# AN ELECTRICAL METHOD OF PROSPECTING

Thesis for the Degree of B. S.

WILLIAM G. KECK    H. WESLEY DOVE

1929

THESIS

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## ACKNOWLEDGMENTS

During the course of making this research, we have used instruments and materials belonging to the Physics Dept. We wish to express our appreciation of this favor and also for the use of the shop. Especially are we indebted to Geo. Chapman, who by his many helpful suggestions and his ability along such lines, has made it possible for us to construct suitable apparatus for our work. We also wish to express our gratitude to the members of the Physics and Electrical Engineering Departments for their constructive criticism, especially Professors Chapman, Kinney, Naeter, and Snow.

# INTRODUCTION

Lack of a method definitely known to be applicable to the locating of geological formations has long hindered the development of mineral resources. It was with the object in mind of devising some method for studying these geological formations that this research was attempted.

The search for Nature's hidden mineral resources has always been fascinating to that type of American known as the "Prospector". His methods have largely been of a hit and miss nature; his results dependent only upon the number of trials he makes. The remuneration resulting from a lucky guess, has caused certain more or less well meaning individuals, to claim powers of locating such resources with infallible accuracy. Reference is made to the "Divining Rod" and "Doodle Bug". In fact Industry, the Petroleum Industry especially, has been duped so many times that it looks with skepticism upon anyone purporting to locate sources of mineral wealth. Many of the men having control of the financial resources of the industry have forgotten much of what they learned in their college physics and consequently are not prepared to differentiate between a sincere attempt on the part of the scientist and the fraudulent operation of the "Doodle Bug Expert". This uncertainty is rapidly being dispelled by the assurance given to scientific methods by some of the leading colleges and universities in the country. The success of such methods is by no means guaranteed, since the task is no simple one, and much research must be done before methods suitable to all conditions are devised.

## REVIEW OF GEOPHYSICAL METHODS FOR PROSPECTING

As has been said previously, there have been devised a number of methods for scientifically searching out these mineral deposits. Of the methods which are being used today, there are four general types:- magnetic, gravitational, seismic, and electrical. We shall briefly consider some of the advantages and disadvantages connected with each of these types.

It is well known that the earth acts as a huge irregular magnet:- the irregularities being caused for the most part by subsurface deposits of magnetic or non-magnetic bodies. For instance, an iron ore deposit near to the surface will concentrate the magnetic lines through that point. To obtain measurements of this sort, two types of instruments have been devised. They are the magnetometer and the magnetic variometer. The first of these measures the vertical and horizontal deflections of a very sensitive dip-needle or compass. By plotting the differences of these deflections from the normal deflection on a graph , the position of the ore body may be estimated with some degree of accuracy. The magnetic variometer measures the intensities of the magnetic fields in these two directions, and graphs are made in a similar manner.

While these methods are undoubtedly of some value to the prospector, a number of difficulties must necessarily be overcome. Earth currents, always present in the ground, have magnetic fields about them and tend to decrease the reliability of the measurements. Magnetic storms have their distructive influences. Substances above the surface which have magnetic properties, such as rail-roads, or any iron articles, will also introduce other sources of error. Probably the greatest fault of this method is the inability to determine the depths at which the deposits lie.

Another system, which has been used with some degree of satisfaction, is the gravitational method. Of the types under this heading, the torsion balance is the most important. This instrument depends on the differences in the pull of gravity from place to place over the earth's surface. A very sensitive beam balance, with weights at different distances from the ground, is used to obtain the measurement. The force of gravity at the point of measurement acts at a different angle on the two weights, and thus causes the beam to be thrown out of the horizontal. The amount of the deflection may be measured, and graphs made of readings taken at various points over the earth's surface. Any heavy ore-body will of course exert a greater gravitational force than would be found if the body were not present. Thus, it is possible to locate certain structures or formations in this way. The instrument of course has a number of disadvantages. It is very expensive, extremely delicate, and must be perfectly shielded from air currents and temperature changes. Calculations are difficult, and many corrections must be taken into consideration. The interpretation of results is an extremely hard task. Another disadvantage that this method has -- and it is common to most of the other methods -- is the failure to obtain any accurate measurement on the depth to the deposit which has been found. However, the instrument has been used with fairly satisfactory results in a number of localities.

The third system is of the seismic type. A charge of explosive is set off at a certain central point. A number of stations at known distances from that point receive, by means of very delicate and sensitive instruments, both the sound waves which are transmitted through the air and the ones conducted through the denser earth. The instrument also records the time of detonation of the charge, and from these time and distance measuremtnes one may calculate the velocity of the sound wave through the earth in the different directions and over different distances. This gives a clue to the sub-surface structure. For instance, sound waves may attain a speed of 16,000 feet per second through a salt dome, while the normal speed through earth is only about 6,000 feet per second. In general, the velocity depends on the density and elasticity of the medium through which it is being conducted. This might seem to be a very good way to locate structures, and probably would be if it were not for a few things which we shall mention. In a populated territory it is inadvisable to use this method , for reasons easily seen. In a mountainous section more complexities arise from reflected waves etc. Any surface disturbance may jar the recorder and introduce errors. Here again it is impossible to obtain a depth measurement. For these reasons, the above mentioned type of measurement is not all that one might desire.

The fourth, and last, type of measurement, and the one in which we are especially interested, is the electrical method. Three classes are important:- natural earth currents, a direct current determination of earth resistance, and the measurement of earth resistivity by the alternating current method. Of course, there are many other electrical methods, but they have not proven to be very satisfactory.

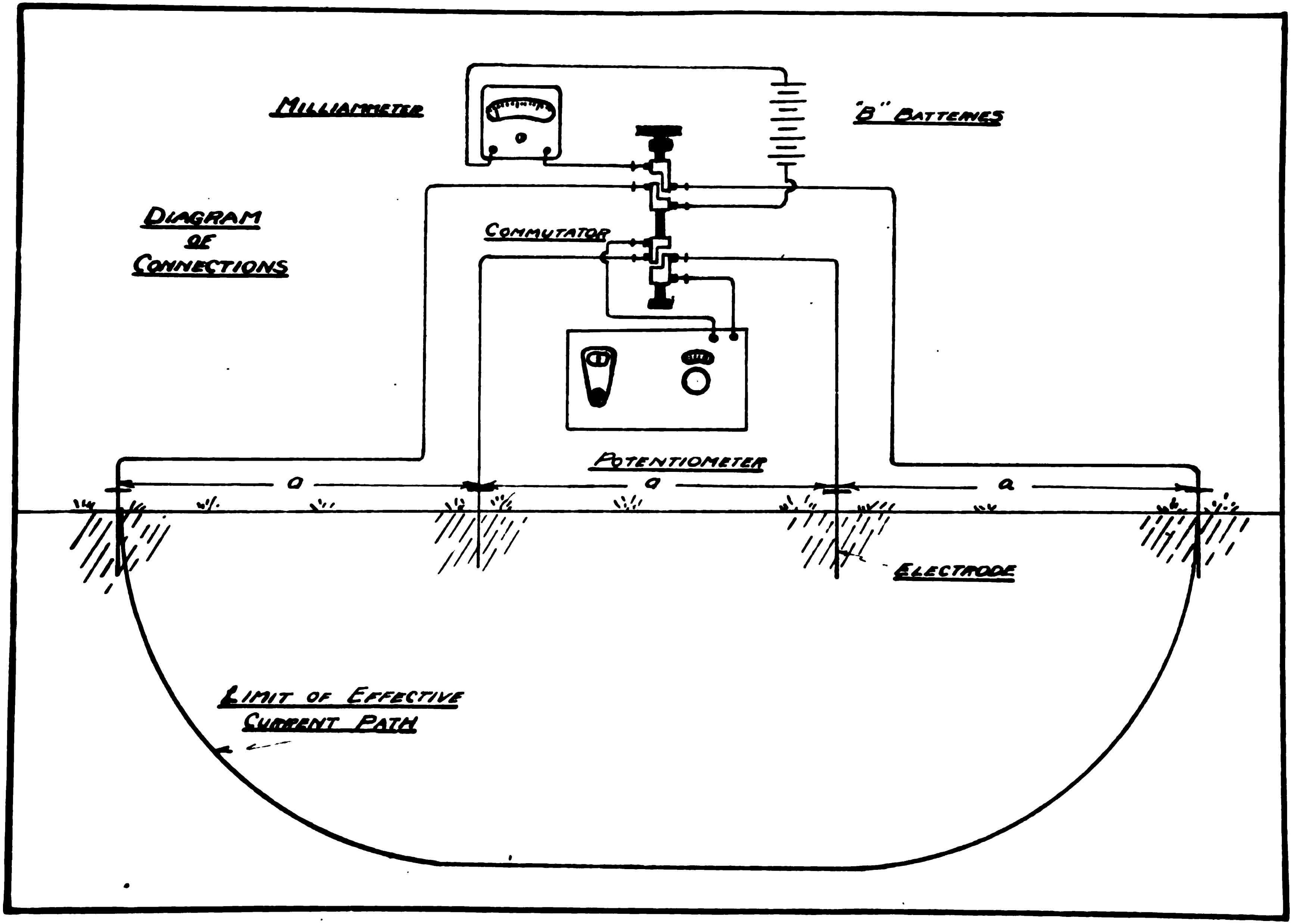
In the first of these three classes, the ground currents resulting from buried ore bodies or salt deposits are measured by means of a null-point (or potentiometric) method.. When these are plotted, one may obtain some idea of the position of the deposit. This method does of course give no indication of the depth at which the body is located, or the composition of the body. It is only possible to use this system for deposits which are very close to the surface.

