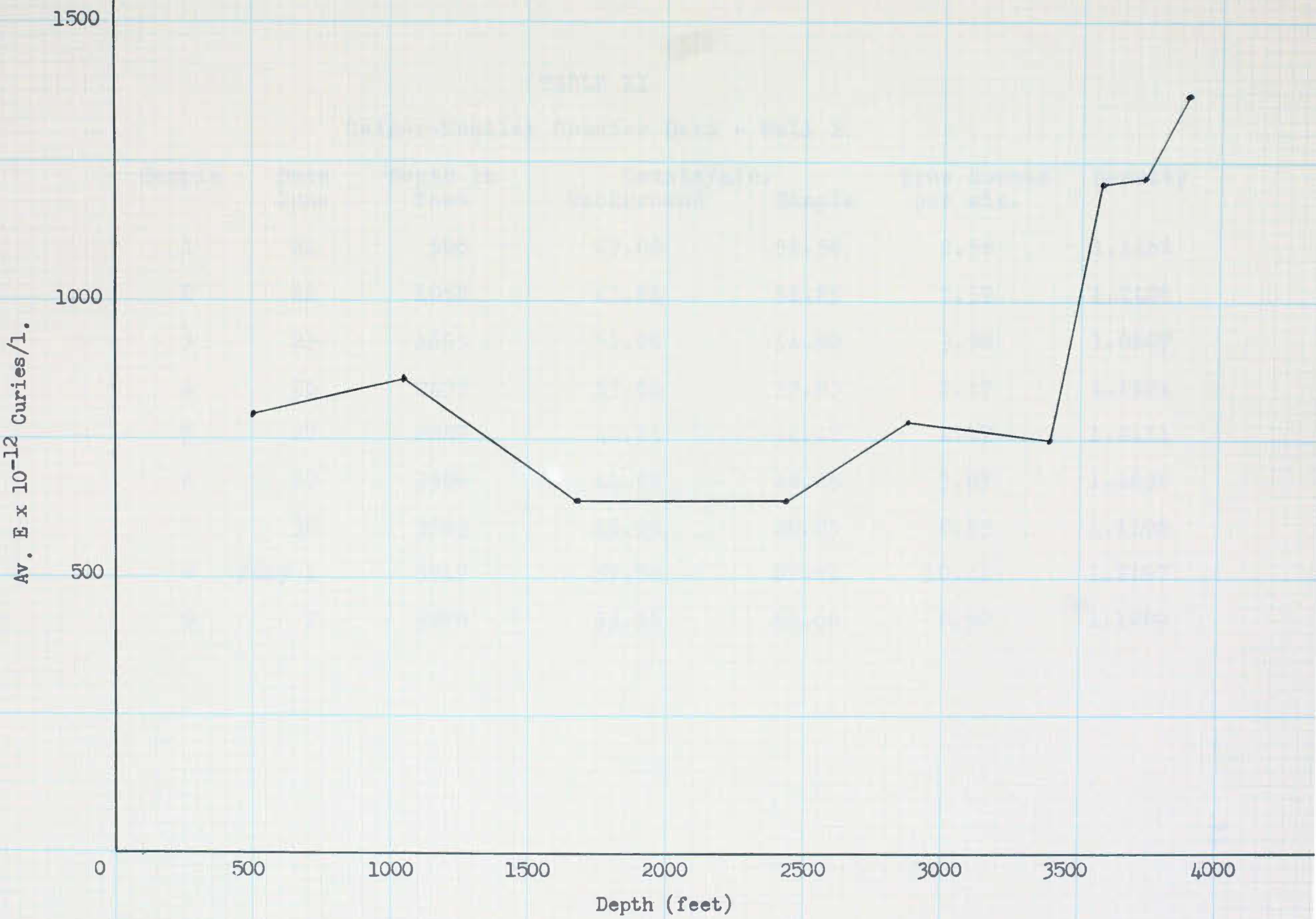

Fig. 17. Radioactivity Curve - Well 2

TABLE XI

Geiger-Mueller Counter Data - Well 2

Sample	Date June	Depth in feet	Counts/min.		True Counts per min.	Density
			Background	Sample		
1	21	506	49.00	51.58	2.58	1.1462
2	22	1058	43.66	51.25	7.59	1.2406
3	25	1695	51.00	54.90	3.90	1.0607
4	26	2433	55.66	57.83	2.17	1.1224
5	27	2887	42.25	44.42	2.17	1.2411
6	29	3396	44.58	48.25	3.67	1.1638
7	30	3563	45.33	46.25	0.93	1.1106
8	July 1	3717	57.50	67.91	10.41	1.2197
9	2	3870	53.16	61.66	8.50	1.1289

