ELECTRICAL INVESTIGATION OF OILFIELDS.*

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The electrical investigation of the earth's crust is made possible mainly by the differences in the electrical conductivity that exists between different rocks and rock formations. It is therefore of great importance to know the factors which are governing the electrical resistivity of individual rocks and we shall now pay some attention to this subject.

Every rock is built up from mineral grains but is more or less porous and the pores are partly or entirely filled with water, oil or gas. Dry minerals occurring in oil-bearing beds are always nearly non-conducting. Minerals of good conductivity are only of importance for electrical prospecting for ores and are so seldom encountered in oil-bearing strata that it is not necessary to discuss them here. The electrical conductivity of the rocks with which we are concerned is practically determined by the following two factors:

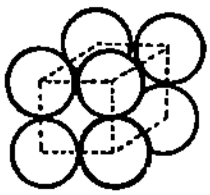

Fig. 1. Pore space 47.6 %

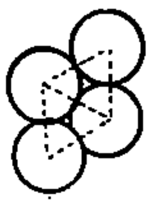

Fig. 2. Pore space 26.2 %

1 The percentage volume of the water in the rock.

2 Specific resistance of the water in the rock pores.

Another factor of minor importance is the temperature.

In sedimentary rocks are the pores at a depth below the ground water-level always completely filled with water except in those few instances where gas or oil takes its place. The amount of water is therefore determined by the pore space which is determined by the arrangement of the mineral grains. Some pore volumes can be calculated under simple assumptions. For spherical

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mineral grains is the pore volume independent of the actual grain size. If the grains are arranged according to Fig. 1 there is a pore space of 47.6% and if according to Fig. 2 26.2%. If the grains also are of different size the pore

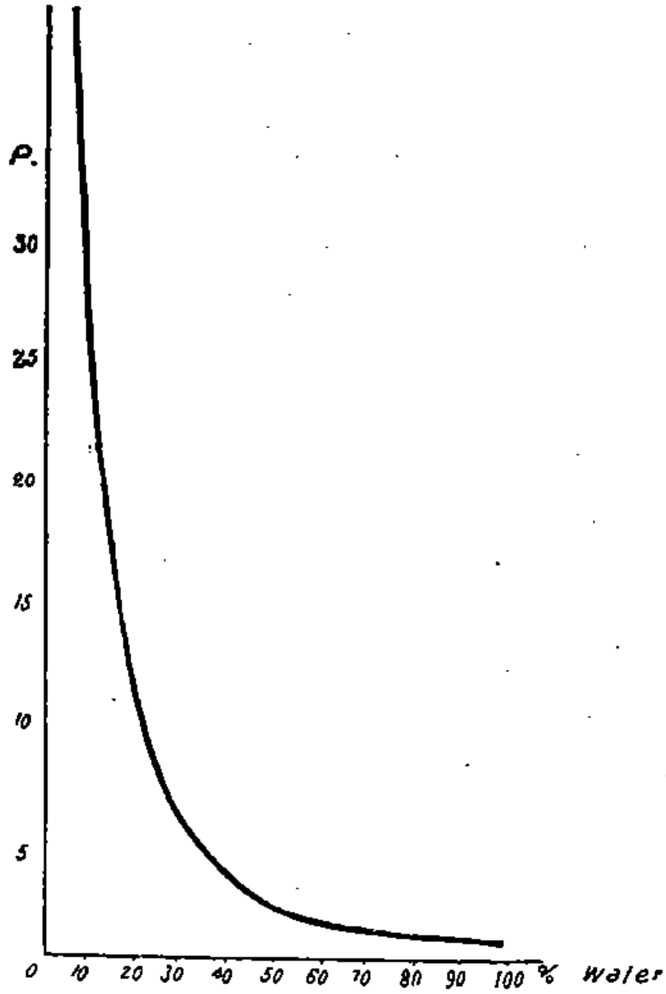

Fig. 3. Relation between resistance factor p. and percentual volume v. of water in rocks

volume can have any value below 47.6% and a mathematical calculation is both difficult and of little practical value. According to Blumer's "die Erdöllagerstätten" are the following figures characteristic for different rocks:

Sandstone	4—27%
Dolomite	2—22%
Limestone	1—17%
Loess	41—46%
Sand and clay	24—50%
Igneous rocks (excluding lavas) below 0.6%	

There is evidently a large variation even between rocks of the same composition but it may be said that the pore volume for one certain bed is the same over large areas. The relation between the resistance and the pore volume is made clear in Fig. 3.