In the measurement of earth resistance with direct current, a potential difference is applied at two points and the equipotential lines traced between the two. If no ore bodies are present, the lines will be symmetrical. If, however, there is an ore deposit near the surface, the current lines will be concentrated through an area near that point, thus indicating the location. Of course variations in the resistance of surface soil tend to change the direction of the lines. So also do rivers, drain pipes, cables etc. and these things must be guarded against. Much difficulty is encountered in interpreting results. No idea of the depth to the deposit or the thickness of the deposit may be obtained by this method. Alternating current may be substituted for direct, and head-phones or an A.C. potentiometer used in locating the equi-potential lines. This removes the errors which are present in the D.C. measurement due to polarization of the electrodes, but does not help any in ascertaining depths.

The third class of electrical method is the one concerning which this thesis has been written, namely the earth-resistivity method. The theory will be discussed later. However, it may here be said that despite the difficulties which accompany any physical research problem, we have developed apparatus and technique to a point where it is possible to obtain accurate results which have a definite meaning. In none of the other methods has anyone been able to get an accurate measurement of depth to the deposit in question. Neither have they been able to get any idea as to the thickness of the deposit or stratum. By the earth-resistivity method which we are using, it is possible to check both the depth and thickness; and, in the case of some salt brines, the concentration may be estimated with a fair degree of accuracy. Surface conditions do not affect the measurements in any way, provided the surface over which the measurements are being taken is reasonably level. This is a distinct advantage, for in the other methods, a thick over-burden of drift causes the sensitivity and accuracy to be greatly lowered. The instruments and apparatus necessary are not expensive, and are easily portable. Another point is that the depth and thickness of a number of different rock strata may be checked at one time in one set of readings. The bad effects of inherent ground potentials and currents, which causes inaccuracies in the magnetic methods, have been carefully avoided. The speed of obtaining measurements compares favorably with the time required in the other systems. The reasons for the advantages as named above will become apparent in the discussion which follows.

## THEORY OF THE EARTH RESISTIVITY METHOD

If an electric current is passed between any two points in an homogeneous conducting material, the current lines distribute themselves in the following manner:- Near the electrodes they will be almost radial, and the current path will be constricted; near the center they will be practically parallel, and the current path almost unlimited. From this it is seen that most of the resistance drop in potential will occur very close to the electrodes; and any measurement which attempts to obtain the resistivity of the material through which the current flows, by a measurement of the potential across these points, will be in serious error, since conditions at the current electrodes are so variable. It is rather simple, however, to use two other electrodes to measure the potential at some points near the center where the current lines are approaching parallelism. Then by making use of the total current flowing through the outer electrodes, to calculate the resistivity is the next step. Wenner, in the U.S. Bureau of Standards Bulletin (1916) 12, No. 4, 469, describes a method by which this resistivity may be obtained. He uses the four electrodes

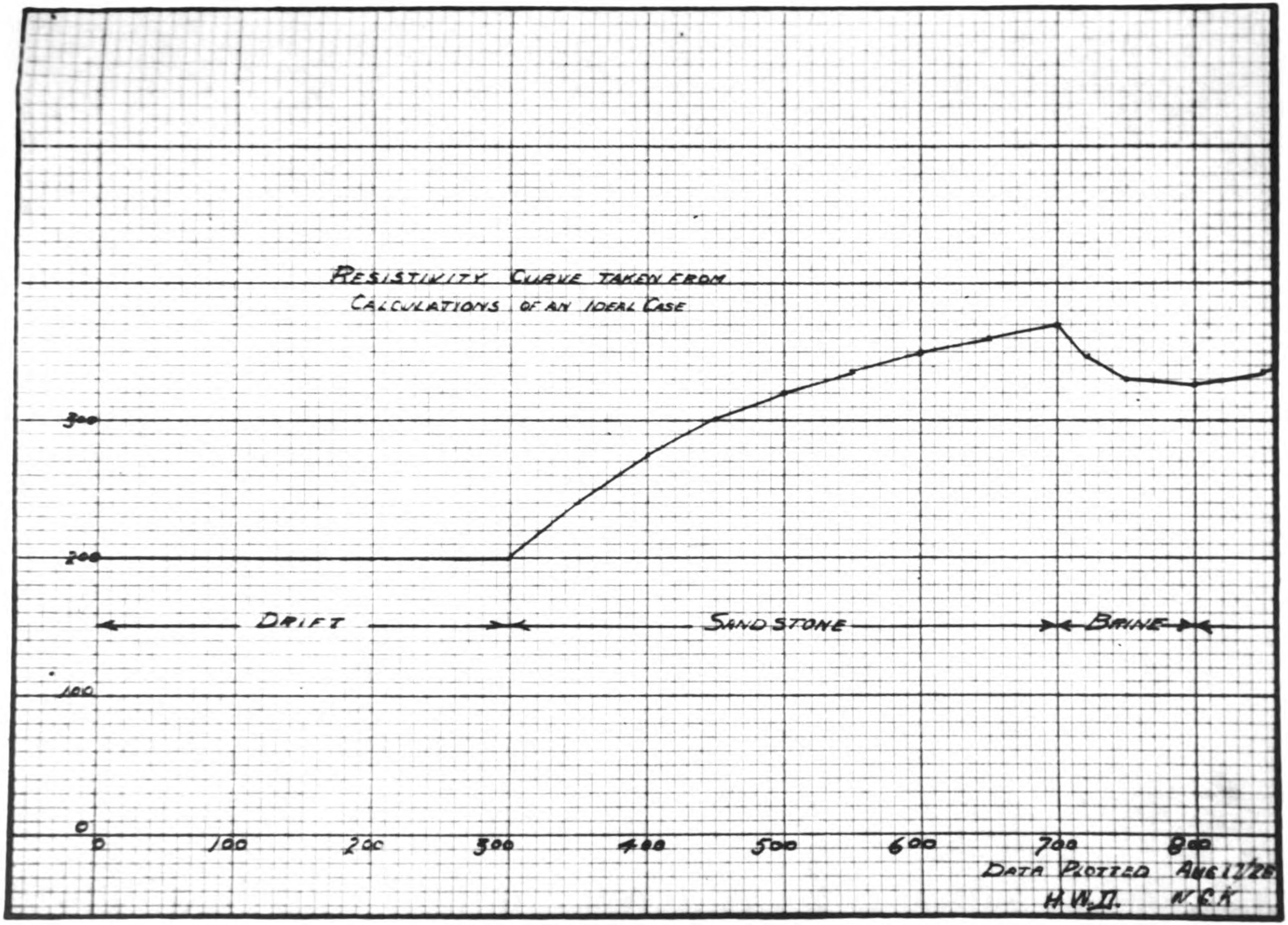


MILLIAMMETER
"B" BATTERIES
DIAGRAM
OF
CONNECTIONS
COMMUTATOR
POTENTIOMETER
a
a
a
ELECTRODE
LIMIT OF EFFECTIVE
CURRENT PATH

as before mentioned, but spaces them equally, in a straight line. If the four points are on a plane surface of a conductor the resistivity is given by the formula:

$$R=2\pi \underline{a}\, V/I$$

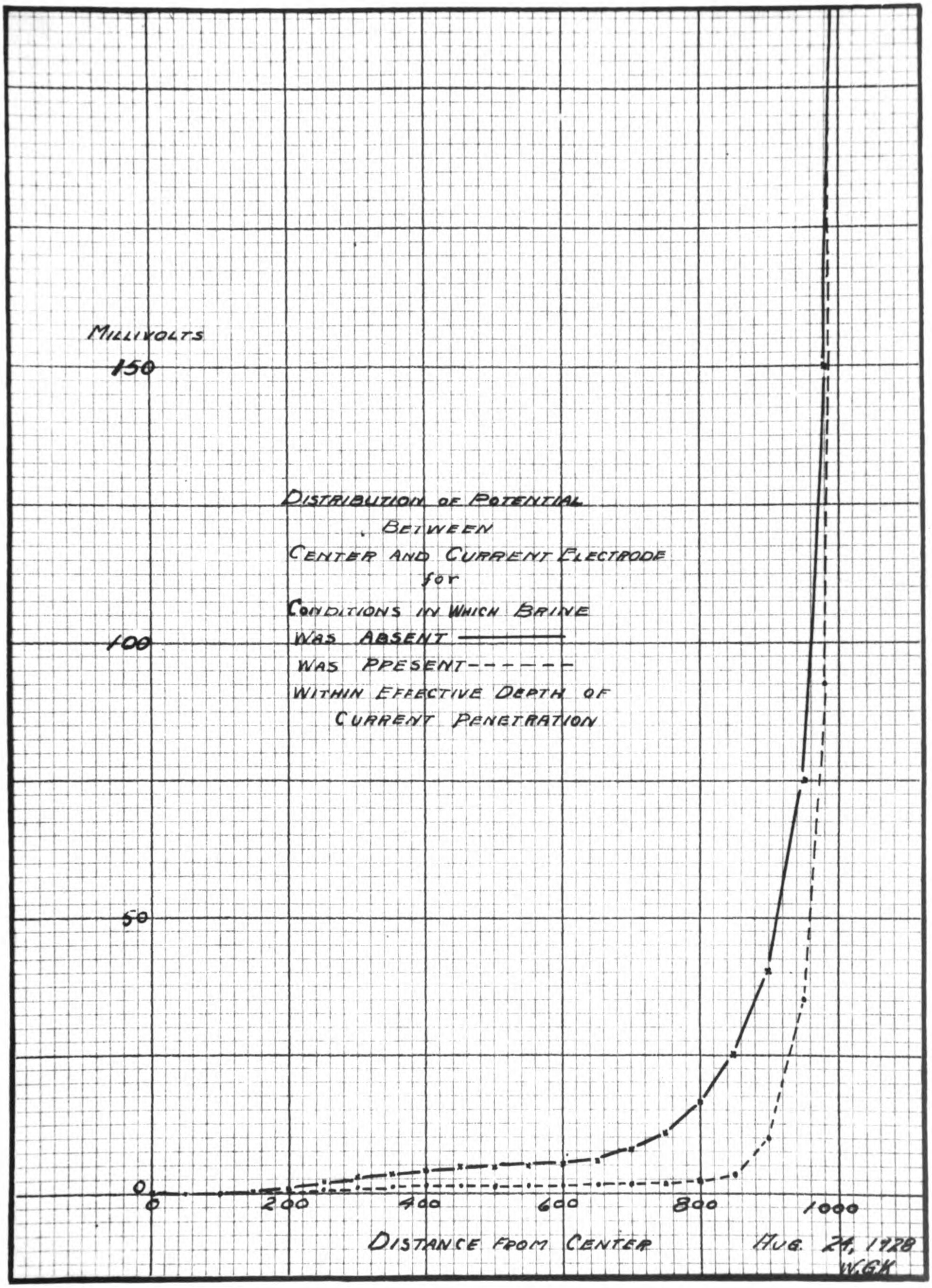
where R is the resistivity, a is the depth to which the measurement is effective, V is the potential existing between the two inner electrodes, and I is the true value of the current flowing through the ground. If the electrodes are within the conductor, so that the distance between them is small compared to the distance to the nearest surface, the factor two is replaced by four. The depth to which the measurement extends for any one reading is the same as the distance between any two electrodes. By increasing the distance between electrodes then, the depth to which the measurement becomes effective is also increased, and any change in the value of the resistivity thus obtained will reveal something of the nature of the structure included below the depth of the first measurement. To more clearly illustrate this, an ideal curve has been plotted, and reference will now be made to it. In this case the first 300 feet is taken to be a drift, and a value of 200 ohms per foot cubed is assigned to it. Any measurement made,



RESISTIVITY CURVE TAKEN FROM
CALCULATIONS OF AN IDEAL CASE
300
200
100
0
DRIFT
SANDSTONE
BRINE
0
100
200
300
400
500
600
700
800
DATA PLOTTED AUG 12/25
H.W.II.
W.C.K

so long as the distance between potential electrodes does not exceed 300 feet, will give this value for the resistivity. If now the distance between electrodes be increased beyond this amount, a new material is included. This is a sandstone whose resistivity is 500 ohms per foot cube. The value now obtained from the measurement must be the average for the volume of the material included in the current path. Thus the resistivity plotted against depth no longer remains a straight line, but rises immediately beyond the 300 foot depth. This continues until a brine is reached, at which point the average resistivity decreases and the curve drops off.

The previous work upon this method has carried the theory to this point. A discrepancy arises immediately however, when one compares curves actually taken in the field with the ideal curve. It appears that when a brine is entered a decrease in resistivity occurs which is so great as to be absolutely impossible for even a perfect conductor. A new theory must therefore be substituted and checked. It is assumed that as long as homogeneity exists in the material included within the current path all previous relations hold. As soon as the brine is brought into the range of the current lines they lose their regularity and rather than pass through the high resistance laterally above the brine sand, they dip directly through the intervening material to the brine strata. This immediately causes the planes of equipotential to spread farther apart, due to the low resistance of the new path, and the reading obtained at the surface is many times lower than would be expected. To check this theory the distribution of potential between two electrodes for which the current was not entering a brine, and that of two electrodes whose distance was great enough to permit the current to enter the brine was recorded. These results have been plotted on an accompanying sheet. The first condition shows the normal distribution. The second reveals that a much lower potential exists between the center and the point at which potential measurement takes place than is shown when no brine is present. This we believe substantiates the foregoing theory. As further proof that no distortion takes place until the brine depth is reached, we have to offer the fact that we can check known data accurately.



MILLIVOLTS
150
100
50
0
0
200
400
600
800
1000
DISTANCE FROM CENTER
DISTRIBUTION OF POTENTIAL
BETWEEN
CENTER AND CURRENT ELECTRODE
for
CONDITIONS IN WHICH BRINE
WAS ABSENT
WAS PRESENT
WITHIN EFFECTIVE DEPTH OF
CURRENT PENETRATION
AUG. 24, 1928
W.G.K.

## REVIEW OF PREVIOUS WORK
## ON THE SUBJECT

The possibility of employing the method discussed above was first experimented with by the Department of Terrestial Magnetism of the Carnegie Institute of Washington, and the Michigan College of Mines and Technology. In conducting the investigation, Dr. W. O. Hotchkiss, Professor James Fisher, and Dr. O. G. Ritzman of the Michigan College of Mines, and W. J. Rooney and J. W. Strohman of the Department of Terrestial Magnetism worked together in the Copper Country of northern Michigan. This location was chosen because of the complete data at hand concerning the geological structures present. Measurements were taken, for the most part, near drill-holes which had been bored for test purposes. Depths to bed-rock were checked in a number of instances with an accuracy which warranted further work of this nature. Next was the task of determining the depths to water level. This was also checked to within a few feet. These men also made a number of measurements to find the specific resistances of various rocks and sands by taking readings along an outcropping of those strata.

During the past summer (1928) we were engaged in checking the depths to salt-brines in the Marshall sandstones. This work was carried out in the central part of the State. This brine bearing stratum, in that locality, was at a depth of 1200 to 1500 feet. We employed the same method of procedure and used equipment similar to that outlined by Messrs. Fisher and Rooney. We found that it was possible to check the depth to this brine in most cases with some degree of accuracy. There were of course many irregularities in the curves similar to those shown in the work done previous to ours. A further discussion of these irregularities and the means of avoiding them will be given later.

## CORRECTION OF ERRORS ENCOUNTERED IN EARLY WORK

A method of taking measurements has been outlined by Hotchkiss, Rooney, and Fisher in a paper presented to the Institute of Mining and Metalurgical Engineers, in February, 1928. This method was the first experimented with. The method of taking measurements was as follows: The source of potential was a bank of "B" batteries. The current from these batteries was sent thru a commutator which reversed it approximately 30 times per second. This alternating current was then carried thru the ground by means of the outer electrodes. This resulted in an alternating potential appearing at the two inner electrodes. This potential was then taken back thru a commutator, built upon the same shaft as the first and exactly like it. The effect was to rectify the alternating potential so that it could be measured by means of the DC potentiometer. An ammeter showed the current thru the ground and a portable galvanometer in the potentiometer circuit indicated when a balance was obtained. The necessity of using alternating current is occasioned by the fact that ground currents of varying intensities are everywhere present in the earth, and if reversed rapidly enough, their effect will be eliminated. Various inaccuracies presented themselves after a number of readings had been completed and it was with the purpose in mind of correcting these inaccuracies that the present thesis was attempted.

