DIRECT OIL PROSPECTING WITH ELECTRICAL TRANSIENT REFLECTIONS

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INTRODUCTION

It may come as a surprise to some readers to learn that, using electrical transient reflections, accumulations of hydrocarbons in the subsurface were being accurately mapped from the surface prior to 1940. As a matter of fact, serious attempts in this direction had been carried out in the 1920s but did not meet with unqualified success, probably due to the state of the instrumentation.

Some will be tempted to reject this claim on the grounds that, should the technique be demonstrable — as indeed it is — the Industry would have already give it wide acceptance. This position implies a stand which runs counter to much of the recorded history of mankind.

Aristarchos of Samos, in 200 B.C., demonstrated that the earth revolved around the sun. In 150 A.D. Ptolemy demonstrated that the earth was round and calculated its diameter with uncanny precision. For the next one and a half millenia the main stream of opinion elected to ignore both demonstrations and had a flat earth throne in the middle of the Universe using, some speculated, an elephant for support. Twenty years ago the Astronomer Royal joined the opponents of the continental drift theory by arguing that the concept was absurd, the earth being far too "rigid" to allow such wanderings and in the U.S.S.R., to this day, the official tectonic view has it that lateral displacements of large earth masses to form nappes constitutes a fantasy.

The short bibliography appended to this paper will show that demonstrations have been presented on a number of occasions in the lecture room, in print and in the field proving that hydrocarbon accumulations in the subsurface have been mapped by electrical transient methods in the past, as they are being mapped today. The innovation is, as has already been stated, not new but it is radical enough to elecit rejection from the very people who would stand to profit most by its application. This presentation constitutes one more attempt to popularize a successful method of discovering the remaining hydrocarbon accumulations hidden in the subsurface, at a time when the energy shortage has never been more acute and conventional methods of prospecting for new reserves have never been less successful.

OIL FINDING: DIRECT AND INDIRECT METHODS

The conventional methods of prospecting for hydrocarbons are indirect and probabilistic, as they rely on chains of inference which make it more or less likely to find hydrocarbons at one location than at another. Thus, an anticline does not invariably contain hydrocarbons and its accurate mapping does not guarantee a success. The limitations of the conventional methods are starkly highlighted by tens of thousands of dry holes.

At this time, the direct methods of oil finding fall into two categories: one uses the property of hydrocarbons to percolate to the surface from the reservoirs underneath, where the main accumulations are trapped. The other family of methods, to which Electraflex belongs, recognizes the presence of hydrocarbon accumulations in the subsurface from their response to a signal generated by surface equipment.

As a matter of fact, direct oil finding is a routine operation which is performed hundreds of times every day throughout the

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world, although it is not usually labelled as such. For instance, the Electric Log, the Induction Log and the Laterolog are direct oil finding tools in the true sense of the word. The tools themselves are located inside the bore hole without any contact with the oil in the formation opposite; they send electrical signals into the neighboring rocks; these signals elicit a response which is routinely interpreted to indicate the presence or otherwise of hydrocarbons in the formations opposite the tool. Electraflex performs a similar function but its radius of investigation is measured in miles rather than feet. There are no other significant differences, except popularity.

PRINCIPLES OF ELECTRAFLEX

Two major requirements have to be met to allow this method to operate. Firstly, the signals emitted by the surface equipment must be capable of travelling, with a tolerable attenuation, through several miles of rock. Secondly, the accumulations of hydrocarbons which are the target for the Electraflex survey must present a significant contrast with the surrounding rocks and their fluids so as to generate a characteristic response, detectable at the surface.

The earth is a good conductor, with resistivities in the range of five to twenty-five ohm mostly, in the sedimentary sections of interest to the petroleum industry. This property is used routinely by magneto-telluric methods, classic "resistivity" methods and long range communications, confined primarily to military uses, which rely on modulation of fields propagated for thousands of miles beneath the surface of the earth. The earth constitutes an obstacle to the transmission of electro-magnetic fields only when high frequencies are used, but Electraflex, like all other methods requiring deep penetration, relies on the low end of the frequency spectrum. New students to this field will be interested in an experiment carried out by Sun Oil Co. in their Shanemen No. 1 NE-SE Sec. 14-22N-54W uncased dry hole. Lane Wells lowered a potential electrode down to TD at 4642 feet, with intermediate stations, while the Electraflex input system was being activated one quarter mile away. The arrivals of the Electraflex transients were clearly perceived at every level. This is far short of the range of the method which has mapped production down to 16,000 feet.