Many rocks show a better conductivity in a direction along the bedding plane than in a direction at right angle to this plane. This is caused by the arrangement of the pores which are often elongated in the direction of the bedding. The contrast in this respect is most pronounced for such rocks as shists but shists generally do not occur together with oil. It has been possible to utilize these differences in the conductivity for the determination of the strike of rocks buried under a shallow overburden where geological investigation can only give results referring to local spots.

The second factor of importance for the conductivity is as mentioned the specific resistance of the waters in the rock pores, which resistance is dependent upon the amount and chemical composition of the dissolved substances. From geoelectrical point of view can the waters in nature be divided in surface waters and deep waters.

Surface waters are the waters above and including the ground waaer. Purest are the meteoric waters i.e. rainwater and snow, which have a high resistivity. When such waters are flowing on the surface of the ground and penetrates to the ground waterlevel the percentage of dissolved salts is increased partly because of the chemical action between the waters and the ground and partly because some of the water evaporates. The dissolved substances are carbonates, silicates, sulphates, chlorides and nitrates in the order mentioned. The variation in dissolved quantities varies considerably According to Clarke's "Geochemistry" the following table is characteristic:

North Am.	South Am.	Europe	Asia	Africa	
2134	9185	122	168	9185	mg. dissolved per liter.

The specific electrical resistivity of surface waters in nature has been found to vary between 300,000 to 80 ohms per cm. cube. Besides such so called normal waters there are local waters in closed basins, saltlakes and mineral waters which however are only of local importance.

Deepwaters are found in sedimentary rocks below the groundwaterlevel and have an average resistivity which is much lower than that for the surface-waters. The chemical composition is not very well known but there are large differences depending upon if the sediments in question have been laid down originally in seawater or in inland lakes. There is also a notable difference between the waters in shales and sandstone. In the former rocks are the pores very small though the porevolume is great, and the waters are still standing and in many cases almost saturated with dissolved substances. In rocks with large pores such as sandstones there is always a downward movement of the waters which therefore may have their concentration decreased by purer waters coming from above. In regions of sedimentry rocks are the resistivities generally for surface waters from 1000 to 12000 ohms/cm. cube. and deepwaters from 10 to 200 ohms/cm. cube. It is now evident that there are large differences in the amount and the nature of dissolved substances in different sedimentary strata and that the electrical properties must also be very considerable.

A sedimentary formation of flatlying strata will therefore be pictured electrically as a number of conducting sheets lying on top of each other and having different conductivities.

Theoretically it is possible to determine the conductivities and the depths to the layers if we cause a current to flow through the ground and then investigate the variations in the electric or the electromagnetic field on the surface. This is the fundamental principle of all geoelectrical methods. When carrying out such an investigation of the configuration of the sedimentary beds as represented by different electrical conductors it is necessary to remember that there are also two other conductors present which have no bearing upon the geological structure. The shallowest is the loose and moist overburden which generally is a good conductor. Next there is the groundwaterlevel which may have an electrical conductivity different to that of the rocks above and below. It is therefore necessary to carry the electrical investigation to depths below these conductors, if we are to get a picture of the strata. This brings up the vital question; How deep can we investigate with electrical methods from the surface? This depends upon the differences in the conductivity between the different conductors. Reactions from a certain bed at a great depth say 400 meters can only be obtained if this bed has a considerably higher conductivity than the overlying beds. If these upper beds are very good conductors the electric or the electromagnetic field on the surface will be determined nearly only by the properties of these upper beds and the influence of deeper beds be small though they may be good conductors. It is thus evident that the depth which can be investigated decreases with increasing conductivity in the upper horizons. The largest depth from which influence has been noticed is about 450 meters but generally are the electrical structure maps based upon conductors at some 200 meters below the surface. The number of actual resistivity changes with increasing depth is also of importance especially for the variations in the electric field.