The commutator was the first piece of apparatus which showed inaccuracy. It was of the ring type and necessarily had a great deal of friction. This friction caused thermal potentials to be induced which, though ordinarily not large, and for any other type of measurement negligible, in this case introduced considerable error. Contact resistance and contact potential showed effects which proved to be a source of error. The potential measured is of the order of 10 millivolts, and potentials resulting from sources of error in the commutator were often one half that value. The inability to interpret variations in such potential readings is evident. As long as the depth is not great and the resistivity is high, everything goes well, for the potentials measured are then as high as 200 millivolts, and slight variations do not affect the results appreciably. It is for the deeper readings that accuracy is needed. For this reason, after six futile attempts to design one which would satisfy conditions when placed under test, a potential commutator which makes friction almost negligable and completely balances contact potentials was constructed. Previous attempts at building a potential commutator had guarded against shorting of the segments when reversal was made. The galvanometer which was a very sensitive one, deflected slightly at each make and break of contact. To eliminate this, the brushes were caused to make a dead short across the two segments, while changing from one to the other, and this of course resulted in a short across the galvanometer during the same time. This had the tendency to "freeze" the needle and eliminate annoying vibration. The early commutator also had a period during which the current was completely interrupted. This for the most part amounted to about 15% of the time of each cycle. The latest one, by means of a special spring arrangement makes the time for changing contacts almost zero. So nearly zero in fact that the milliammeter shows no change in deflection between the steady state and the operating condition. This too, had been a source of error since the commutating factor varied somewhat with the speed.

Another source of error was due to capacitance effects. A #14 B&S, double covered wire was used to conduct the current to the outside electrodes. This was laid directly upon the ground, which constituted the return circuit. Leakage naturally resulted. The most harmful feature was not the error in current reading due to leakage, however, but the fact that the leakage occurred close to where the potential had to be measured, or in other words, all along the line of measurement. Had this leakage been constant all would have been well, but the nature of the surface soil is to furnish better conductivity in some places than in others. The result was a varying potential reading which showed surface conditions rather than subsurface conditions. To remedy this a #20 bare copper wire was used and supported upon stakes spaced 100 feet apart. At the top of each stake an insulator held the wire in place. No more trouble was encountered due to leakage.

Early reports upon the subject indicated that linear distance measurements need be accurate to only 5% of the distance between electrodes. This may well have been true with the accuracy of measurement attained at that time, but decidedly is not true at present. In making a set of readings over the river bed at the Logan St. viaduct in Lansing, the electrodes were supported from a footbridge and allowed to dip into the water. A breeze had the tendency to sway them through a distance of a few inches, when they were 50 feet apart. The galvanometer changed its reading in perfect synchronism with the swaying of the electrodes. The conclusion is that distance readings must be exact or erroneous results will be obtained. In addition to this it was

discovered that the surface over which measurements were to be taken should be fairly level.

The correction of all these faults took considerable time, and it was not until the spring vacation (1929) that the new and improved apparatus was put to test. The results were gratifying in the extreme.

## EXPERIMENTAL

Construction of Apparatus.

The commutator in use is a double commutator, one side reversing the current, the other rectifying the potential. The current commutator has four rings, two of them continuous, and the other two split. These slots are not filled with insulating material. The brushes are all on one side and their tips are in a straight line. They are made of brass and are under tension. When the commutator is turned the two upon the split segments drop over the edge of the slot and immediately make contact upon the opposite segments. This causes the time for contact to be very nearly 100%, which is very desirable. The potential side of the commutator is the more difficult to construct. It is here that friction must be reduced to a minimum and balance of segments be almost perfect. These two requirements are exactly opposing each other. If friction be reduced, the diameter of the segments must be small; if the segments are small, a balance of the time in contact on each segment is almost impossible.

It was for this reason that various types of vibrating contact commutators were attempted. In all six different commutators were constructed, each one failing to give the desired results. The seventh, and last, was built as follows:-

A hole was drilled and tapped into the end of the current commutator shaft, which was of one and one eighth inch bakelite. Into this hole was placed a threaded rod about one eighth inch in diameter and two inches long. Upon this steel rod was pressed a hollow cylinder of composition insulating material. The whole commutator was then placed in the lathe and this insulating material was turned down until it was about one fourth inch in diameter. Over this composition was pressed a one half inch nickel cylinder with the required slotting. This cylinder was then turned down until it was perfectly smooth and centered exactly in the end of the commutator shaft. The slots between the segments were left open and were very narrow. They were placed as nearly 180° apart as was possible. The balance in time of contact of one segment to that of the other was attained by position of the brushes. In our apparatus, since they were designed to short directly across the segments for a small period of the total time for one revolution, any unbalance in construction of segments would then be taken up in the time of shorting. Since the needle tends to read zero during the time of shorting, the time over which impulses are delivered to the needle is immaterial, and the reading is that of the maximum applied potential. The commutating factor does not enter into the reading where a null method is used. The whole commutator is driven by means of a six volt direct current motor, which is operated by ordinary automobile storage batteries.

The necessary meters (milliammeter, galvanometer, and potentiometer) are mounted on the top panel of the instrument case. This case is about three feet wide, three and one half feet high, and one foot deep. The panel is placed horizontally and the meters mounted flush to it. On a vertical panel, extending downward from the front edge of the top panel are mounted the necessary resistances and controls. The right hand control limits the current through the ground, the center one is the potentiometer rheostat, while the one on the left supplies a steadying potential to the ground electrodes. The necessary switches for these circuits are placed in convenient positions. In the bottom of the case is a compartment in which the "B" batteries are placed. A total of 270 volts is available. This is an ample source of potential for almost any type of soil which may be encountered. The motor and commutators are placed on a shelf between the instruments and the batteries. The whole case complete weighs approximately 75 pounds and may conveniently be carried by two men, handles being placed on the ends for this purpose. The top cover is hinged at the back, and when opened forms a desk upon which graph and data sheets may be placed.

The supports for the wire are three eighths inch steel rods which are about four feet long. At the top of each rod an insulator for holding the No. 20 bare copper wire may be placed. The insulators we now have serve very well for experimental purposes, but to facilitate the making of measurements in a commercial way, a better type may easily be designed. The copper wire is carried on a spool about five inches long and having a diameter of approximately four inches. It is fitted with a crank, which easily allows one to draw in and reel up 1500 feet of the wire with no walking necessary on the part of the operator. For greater lengths, it is necessary to walk the length of the wire while winding it in, or loop part of it back toward the spool. In all, 5000 feet of this wire may be wound on one of these reels or spools.

The electrodes consist of half inch steel rods about three and a half feet long with a cross arm handle at the top end and pointed at the lower end. These are forced into the ground to a depth of about two or two and one half feet. The connection of the current electrodes to the bare wire is accomplished by twelve foot leads of rubber covered wire fitted with spring battery clips. The potential electrodes are fastened directly to the ends of No. 14 insulated copper wire which is allowed to rest on the ground. There is no danger of leakage here, consequently no supports are necessary.

## METHOD OF

## OBTAINING READINGS

In beginning a set of readings in a section of the country about which information is desired, a stretch is selected which is level for a distance three times the depth to which the measurements are desired. In other words, over the distance to which the electrodes are to be set. The supporting stakes are placed accurately every hundred feet, thus serving as a means of measurement for electrode distances, and the bare wire is strung out the required distance each way from the center of measurements. The instrument case is placed at the center and the leads for the current are attached to the bare wire. The potential leads are attached to the insulated wires which terminate at the potential electrodes. The first reading is usually started at about 150 feet, for in Michigan the drift extends to almost that depth, and since we are not interested in it, we save time by starting below it. (In case it is desired to check the depth or thickness of this drift, it is only necessary to begin our readings at a point nearer the surface.) At this setting each of the potential electrodes are placed 75 feet from the center of measurements and each current electrode is 225 feet from the center. The commutator is then started and readings taken which show whether ground potentials are eliminated. A dial setting soon remedies this fault should it be present. The battery switch is then closed and simultaneous readings of potential and current are made. These are then recorded. The operator or instrument man signals and the electrodes are changed so that their effective depth is now 160 feet. The process of taking a reading is then repeated. In some instances increments of twenty feet are suitable. If the formation is large, such as a 100 foot brine sand, there is no need of ten foot increments to reveal it, and the twenty foot increments will proceed more rapidly. This process is repeated until the required depth is reached, depending upon what indicator it is desired to pick up. In the work done in Livingston County it was not necessary to go more than 1000 feet. In the central part of the state however, the Marshall brine is much lower, and the measurements were made accordingly.

## FIELD TESTS

In the Fall of 1928, arrangements were made with the State Geology Department at Lansing to carry on a series of measurements. We are indebted to them for their hearty co-operation and the funds which were necessary to equip a party for the field trips. These consisted of an assistant, Gerald Eddy, from the Michigan State College Geological Department, and the necessary transportation. In addition wire and apparatus which could not be obtained at the college and which would have been too expensive for us to buy, were supplied by this department.