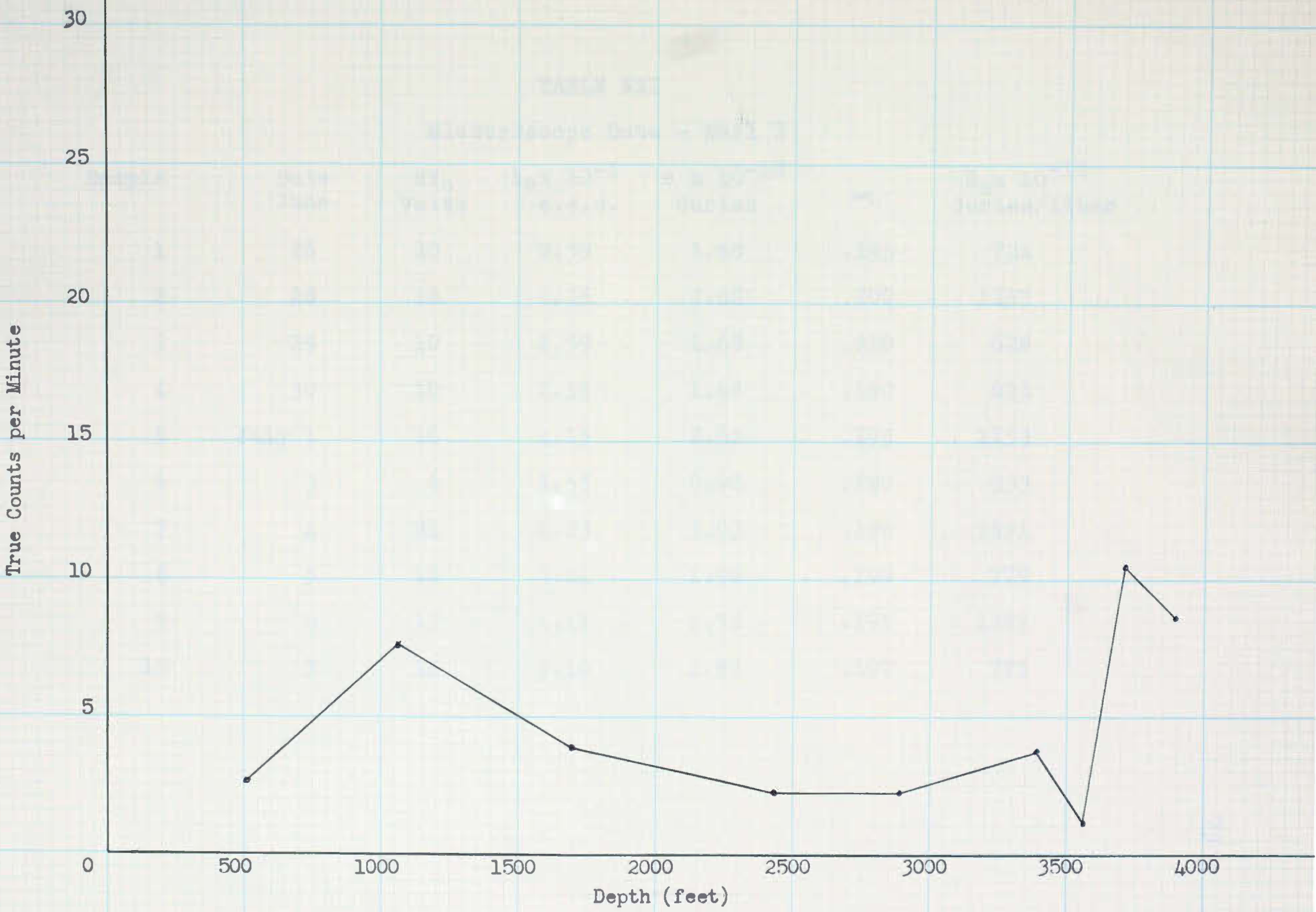

Fig. 18. Radioactivity Curve - Well 2

TABLE XII

Electroscope Data - Well 3

Sample	Date June	dV_o Volts	i_ox 10^{-4} e.s.u.	e x 10^{-10} Curies	α	E_ox 10^{-12} Curies/liter
1	26	10	2.59	1.68	.195	724
2	28	16	4.15	2.62	.200	1157
3	29	10	2.59	1.68	.210	628
4	30	10	2.59	1.68	.190	623
5	July 1	16	4.15	2.62	.195	1153
6	3	6	1.55	0.98	.190	333
7	4	24	6 23	3.93	.190	1651
8	5	12	3.11	1.96	.190	775
9	6	17	4.41	2.78	.195	1227
10	7	12	3.10	1.97	.190	775

TABLE XIII

Electroscope Data - Well 3

Sample	Date June	dV_{max} Volts	$i_{max} x 10^{-4}$ e.s.u.	$e x 10^{-10}$ Curies	α	$E_{max} x 10^{-12}$ Curies/liter
1	26	27	7.00	1.85	.190	746
2	28	43	11.10	2.95	.195	1325
3	29	23	5.96	1.58	.210	647
4	30	23	5.96	1.58	.195	646
5	July 1	43	11.10	2.95	.190	1321
6	3	13	3.33	0.89	.195	359
7	4	62	16.1	4.62	.190	1912
8	5	29	7.50	1.99	.190	844
9	6	45	10.17	3.19	.195	1396
10	7	29	7.50	1.99	.197	802

TABLE XIV

Calculated Results for Electroscope Data - Well 3

Sample	Date June	Depth in feet	E_0 x 10^{-12} curies/l	E_{max} x 10^{-12} curies/l	Av. E x 10^{-12} curies/l
1	26	280	724	746	735
2	28	939	1157	1325	1241
3	29	1577	628	647	638.5
4	30	2114	623	646	634.5
5	July 1	2504	1153	1321	1237
6	3	2950	333	359	346
7	4	3198	1651	1912	1781.5
8	5	3369	775	844	809.5
9	6	3491	1227	1397	1312
10	7	3590	775	802	788.5