The theoretical considerations are for all electrical prospecting methods based upon assumed electrical conductors in the form of large sheets parallel to the surface and occurring at various depths and having different resistivities and thickness. The influence of one or several such sheets upon the surface potential or magnetic field derived from currents sent through the ground can be calculated. If many conducting sheets occur the calculation is somewhat laborious. By such calculation is use made of the theory images which applies to the electrical potential as well as to the electric current.

Calculations have also been carried out under the assumptions that the subsurface conditions correspond to faults.

With this fundamental base is the theory strictly applicable to all regions where the geological strata are paralleling the surface no matter whether the surface is a plain or steeply tilted. When investigating the electrical or the electromagnetic field in a certain point we will find that the results are mostly influenced by the electrical properties of the beds in the immediate surrounding of the point and only to a minor degree by the conditions far away. This makes it possible to apply the above theories also to areas where the sedimentary beds are slightly tilted as are the conditions in most oilfields.

If the geological strata are steeply dipping or vertical the theories above do naturally not apply without a correction.

We have seen that it is possible to calculate the influence of several known electrical layers. If we now try to do the reversed i.e. to calculate the electrical layers from their influence as we measure it in the field we will find it more difficult. The solution of this problem is worked out from a number of diagrams which show the influence of varying subsurface conditions upon the field data. The principle is to take a number of data from every point which is to be investigated and that thereafter with the help of the diagrams work out a solution which fits all the measured data. This procedure is sometimes complicated and requires a large store of typical cases with which to make comparisons and interpolations before a satisfactory result is obtained.

The practical methods can be divided in potential methods and electromagnetic methods.

Potential methods are based upon resistivity measurements or potential measurements. Quite a number of papers have already been published and to-day time does not permit any discussion. For further information I refer to:

"Applied Geophysics" by Eve and Keys,
Technical Publications of the A.I.M.M.,
Mining Magazine of London,
U.S. Bureau of Mines Information Circulars,
and other mining papers.

ELECTROMAGNETIC METHOD

The first successful electromagnetic method for structural studies was developed by Karl Sundberg about five years ago. This process consists in setting up a primary alternating magnetic field and observing at the surface the resultant field components or field vectors caused by the reaction of conducting sheets of different resistivity upon the primary field. The reaction is due to the fact that any alternating magnetic field induces secondary alternating currents in any conducting medium within its range, and that these secondary currents set up secondary alternating magnetic fields which in turn influence the exciting field.

An insulated copper cable of great length is laid out on the ground usually in the shape of a large rectangular loop or as a straight line grounded at both ends. An alternating current is sent through this cable thereby creating an electromagnetic field around the cable or loop. The machines used are gasoline driven dynamos suitable for transportation and giving an electric voltage amounting to 100-150 volts. The frequency used varies according to local conditions from 500 cycles per second to 150 cycles. The strength of the current in the cable naturally varies a lot with the resistance in the loop but values from 1 to 4 amperes are common. There are two or three types of machines used, the main differences being the weight and fuel consumption and revolutions per minute.

The measuring apparatus consists of receiving antenna, an amplyfier, compensator and headphone.

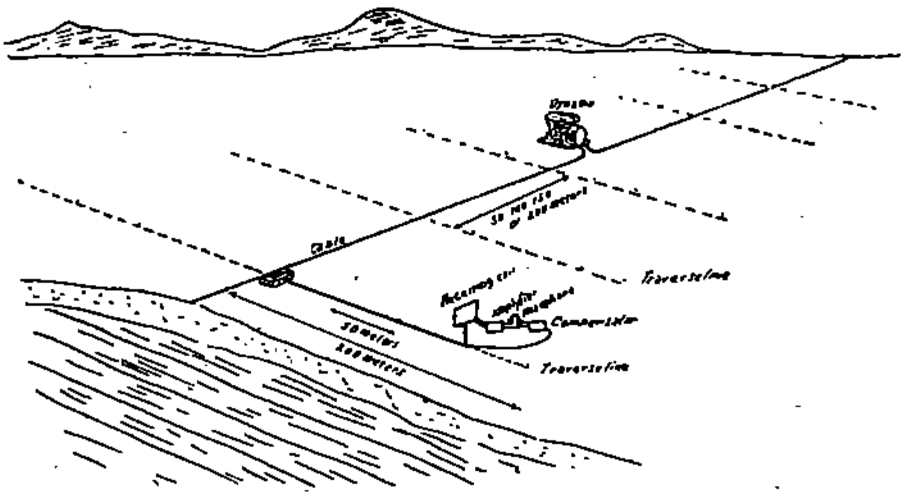

Fig. 4. General field lay out for electromagnetic survey.