The district in which it was planned to conduct tests, centered about Fowlerville. For some time it has been known that a folding of the substrata had occurred in this area. Several wells have been drilled north and east of Fowlerville with the intention of revealing this structure and in the possibility that oil might be discovered there. Several of these showed indications of gas and oil but no commercial quantities were discovered. Proceeding on the assumption that the existing wells were on the top of the anticline, as a fold of this kind is called, more wells were drilled to the north and slightly west of this place. These wells also revealed a high structure and so the direction of the anticline was assumed to be almost due north, and slightly west. In none of these wells however was oil found in paying quantities. This fact, coupled with the size of the structure led the geological department to believe that the wells already drilled were not actually upon the summit of the anticline. It was to check this theory that tests were planned for this district.

During the winter vacation a number of tests were made near the wells already existing, as well as in the territory to the west. A big difficulty presented itself in the fact that the Berea formation, which is nearest the surface here, is rather patchy and does not contain a brine in any appreciable quantity. The well data was checked however by a method of interpretation not before employed. Previously a structure of this kind was shown by a strong dip in the curve due to the presence of brine. (See Haslett and Robb-Well curve sheets.) Where this was absent however no break of importance showed. The formation, for the most part shales, directly above and below the Berea have slightly different electrical characteristics and are very thick, sometimes four to six hundred feet. The readings through any one of these formations have a definite slope, and the intersections of these two slopes gave indication of the depth of the Berea, or dividing structure. This method was applied successfully to several other localities.

Knowing that the Marshall brine, which is above the Berea about 1200 feet, is found at Lansing and not at Fowlerville, a series of measurements extending to the westward was planned in the hope that this indicator could be picked up. The Marshall sand is the most productive brine bearing strata in this area and definite measurements were expected. It was here in this attempt to locate the Marshall that the fact was revealed that the structure was much broader than had previously been supposed. In fact although readings were taken as far west as Williamston, the Marshall was never picked up. The Berea was found however, this time with brine, at a depth which indicated a very steep dip for the western side of the anticline. The work for this time ended with the impression that the structure was much broader than previously supposed, that it proceeded much farther to the west than well records showed, and that if more readings were to be taken in the Berea sand, measurements would have to be more accurate, since some of the tests did not allow us to arrive at definite conclusions. It was for this reason that new apparatus was designed and constructed.

During the spring vacation (1929) more measurements were taken with the newer apparatus. This time the measurements began at Lansing, where the Marshall was definitely known to exist. Here the Marshall was picked up easily because of the high brine content of the formation. The line of measurements swung somewhat to the north of Williamston in the hope that the structure could be defined in the Marshall alone. It was not supposed at the geological department that the Marshall outcropped very far north of Williamston. Indications were very strong in this formation up to about three and one half miles east of Haslett. The next reading, about six miles east of Haslett, gave indications very much like the Berea formation. A check was made between these last two readings and results obtained which showed no brine at all and which were different than any previously encountered. Another reading only one half mile away gave a similar curve but the depth readings were high by 300 feet. This gave the slope of the structure to be approximately 600 feet per mile. The Marshall was shown to outcrop where no previous data had indicated that it should. The indication that had been obtained in the winter's work was verified and the line of outcropping of the Marshall fitted in as was expected it might. The structure was defined as extending to the westward for a distance of approximately ten miles from what had previously been supposed.

Acting upon this data a new set of readings was planned. The city of St. Johns obtains its water supply from a deep well within the city limits. This well penetrates the Parma.sand, a fresh water bearer, and the Marshall sand, a brine bearer. The brine is of course plugged off and the fresh water used for the city. Data however was in this manner available upon which to base further measurements. The fact that the brine is higher here than ordinary geological data would indicate gave weight to our previous results since it was directly in line with the new direction of the anticline. The first readings taken near the well checked the depth to the brine within five feet, and in addition the fresh water strata was checked to within the same distance. The fact that we were measureing up the slope of the anticline, and that the brine was shown to be higher, indicated that our results were even more accurate. The next reading was taken a distance of three and one half miles east of St. Johns, and an absolute indication of the Marshall was obtained 140 feet higher than previously. The next measurement was seven miles east of St. Johns and here the Marshall had dropped down again to only 10 feet higher than at St. Johns. This outlined the structure entirely in the Marshall and fitted in exactly with previous data. More readings are to be taken in this area, but cannot be included in this report.

## DATA AND INTERPRETATION OF SOME CHARACTERISTIC MEASUREMENTS

The first measurement attempted was that near the Robb Well, north and east of Fowlerville. At the first setting, which was 280 feet, a surprisingly low value of resistivity was obtained. From this depth on down to about 340 feet a definite slope occurred as shown in the accompanying graph. Between the depths 340 and 730, or for practically 400 feet, the resistivity remained fairly constant. It is safe to say that the average resistivity of this stratum of shale is about 75 ohms per foot cubed. From 730 feet on to 900 feet the curve rises with another definite slope.

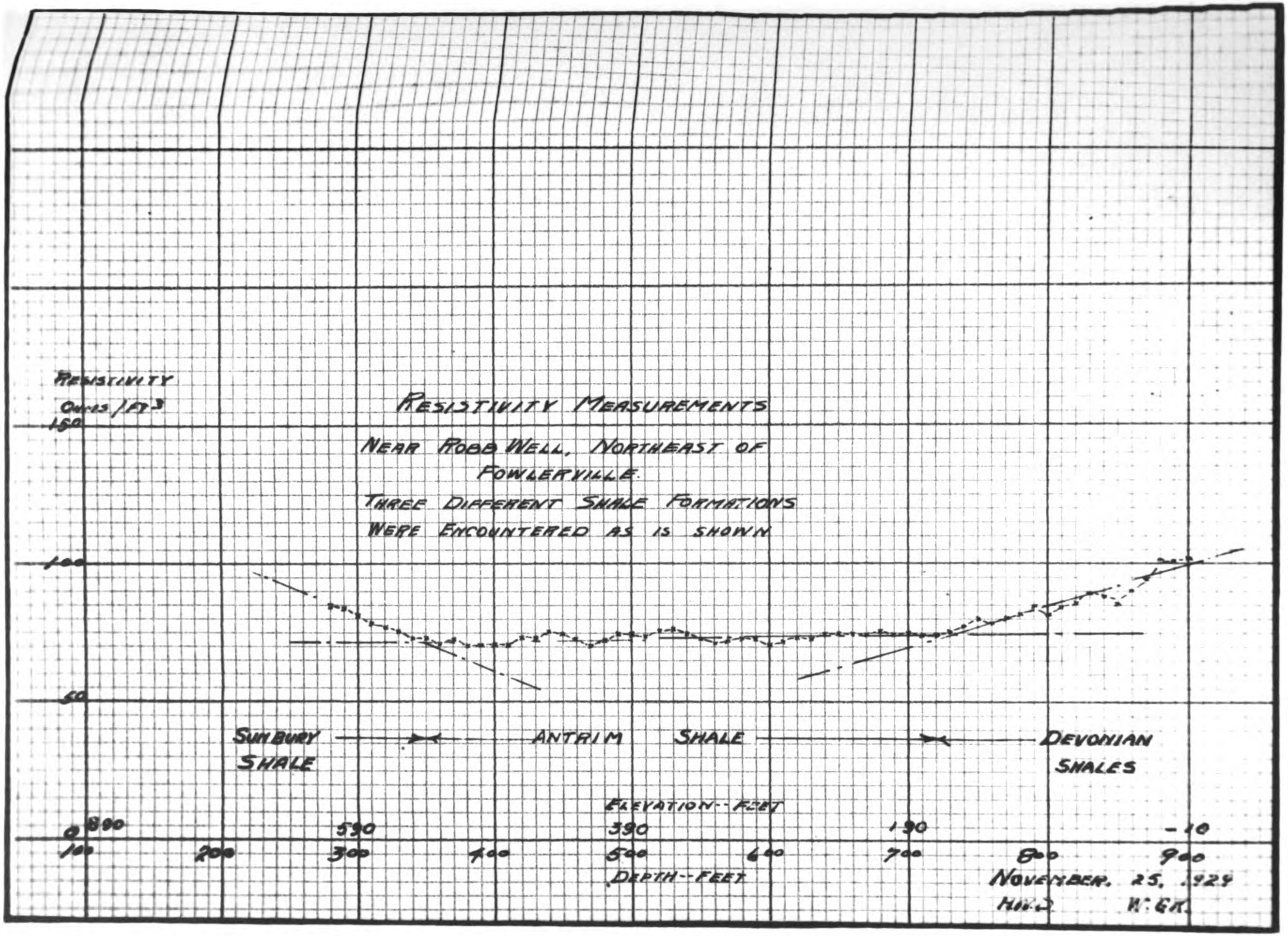
The interpretation is as follows: The first portion of the curve represents the Sunbury Shale which, at the Robb Well, extends to 317 feet. Our location was about one half mile from the well and our readings show the middle of the Berea at 340 feet. Knowing that the Berea is about 60 feet in thickness, this brings the depth of the Sunbury Shale to about 310 feet, which agrees very well with the well data. The horizontal portion of the curve represents the Antrim Shales. Evidently these are very low in resistivity.