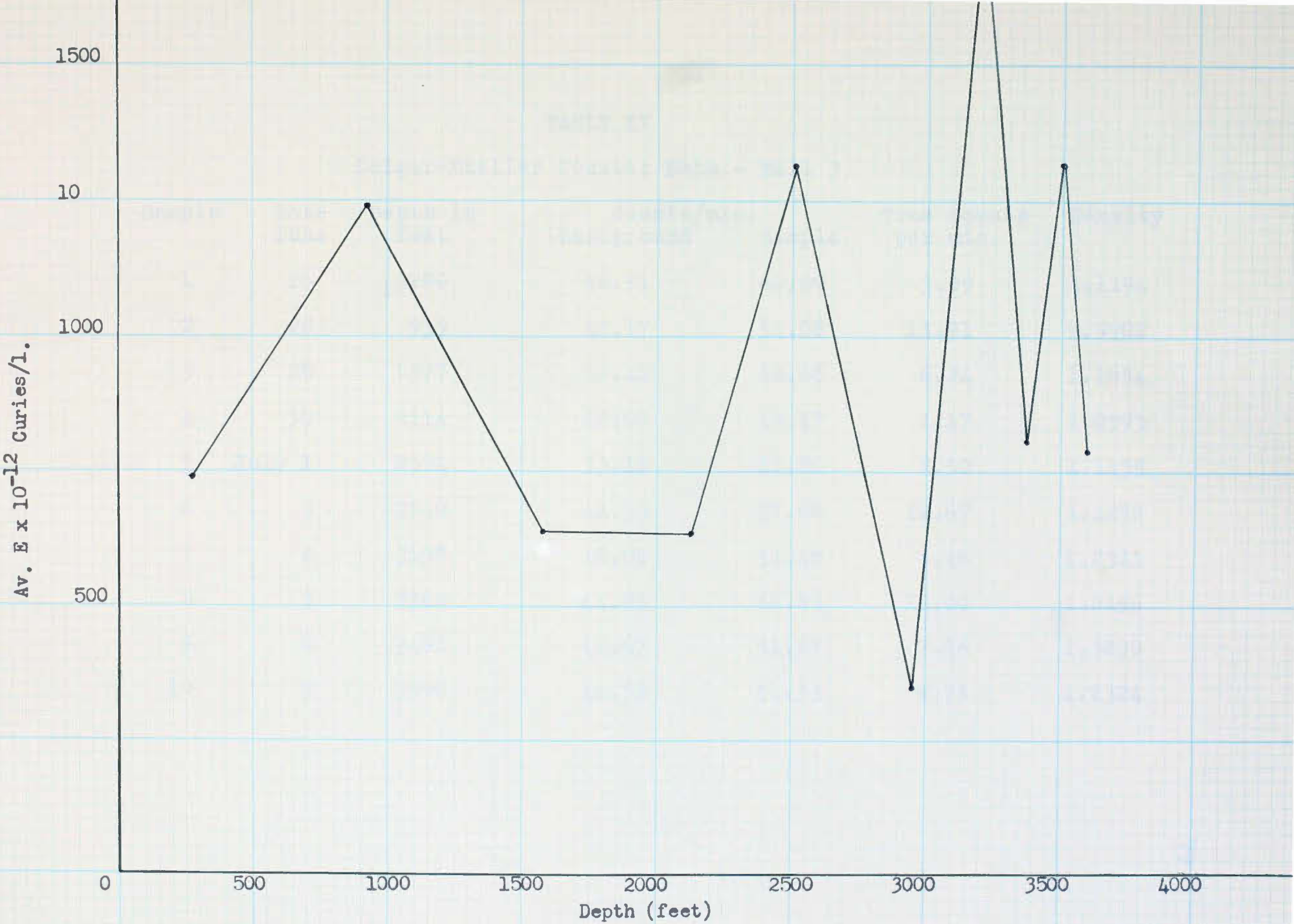

Fig. 19. Radioactivity Curve - Well 3

TABLE XV

Geiger-Mueller Counter Data - Well 3

Sample	Date June	Depth in feet	Counts/min.		True Counts per min.	Density
			Background	Sample		
1	26	280	58.91	62.00	3.09	1.1194
2	28	939	42.17	54.08	11.91	0.9902
3	29	1577	52.42	58.66	6.24	1.1654
4	30	2114	48.00	49.17	1.17	1.0593
5	July 1	2504	53.16	61.66	8.50	1.1455
6	3	2950	44.33	57.00	12.67	1.1472
7	4	3198	46.00	51.46	5.46	1.2311
8	5	3369	44.83	56.83	12.00	1.2456
9	6	3491	44.67	51.83	7.16	1.3230
10	7	3590	44.58	54.33	9.75	1.2324