The receiving antenna is a wooden frame holding several hundred turns of fine insulated copper wire and is so mounted that it can be set in any position. The electromagnetic field created by the primary cable causes when passing through the receiving antenna or frame a certain voltage which is taken through the amplyfier. In this apparatus two—three or four tubes can be used according to what is necessary.

The compensator which is a hook-up of several resistances is the measuring instrument and the headphone the means to put the resistances in the correct position.

Before survey is started the whole arrangement i.e. frame, amplyfier and compensator is calibrated so that the readings at the variable resistances of the compensator give the strength of the electromagnetic field per one ampere of the current in the primary circuit. This has the advantage that the measured data are independent of the absolute strength of the electric current flowing in the exciting loop and that thus directly comparable results are obtained from field works in different places.

The measurements of the electromagnetic field are taken on the ground along traverse profiles which cross the cable at right angle, and on each line readings are obtained from several points f.i. 50-100-150-200 m. from the cable. Both the horizontal and the vertical components are measured.

The distance between the traverse lines varies. In the case of a large scale preliminary reconnaisance survey the traverse lines are generally 200 meters apart. For more detailed investigation the lines must be closer as warranted by local condition.

The results of the survey refer to the conditions below the intersection point between the cable and the traverse line and the complete survey shows the subsurface conditions as a profile along the cable or the sides of a loop. We thus obtain geoelectrical profiles and by laying out the cables in a suitable position in regard to the known geology information can be won at places where such is wanted. In the case of a large scale survey it is advisable to investigate the strike of the formations first and thereafter investigate the whole area along profiles parallel to each other but running as much as possible at right angle to the strike.

The speed of the survey is naturally very much varying with local topographical conditions and with the closeness of the traverse lines and the profiles. With a distance of 100 meters between the traverse lines from 1000 to 1500 meters of a profile can generally be covered in one day. With good ground condition and motorcars available the speed can be largely increased. In the case of a large survey it is also possible to make up definite plans for the field work so that when the whole survey goes smoothly the speed of electrical prospecting is greater.

The costs are naturally also varying with the closeness of the traverse lines and the profiles, but in an ordinary oil country an ordinary survey with

100 m. between the traverse lines the expense involved amounts to 2000 to 4000 yen per square km. If a large scale survey is carried out is naturally the cost per square km. decreased, but on the other hand rough topography will increase the expense.

INTERPRETATION.

The field data from the electromagnetic surveys for structure mapping give the amplitude and phase of the electromagnetic field on the ground at several different distances from a primary cable along a line perpendicular to the cable. According to experience the electromagnetic field thus measured can be explained, except by strictly local disturbances, by the presence of a system of subsurface conductors in the form of horizontal conducting sheets. In the interpretation is therefore use made of the theories for the electromagnetic field above thin and thick conductors. The sedimentary formations generally are composed of a very large number of interstratified beds. The electrical conductivity is therefore likely to show a very vivid variation in a vertical direction, whereas the electrical conditions are comparatively consistent in directions along the bedding planes.

It is plain that such conditions are only satisfied by the theory for thin conductors and that the theory for thick conductors only apply where geological conditions are simple.

The theory for a thin conducting sheet as given by Levi Civita, founded on work of Maxwell Helmholz and Herz shows that if an alternating current is flowing in a straight wire of infinite extension parallel to a thin conducting sheet, then the electromagnetic field in any point is determined by the strength of the primary current, by the induction factor of the conducting sheet, and by the mutual position of the primary cable, the conducting sheet and the observation point. The value of the induction factor is directly dependent upon the frequency of the alternating current used upon the effective thickness of the conducting sheet and the specific resistance. In other words the induction factor is the individual mark of the different electrical layers and can be varied at will by changing the frequency.