Between the Antrim and Devonian Shales is the Traverse formation. This is shown at 730 feet. It is very narrow according to well data and occurs at 740 feet there. The check is remarkable considering that no brine was obtainable as an indicator. This method of interpretation has been employed in many other instances with a great deal of success, and always serves as identification of a formation, even when a brine is present.

The data for the accompanying graph is given below:-

| Current | Potential | Depth | Resistivity |
|---|---|---|---|
| .545 ampere | .0274 volt | 280 feet | 89.0 |
| .530 | .0256 | 290 | 88.0 |
| .548 | .0240 | 300 | 83.0 |
| .540 | .0217 | 310 | 78.5 |
| .548 | .0210 | 320 | 77.0 |
| .553 | .0202 | 330 | 76.0 |
| .558 | .0190 | 340 | 73.0 |
| .555 | .0183 | 350 | 73.0 |
| .558 | .0177 | 360 | 71.0 |
| .552 | .0172 | 370 | 72.0 |
| .5600 | .0164 | 380 | 70.0 |
| .558 | .0621 | 390 | 71.0 |
| .550 | .0155 | 400 | 71.0 |
| .553 | .0152 | 410 | 71.0 |
| .555 | .0164 | 420 | 78.0 |
| .552 | .0144 | 430 | 70.5 |
| .552 | .0160 | 440 | 80.0 |
| .552 | .01635 | 450 | 83.7 |
| .552 | .01405 | 460 | 73.5 |
| .552 | .0133 | 470 | 71.0 |
| .552 | .01325 | 480 | 72.5 |
| .550 | .01335 | 490 | 75.0 |
| .548 | .01305 | 500 | 75.0 |
| .550 | .0126 | 510 | 73.5 |
| .548 | .0128 | 520 | 76.5 |

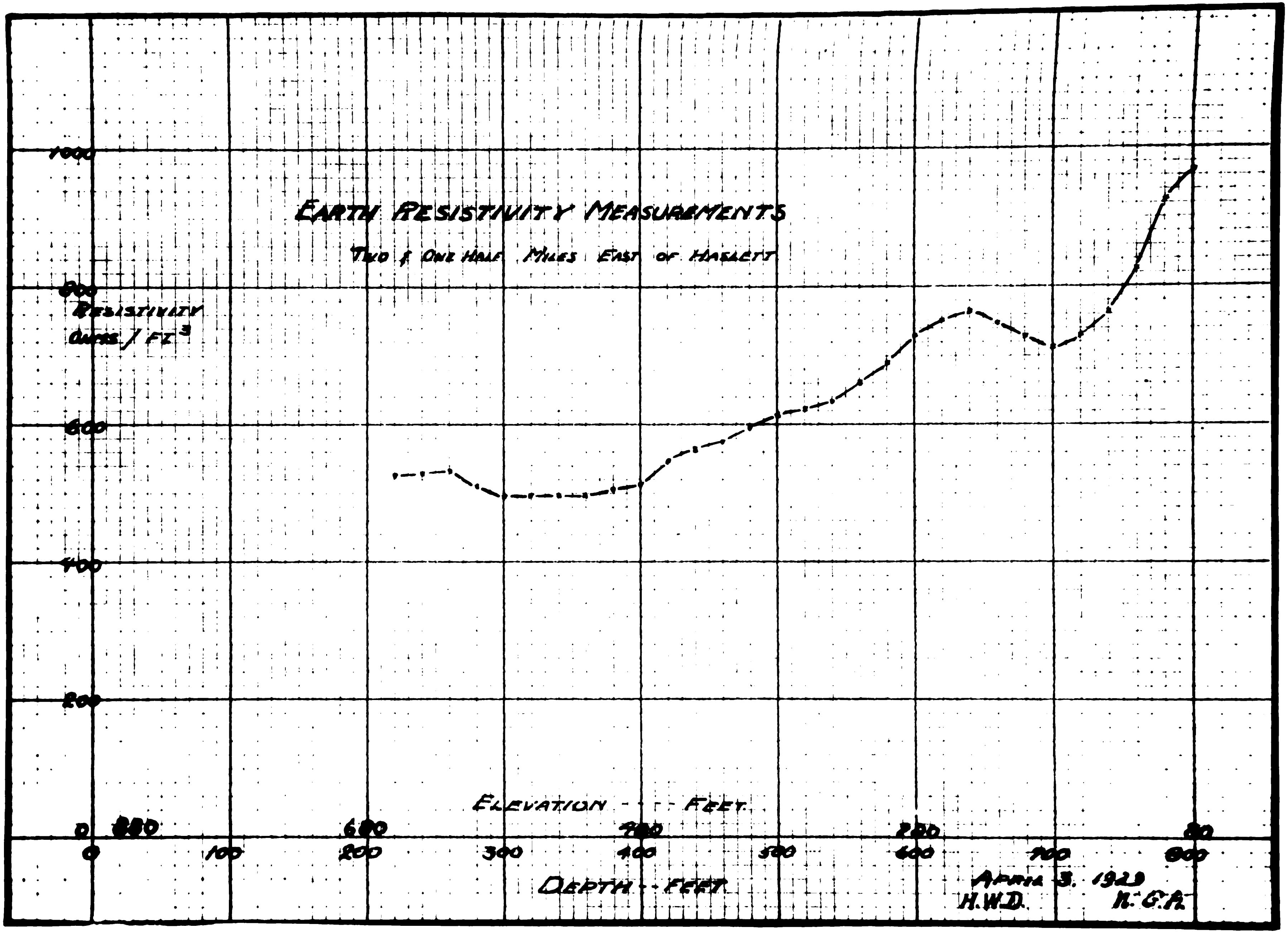
| | | | |
|---|---|---|---|
| .555 | .01295 | 530 | 78.5 |
| .555 | .0123 | 540 | 75.0 |
| .550 | .01245 | 550 | 78.5 |
| .550 | .01165 | 560 | 74.5 |
| .552 | .0113 | 570 | 73.0 |
| .553 | .0115 | 580 | 67.0 |
| .552 | .0113 | 590 | 76.0 |
| .548 | .0102 | 600 | 70.5 |
| .550 | .0103 | 610 | 72.5 |
| .553 | .0107 | 620 | 75.5 |
| .552 | .0100 | 630 | 72.0 |
| .551 | .0102 | 640 | 75.5 |
| .556 | .01025 | 650 | 75.5 |
| .555 | .0101 | 660 | 65.5 |
| .555 | .0097 | 670 | 74.0 |
| .552 | .0100 | 680 | 77.5 |
| .555 | .0094 | 690 | 74.0 |
| .558 | .0094 | 700 | 75.0 |
| .555 | .00925 | 710 | 74.0 |
| .555 | .0090 | 720 | 74.0 |
| .555 | .00925 | 730 | 76.5 |
| .557 | .00865 | 740 | 72.0 |
| .555 | .00945 | 750 | 80.2 |
| .555 | .00910 | 760 | 78.0 |
| .555 | .00930 | 770 | 81.0 |
| .555 | .00930 | 780 | 82.0 |
| .555 | .00960 | 790 | 86.0 |
| .555 | .00901 | 800 | 81.6 |
| .552 | .00905 | 810 | 84.0 |
| .555 | .00930 | 820 | 86.0 |
| .555 | .00959 | 830 | 89.0 |
| .558 | .00930 | 840 | 88.0 |
| .555 | .00880 | 850 | 85.0 |
| .558 | .00940 | 860 | 91.0 |
| .550 | .00940 | 870 | 94.0 |
| .555 | .0104 | 880 | 103.0 |
| .552 | .0100 | 890 | 101.0 |
| .555 | .0101 | 900 | 102.0 |


RESISTIVITY
OHMS / FT^3
150
100
50
0
RESISTIVITY MEASUREMENTS
NEAR ROBB WELL, NORTHEAST OF
FOWLERVILLE.
THREE DIFFERENT SHALE FORMATIONS
WERE ENCOUNTERED AS IS SHOWN
SUNBURY SHALE
ANTRIM SHALE
DEVONIAN SHALES
ELEVATION--FEET
890
590
390
190
-10
100
200
300
400
500
600
700
800
900
DEPTH--FEET
NOVEMBER 25, 1929

The next curve is one which is characteristic of those obtained when a salt brine is available as an indicator to structure. The location was two and one half miles east of Haslett on a level stretch skirting a swamp. Initial readings taken at 220 feet showed a resistivity well over 500 ohms. This at once indicated that the high resistant sandstones overburdening the Marshall, as well as the high resistant shales directly beneath it, were present. The curve drops at approximately 260 feet and indicates no doubt the top of the fresh water of the Parma sandstones. From this point on it rises steadily until, when a penetration of 640 feet is reached, the resistivity is 760 ohms. At this point the resistivity drops noticeably for about 60 feet. This without question is the Marshall brine sand. Immediately below this the resistivity again rises due to the high resistant Coldwater shales which occur beneath the Marshall.