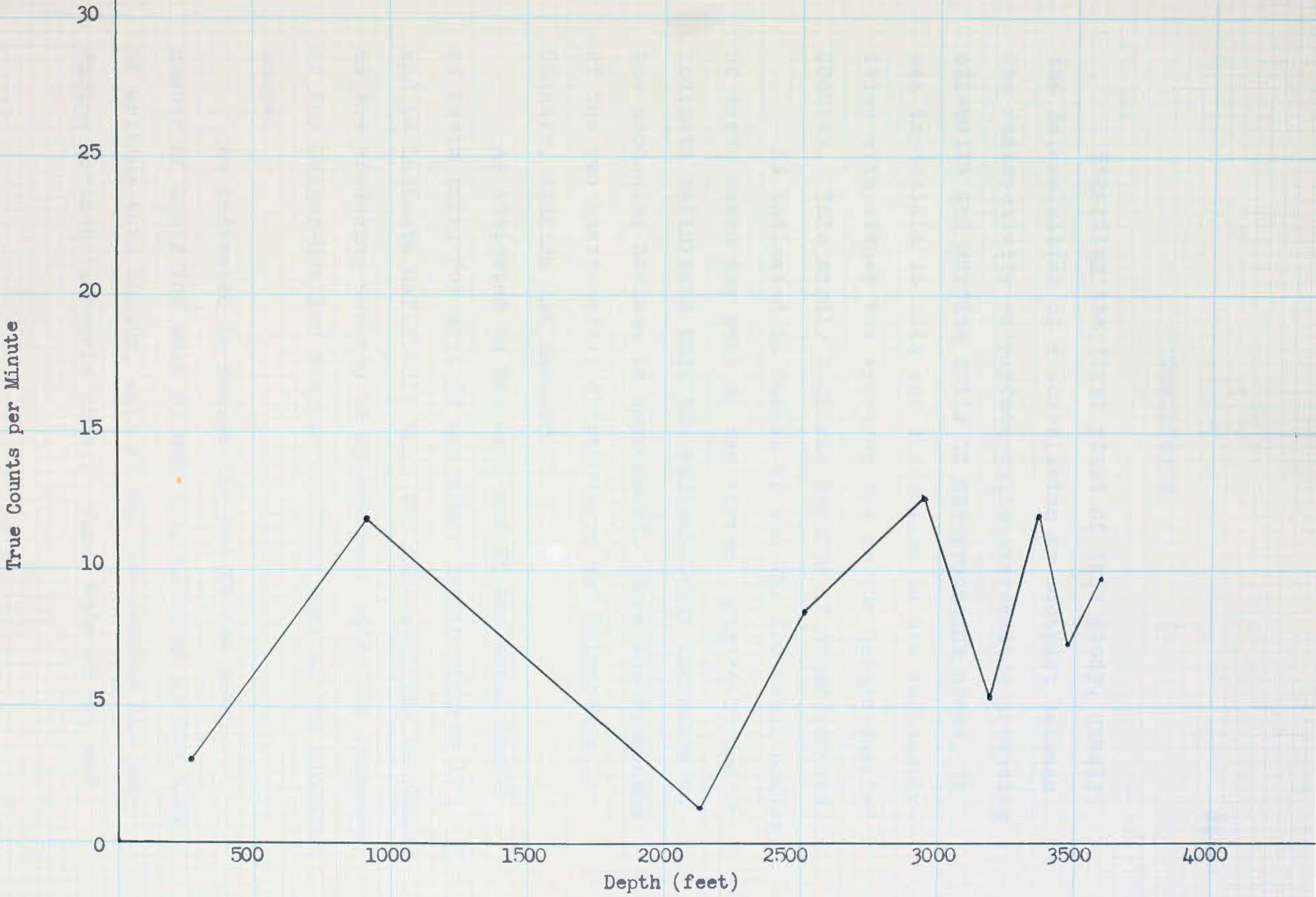

Fig. 20. Radioactivity Curve - Well 3

CONCLUSION

Regarding the first phase of this study, namely, the determination of a correlation or contrast between the radioactivity of surface soils surrounding producing oil-wells and surface soils in non-producing areas, it was impossible to note any difference in the radioactivities with either the electroscope or the Geiger-Mueller Counter. This merely confirms reports of other workers.

As indicated in Tables VI and VII the total number of tests taken for well #1 was eleven. Figures15 and 16 indicate definitely that the radioactivity increases as the producing horizon is approached. Here the responses of the two instruments, electroscope and Geiger-Mueller Counter, confirm one another.

As indicated in Tables X and XI the total number of tests taken for well #2 was nine. Again Figures 17 and 18 indicate definitely that the radioactivity increases as the producing horizon is approached. Also the response of the Geiger-Mueller counter confirms that of the electroscope.

As indicated in Tables XIV and XV the total number of tests for well #3 was ten, although at the time of writing this thesis, well #3 had not reached the producing horizon (Arbuckle lime). Since this is so, and since the response curves of Figures 19 and 20 do not show a definite increase of radioactivity with depth, it is questionable whether well #3 will turn out to be a producing well. This supposition is borne out by the low-productivity of the offset of well #3.

An improvement to this investigation would be to relate graphically the depth readings to known geological horizons indicating the identity and thicknesses of the various formations through which the respective wells are driven; also to procure a radioactive standard with which to interpret and compare the Geiger-Mueller counts for depth with the corresponding response of the electroscope which latter were calculated by means of Duane's formula.

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