Assuming a single horizontal conducting sheet below a long straight current-carrying cable stretched parallel to the conducting sheet, all possible vectors of the resultant horizontal as well as vertical field components at a certain distance from the cable can be represented by so-called vector diagrams. Such a diagram is illustrated schematically in Fig. 5. The abscissa axis X'OX, called the real component axis, contains the parts of the field vectors in phase with or opposite in phase to the primary current. The ordinate axis Y'OY, called the imaginary component axis, contains the parts of the field vectors which are either 90° leading or 90° lagging in regard to the phase of the primary current. The axes are divided into positive and negative microgauss. The solid-line curves represent lines of constant depth and the

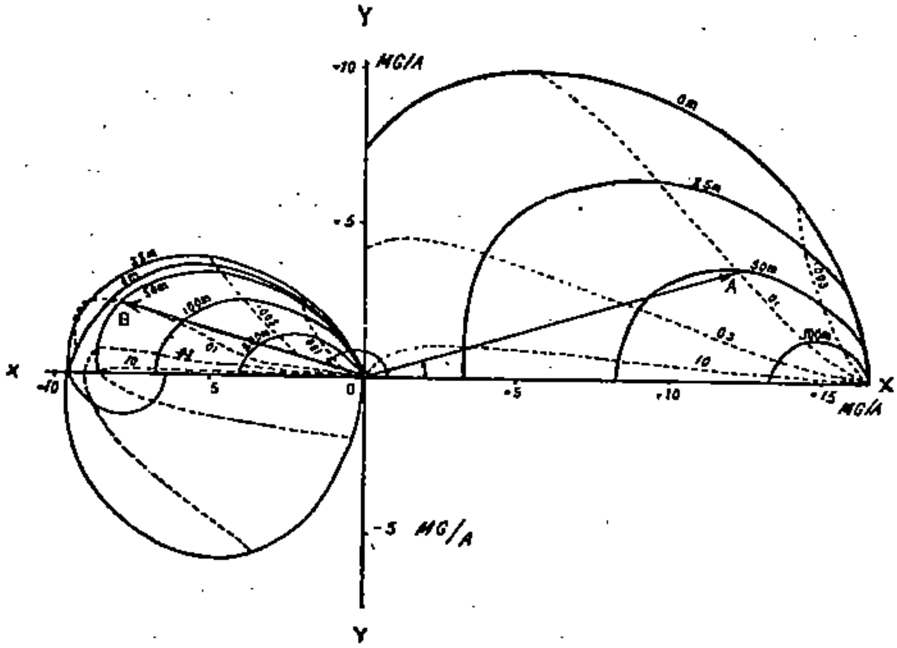

Fig. 5.

broken-line curves represent lines of constant induction factor. The right side of the diagram contains the vectors of the vertical field component, while the left side contains those of the horizontal field component. The side of the vertical vectors is larger than the side of the horizontal vectors, dut to the fact that, in this case, the vertical component represents the geometrical sum of the primary and the secondary fields, while the horizontal component is due to the secondary fields only. The diagram is valid for fields of all frequencies. Diagrams have been computed for all standard distances.

The practical meaning of the diagram is the following: Assuming a single conducting sheet of a certain induction factor p at a certain depth t below the cable, then the resultant vectors of the vertical and horizontal field components are represented by the lines OA and OB, which connect the origin of the diagram with the intersection points A aud B for the assumed p and t values. The length of the lines is called the amplitude of the vectors and the angle they form with the real component axis their phase or phase displacement. The amplitudes as well as the phase displacements AOX and BOX are simple geometrical functions of the coordinates of the two intersection points. The coordinates, in turn, are identical with the complex readings of the compensating arrangement. Therefore, if only one conductor is present, it is evidently possible to determine the depth as well as the induction factor with the help of the correct diagram and of only one observation of either the horizontal or the vertical field vector. Generally, however, we have to deal with a series of several conducting layers below one another. In this case, the resultant readings have no direct relations to the vector diagrams. The problem is then solved by a mathematical analysis of a series of readings for different components or different frequencies.