The data is given below:-

| Current | Potential | Depth | Resistivity |
|---|---|---|---|
| .304 amperes | .1062 volt | 240 feet | 526 ohms |
| .292 | .0952 | 260 | 532 |
| .335 | .0979 | 280 | 514 |
| .424 | .0850 | 300 | 494 |
| .343 | .0840 | 320 | 495 |


EARTH RESISTIVITY MEASUREMENTS
TWO & ONE HALF MILES EAST OF HASLETT
RESISTIVITY OHMS / FT.$^3$
1000
800
600
400
200
0
ELEVATION - - FEET
880
680
480
280
80
0
100
200
300
400
500
600
700
800
DEPTH - - FEET
APRIL 3. 1929
H.W.D.
K. G. R.

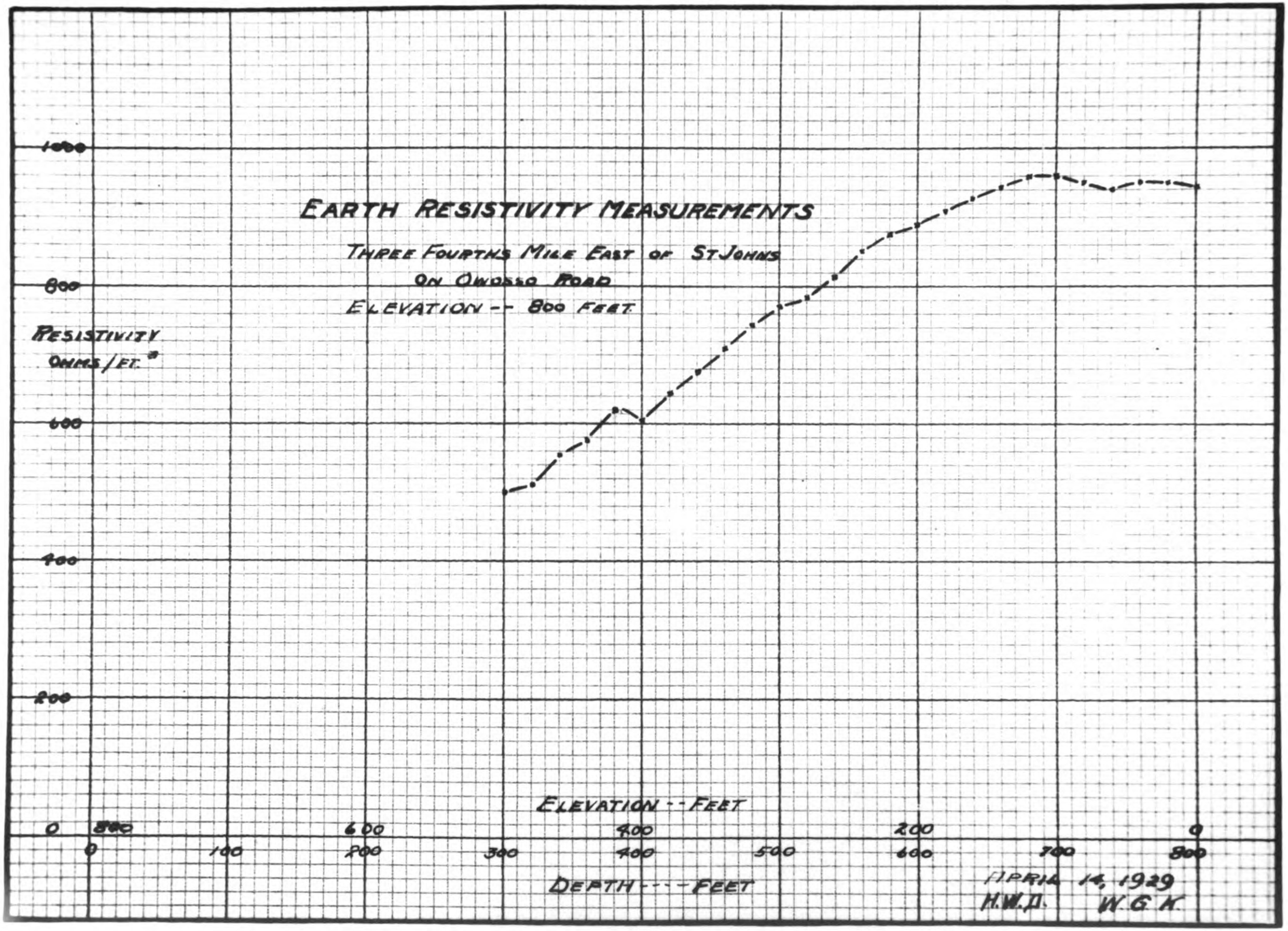
| | | | |
|---|---|---|---|
| .305 | .0706 | 340 | 495 |
| .300 | .0658 | 360 | 495 |
| .335 | .0708 | 380 | 504 |
| .336 | .0690 | 400 | 516 |
| .342 | .0709 | 420 | 547 |
| .343 | .0701 | 440 | 565 |
| .310 | .0618 | 460 | 575 |
| .338 | .0668 | 480 | 596 |
| .298 | .0583 | 500 | 615 |
| .331 | .0631 | 520 | 623 |
| .320 | .0559 | 540 | 635 |
| .324 | .0609 | 560 | 661 |
| .293 | .0556 | 580 | 691 |
| .299 | .0577 | 600 | 730 |
| .342 | .0650 | 620 | 751 |
| .322 | .0614 | 640 | 766 |
| .338 | .0679 | 660 | 749 |
| .340 | .0563 | 680 | 727 |
| .347 | .0540 | 700 | 713 |
| .333 | .0548 | 720 | 733 |
| .332 | .0597 | 740 | 767 |
| .346 | .0585 | 760 | 825 |
| .370 | .0699 | 780 | 925 |
| .295 | .0569 | 800 | 972 |

One of the readings taken near known data was the one about three fourths of a mile east of St. Johns. No knowledge of the depths to the various formations was obtained until after the readings had been taken. Readings commenced at 300 feet with a resistivity of 500 ohms, indicating again that the Marshall would be present at a lower depth. At 380 feet a decided break occurred for a short distance. The curve immediately began to climb again, and continued to do so for 290 feet. At 690 feet it broke over, and lack of wire prohibited carrying the curve out farther.

The interpretation was as follows: The Marshall occurred at 690 feet, the Parma at 380 feet. When the well record was examined, it was found that the Parma had been encountered at 375 feet and the Marshall at 700 feet. There was a five foot difference in elevation between the well and our location. The error is given then, as 5 feet. It is noticed that the sandstone covering the Marshall has great thickness here, due to the depth at which the Marshall occurs. It is only reasonable to expect a high value of resistance just above the Marshall. Inspection of the graph gives it as almost 1000 ohms.

Data is given below:-

| Current | Potential | Depth | Resistivity |
|---|---|---|---|
| .330 | .8000 | 300 | 500 |
| .288 | .0728 | 320 | 510 |
| .205 | .0530 | 340 | 555 |
| .220 | .0560 | 360 | 577 |
| .272 | .0695 | 380 | 610 |
| .220 | .0525 | 400 | 602 |
| .223 | .0544 | 420 | 645 |
| .176 | .0430 | 440 | 675 |
| .228 | .0560 | 460 | 710 |
| .279 | .0686 | 480 | 745 |
| .272 | .0667 | 500 | 775 |
| .292 | .0700 | 520 | 785 |
| .320 | .0770 | 540 | 815 |
| .280 | .0680 | 560 | 856 |
| .280 | .0670 | 580 | 885 |
| .300 | .0707 | 600 | 890 |
| .283 | .0660 | 620 | 912 |
| .253 | .0585 | 640 | 932 |
| .326 | .0537 | 660 | 945 |


EARTH RESISTIVITY MEASUREMENTS
THREE FOURTHS MILE EAST OF ST JOHNS
ON OWOSSO ROAD
ELEVATION -- 800 FEET
RESISTIVITY
OHMS/FT.³
1000
800
600
400
200
0
ELEVATION -- FEET
800
600
400
200
0
DEPTH --- FEET
0
100
200
300
400
500
600
700
800
APRIL 14, 1929
H.W.D.
W.G.K.