Since every reading taken means the determination of two coordinates in the vector diagram it will allow the solution of two unknowns. Every reading added whether taken from another component of the field vector, at another distance from the primary cable or at another frequencey will therefore make it theoretically possible to determine two more unknowns. By measuring the field at several distances from the cable we thus get material enough to solve many unknowns, and as the number of unknown quantities generally does not amount to more than six we have enough field data for a reliable solution of these.

The complex system of a large number of conducting layers, which make up the sedimentary formations in general can for interpretation purposes be substituted by a three layer system. In this system the variations in depths to the lowest conducter will then represent the variations in depth to a certain electrical key bed below the ground water horizon.

So far this three layer theory has been found quite sufficient for interpreting all the variations in the electromagnetic field caused by layers within the depth attainable by the method.

In many instances an interpretation assuming only two layers has been very satisfactory and on one or two occasions one layer interpretation has been verified.

The question might raise when shall one-layer, two-layer, or three-layer interpretation be used. The answer is that this is automatically shown by the measured field data. If three-layer conditions exist no results can be got from one-layer interpretation that will satisfy all the measured field data.

Complication is introduced by the fact that normally the readings are not taken in the plane of the loop but at different elevations above or below the cable and must be corrected to a standard elevation.

It may happen sometimes that the specific resistance of the surface or intermediate conductors is extremely low or, in other words, that the shielding effect of the upper beds prohibits an effective reaction of the lower conductors upon the resultant field at the surface. This condition can be remedied easily by a lowering of the frequency of the primary current, because this operation automatically lowers the induction factor and thereby the shielding effect of the upper layers. In this way, it is nearly always possible to penetrate to greater depths, even if the surface or intermediate conductor possesses low specific resistivity. The most suitable frequencies for electromagnetic structure investigations lie between 500 and 100 cycles. Higher frequencies are seriously handicapped by the correspondingly high shielding effect of the upper beds, while lower frequencies require more complicated measuring arrangements.

Two typical electrical indications across certain basic geological structures are given in Figs. 6 and 7. The following abbreviations are used: Po—Po induction factor of surface conductor, t_{I}—t_{I} and P_{I}—P_{I} depth and induction factor of intermediate conductor, t_{II}—t_{II} and P_{II}—P_{II} depth and induction factor of subsurface conductor. Fig. 6 represents the indications across a fault. The fault is reflected electrically as a jump in the depth lines of the two conductors, the induction factors remaining at constant value.

Fig. 7 represents the results of an electromagnetic investigation across a salt-dome structure. The intermediate as well as the subsurface conductor is pushed upward by the dome. The subsurface conductor disappears within the salt. In many cases it is preferable to present the final result in the form of a contour map of the subsurface conductor, the maps being easily constructed from the individual electromagnetic cross-sections.

RESULTS

Investigations on salt domes

The salt domes of Texas Lousiana are round plugs of salt which have from below penetrated overlying strata and in some instances have reached the surface. The diameter of the domes is as a rule a few miles or less. The oil can occur at the top of the salt in the overlying caprock which is a porous limestone

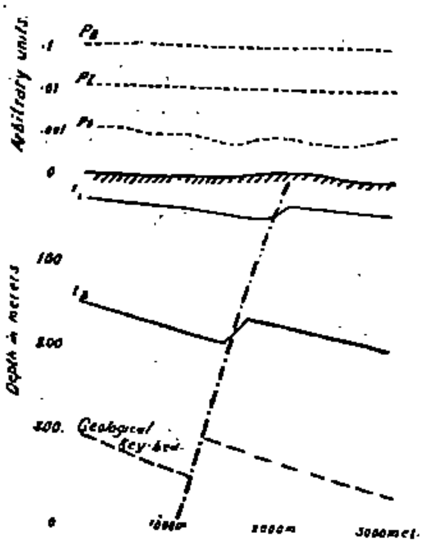

Fig. 6. Electromagnetic indication across fault.