| | | | |
|---|---|---|---|
| .255 | .0572 | 680 | 960 |
| .292 | .0630 | 700 | 960 |
| .271 | .0565 | 720 | 951 |
| .228 | .0460 | 740 | 940 |
| .235 | .0484 | 760 | 950 |
| .265 | .0514 | 780 | 951 |
| .290 | .0545 | 800 | 945 |

To bring out the similar electrical characteristics of the same strata at different localities, even though separated by distances as great as 15 miles, the curve obtained east of St. Johns about four and one fourth miles will be shown. Resistivities to begin were about 400 ohms per foot cubed. This value increased slightly with an increase in depth. At 560 feet it had reached a value of about 520 ohms. Here it broke and dropped slightly for a depth of 60 feet. From this point on it began to climb again. The characteristics of the curve are practically the same as those shown by the curve obtained east of Haslett where the Marshall was encountered at approximately the same depth. One difference does show, that is the difference is absolute values of resistivity. It would be foolish though to expect exactly the same value of resistivity when surface conditions have varied so much between the two places. The effect of the drift is to raise or lower the curve by the difference in value for the resistivity from one place to the next, but the variations in the resistivity at the lower depths remain unchanged, hence the

similarity when practically the same amounts of the substrata are contained in the measurement.

The data is given below:-

| Current | Potential | Depth | Resistivity |
|---|---|---|---|
| .233 | .0495 | 300 | 397 |
| .233 | .0452 | 320 | 390 |
| .232 | .0425 | 340 | 400 |
| .235 | .0440 | 360 | 410 |
| .255 | .0435 | 380 | 412 |
| .242 | .0410 | 400 | 452 |
| .233 | .0400 | 420 | 465 |
| .234 | .0432 | 440 | 472 |
| .250 | .0410 | 460 | 475 |
| .252 | .0400 | 480 | 480 |
| .244 | .0375 | 500 | 485 |
| .220 | .0380 | 520 | 490 |
| .225 | .0340 | 540 | 500 |
| .230 | .0330 | 560 | 521 |
| .240 | .0330 | 580 | 502 |
| .209 | .0270 | 600 | 487 |
| .220 | .0275 | 620 | 488 |
| .225 | .0280 | 640 | 500 |
| .230 | .0296 | 660 | 508 |
| .232 | .0284 | 680 | 542 |
| .220 | .0280 | 700 | 560 |
| .221 | .0280 | 720 | 576 |
| .218 | .0286 | 740 | 610 |
| .231 | .0310 | 760 | 640 |
| .232 | .0320 | 780 | 676 |
| .222 | .0320 | 800 | 693 |

# CONCLUSION

The results of this research may be divided into two parts. The one is the development of apparatus and theory to such a degree that they may be relied upon to the utmost. That accurate determination of dissimilar structure had been made at depths to 1000 feet has been proved by comparison with actual well records. That the limit is well over 1500 feet has been shown to the satisfaction of those interested in the work by results obtained where no check against known data was available.

The second division in which results may be classed pertain to the data obtained upon the Fowlerville anticline. Indications are that the accepted theory among geologists that the Howell and Owosso anticlines are one and continuous is decidedly wrong. Evidence indicates strongly that up to date no wells have been drilled on the exact summit of this anticline.

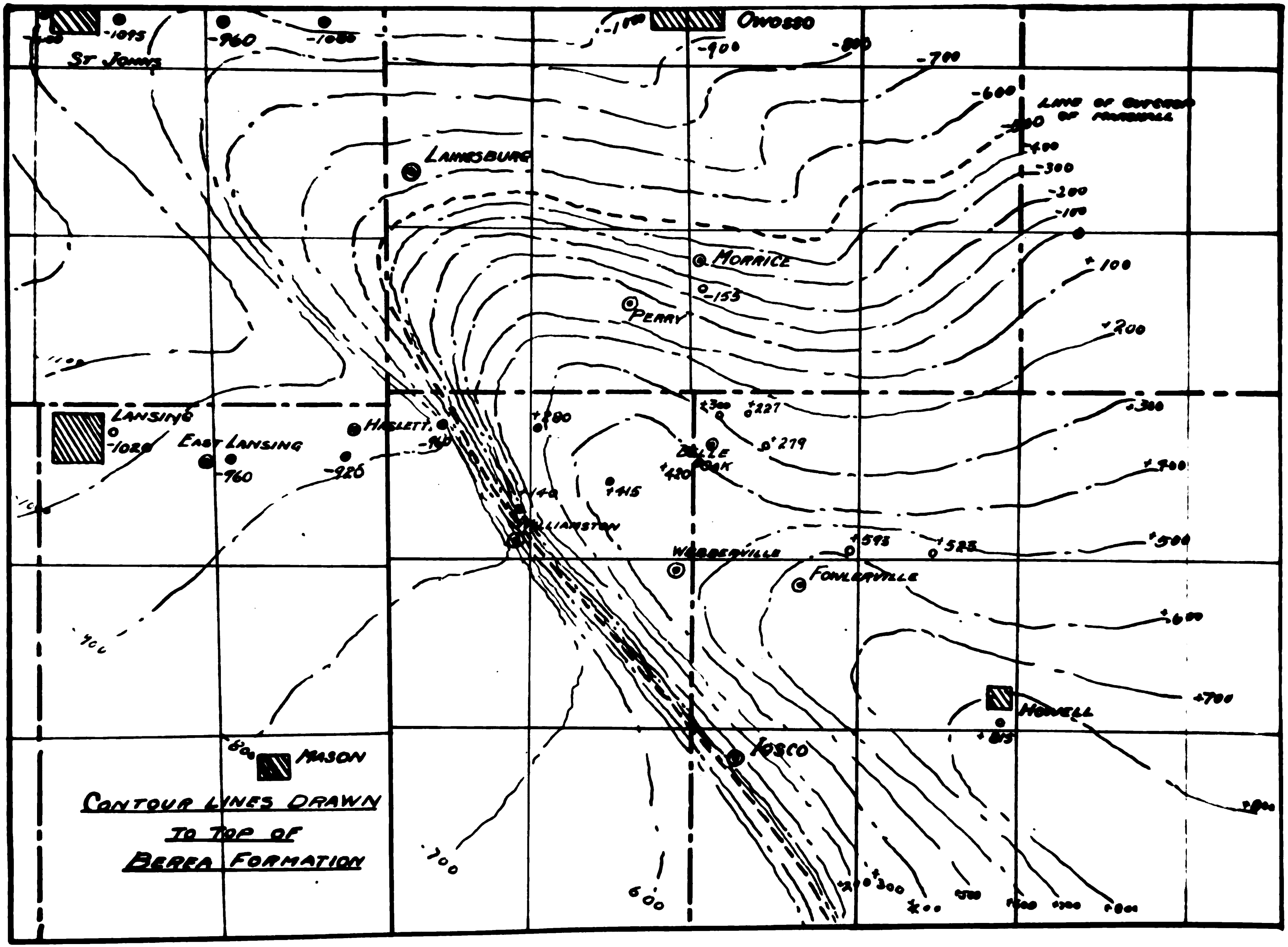
The accompanying contour map shows most clearly what is meant. This map has been drawn with elevations given to the top of the Berea formation. In such places where the Marshall could be obtained the Berea was considered to be 1200 feet beneath it, which is correct as far as present geological data shows. The line of outcrop of the Marshall is given by the - 500 contour line, which is a

broken line. Calculations will show that this places the Marshall at elevation 700, just under the drift.
An anticline extending from a point south and west of Howell, in a more or less straight line, to a point east of St. Johns is clearly shown. This anticline plunges rapidly the farther north it proceeds. The map shows that all the existing wells are to the north and east side of the structure. The fact that gas and oil were encountered here speaks well for the territory immediately to the south and west. The structure slopes gently to the north and east and plunges steeply along the south and west side. It would be natural then to expect to find the highest part of the structure near the southern border of the anticline, and consequently the best possibilities for oil.

However, no undue importance must be attached to the fact that such a structure does exist. A great uncertainty that any anticline will bear oil is present in this section of the country, even when conditions are most favorable. This is because all Michigan formations bear their oil in limestone formations and these at best are not very reliable. Then too, the structure seems to be a large one and extends to the southward for some distance, all of the major oil bearing strata outcropping.

If no transverse structure were present all of the oil may easily have seeped to the surface. The presence of such a structure has yet to be proved.

The location of oil in any section of the country has not been the purpose of this thesis. Our main objective has been to develop an existing method, which had many inaccuracies, to such a point where it could be relied upon. The development of apparatus had no small share in making this possible. We believe that our objective has been accomplished and that we are ready to carry on work of much the same nature as that done in the Fowlerville area.




Structural Contour Map

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