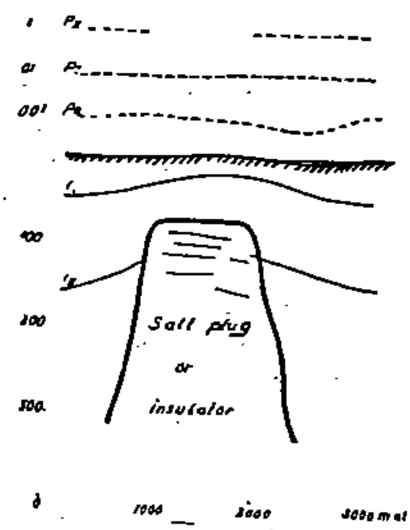

Fig. 7. Electromagnetic indication across a salt dome-structure.

carrying gypsum and sometimes native sulphur. Another place where the oil may be accumulated is in the tilted strata along the sides of the saltplug. Equally favourable places for oil deposits are the faults around the saltdome. There faults were probably developed when the salt plug penetrated the overlying beds.

The slides from Hawkins Ville and Moores. field show typical electrical maps of salt-dome. At *Hawkins Ville* the interpretation was made under the assumption of three conductors but in the central part of the area the salt influence made possibly the use of two-layer interpretation only.

At *Moore's field* a two conductor interpretation was used. The map gives the depth to the second conductor. The producing area is around the eastern flank of the dome indication but the two largest producers were found outside the proper dome structure close to the electrical fault indication C-D. It seems reasonable to connect this well with the fault.

The measurements with 400 cycles frequency took about 4 weeks. Altogether 107 observation lines were investigated covering an area of about 5 square miles.

The surface conductor showed in this case a dome structure similar to but less pronounced than the structure of the second conductor. The fault C-D also showed up in the surface layer but somewhat more to the north thus indicating a dip of the fault plane to the south. Within the line marked limit of salt influence the measurements indicate a non-conductor (the salt) beneath the upper conductive beds. This "salt indication" is strongest within the area marked, indicating that the depth to the salt is shallowest within this area.

Investigations on faults

A typical example is the *Bruner fault* in the Balcony fault zone of Central Texas. Here the oil is accumulated in closed basins which are developed by reversed faults. The faults themselves do not permit any oil or water to penetrate. The oil as well as the saltwaters associated with the oil lies at a depth of 2500 feet below surface. This is far too deep to have any noticeable influence on the electromagnetic field investigated at the surface. This field is mainly influenced by conducting clav-beds which lie between thick sand beds at a depth of about 500 feet. Here however is no unconformity between these shallow beds and the deeper oil-bearing strata. Therefore any sudden change in the configuration of the shallow clay beds must correspond to some sudden change in the deeper beds. The cross sections show the general dips of the strata and the electrical conductor and also the faults. The displacement of the faults at the 500 feet level depend upon the fact that the fault plane is dipping 20° to 35°.

The electrical survey of the Bruner oil field was started after the discovery of the first well. The fault was outlined in about one month and subsequent drilling showed the close relation between the fault and the oil deposits.

It is evident that even a shallow overburden will make a geological mapping of faults impossible. Both seismic and gravimetric surveys have been tried for the location of these faults but the best results have been obtained by electromagnetic methods. In the Balcony fault zone 4000 km have been surveyed electrically and several fault indications discovered. Until now drilling has been carried out on 38 of the indications. This has resulted in that in 31 cases faults were proved to exist, 5 cases are doubtful and in two cases the indications were shown to be caused by outpinching conducting beds.

Anticlinal survey

The picture shows the result of a survey at Yates pool which is one of the largest oil fields in the world. The strata encountered near the surface are Cretaceous limestones and sandstones. Thereafter Triassic conglomerals, sandstones and limestones for 100 feet. Below this is a series called anhydrite series about 600 feet thick, and underneath is the oil-carrying "Big lime" series. The electrical conductor mapped corresponds to salt water carrying sand layers in the anhydrite at a depth of about 200 m. Satisfactory results were obtained with 2 conductor interpretation. Uppermost conductor being the ground water generally at 50 m. depth. No surface influence. Comparing the geological contour lines with the electrical, the general parallelism is striking. The crest of the geological anticline coincides with crest of electrical anticline. The strike and the dip according to the electrical survey agree well with the actual except in the south western corner. This disagreement is considered due to inaccurate correction for very rough topography but at the time of the survey the method for topographical correction was not completely developed. Most of the drilling has been carried out afterwards.

The extension of the Yates anticlinal to northwest was predicted by the electrical survey, and was afterwards proven to be productive of oil.

Similar electrical surveys have been carried out in California in the areas Fruitdale, Newport and Bravo-Buena-Vista. In the first two areas the agreement between electrical results and later drilling is good. In Bravo-Buena-Vista no definite statement can be made because the correlation between the different wells drilled is uncertain.

In Europe electrical surveys for domes and anticlines have been carried out at Hanover in Germany, in Austria, Tzecoslovakia and in Roumania. Only few salt-domes have been surveyed.

Most of the work done electrically is carried out on contract for private firms for economic reason the results cannot be published until some years after the survey has been carried out. Some older surveys near Vienna have been described by K. Friedle in his paper "Über die Jungsten Erdöl Forschunger im Wiener Becken."

However I have today shown surveys over salt-domes, faults and anticlines and hope that the examples give a good picture of what can be done electrically.

From these examples and the experience in other places it is evident that the full advantage of geophysical prospecting can only be reached if the investigation is carried out on a large scale.

Direct Location of Oil With Electrical Methods

This problem has been intensively studied and many experiments undertaken. A reliable method for this purpose must naturally be of very great economical importance and though the results as yet are not encouraging we must pay some attention to the subject.

Electrically oil accumulations are insulaters and strata saturated with oil poor conductors and it is theoretically possible to locate such electrical bodies if they occur in a good conducting medium. This is nearly always the case as the sediments in which oil occurs are conducting. However the largest difficulty arises from the fact that oil generally occurs at depths which cannot be reached by electrical motheds at their present state of development.

The problem to be considered is now restricted to locating an insulater at a shallow depth below the surface. This does not meet with any obstacles that cannot be evercome, but then there is the question of how many of the insulating bodies located are oil deposits? Our previous study of the electrical properties of rocks shows that there are many rocks of poor conductivity and these must naturally give the same indications as oil accumulations and as yet there is no reliable method available to distinguish between different indications.

The methods that can be used are similar to those already described i. e. potential and electromagnetic, and the principles for the work are the same. Surveys over shallow saltdomes with the electromagnetic method give distinct indications of the non-conducting salt andit is to be expected that larger oil accumulations will give similar indications. However large scaled surveys for direct location of oil have not been carried out to any extent depending upon the fact mentioned i. e. that oil mostly occurs at depths which cannot be investigated electrically from the surface.

In special cases have detailed surveys proven successful. If drillholes have been put down to the horizons expected to be oil-bearing an exiting electrode can be placed at any depth wanted. By investigating the potential drop on the surface round the drillhole it is possible to get information about the conductivity of the ground and about the possible occurrence of insulaters. In some cases if there is a large enough insulating body present the equipotential lines will show irregularities above such a body. The figure below shows the distribution of primary current in the ground round a bad conductor. One drillhole is used for one of the exiting electrodes, the other electrode being grounded at any point on the surface.

Such an indication can also be caused by structural features especially faults, and it is therefore necessary to make a regular structure-investigation to check the indication.

Oil indications obtained electromagnetically can show up as in the same way as salt indications. Another way of direct oil prospecting with the electromagnetic method is to determine the thickness of the sediment above oil deposits. For this it is necessary that the overlying strata have good conductivity and that the oil-bearing beds have great thickness.

From the above it is evident that there are many obstacles met with when trying to locate oil directly. The following favourable conditions may however make the application of the methods succesful:

1. Shallow depth to the oil.
2. Great thickness to the oil-bearing strata.
3. Constant electrical conductivity over a large section and area of the beds above the oil.
4. Drillholes in the area to be prospected down to the depth at which the oil is expected.

As a summary it can be said that the methods for direct location of oil are still in an experimental state and that their application is limited to small areas where the local conditions are favourable. However with the present rapid development of geophysics it is to be expected that the methods will become of ever increasing importance.