The second requirement for the successful operation of Electraflex is that the hydrocarbons, in the subsurface, would present a characteristic singularity to the input signal and generate a specific response which can be detected at the surface. A body of hydrocarbons has physical characteristics markedly different from that of the rocks which surround and contain it and from the water which otherwise fills the pore space should one choose to compare densities, acoustic velocity, thermal conductivity or radio activity. None of these parameters shows as stark a contrast as the electrical resistivity. Below is a table with typical resistivities found in sedimentary basins; units are the usual ohm/m/m^2:

Salt Water	0.01
Fresh Water	1
Shale	5
Sand	10
Carbonate	50
Coal	100
Oil	300,000,000,000

From the perspective of Electraflex, the detectable hydrocarbon accumulation forms a continuous body, in the form of a lattice of almost infinitely resistive material which occupies part of the pore space available in the reservoir rocks. This perspective is different from that of a down-hole "resistivity" tool such as the Electric Log, which measures the bulk conductivity of the rock and the fluids it contains. Thus, the conductivity of a given rock volume is measured as:

$$C_{\text{rock volume}} = \frac{1}{R_{r.v.}} = F\left(\frac{1}{R_{s.w.}} + \frac{1}{R_{r.}} + \frac{1}{R_{oil}}\right)$$

The resistivities form a parallel circuit and the term $\frac{1}{R\ \text{oil}}$ approximates zero and has no practical effect on the measurement. In other words, the "resistivity" down-hole mainly measures the amount and the conductivity of the water in the formation (which it reports as resistivity) and it "detects" the presence of hydrocarbons only because the space available for the conductive water is less than when hydrocarbons are absent. Electraflex, on the contrary is "blind" to conductive material of any kind and reacts only to extremely resistive bodies such as hydrocarbons or the cap rock of a salt dome.

METHODOLOGY

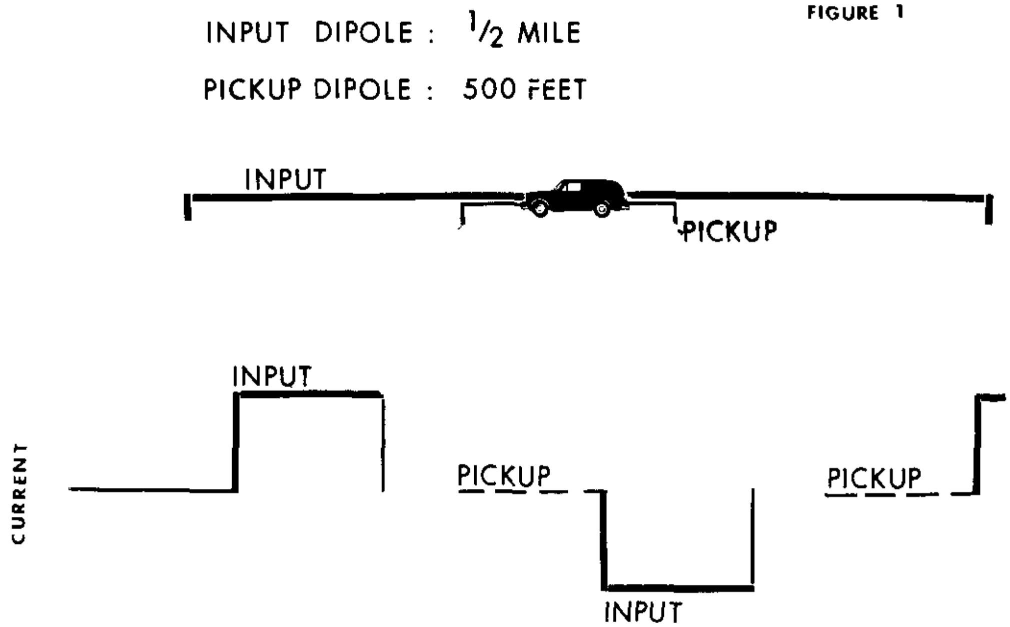
In presentations dealing with subjects of applied science, it is customary to make every effort to present the theoretical explanations together with the empirical observations. This is a desirable objective but it cannot always be achieved in the early stages of the development of a new technique since the effort which is necessary for the elucidation of the processes involved may not be available at that stage or the body of accumulated observations may yet be too fragmentary for that purpose. Critics may object to the premature character of the publication and may wish to send the innovator back to the drawing board, to return only when all the answers to all the questions have been neatly worked out. This procedure disregards both history and purpose.

Even Darwin did not have all the answers when he published his Origin of Species; as a matter of fact, more than one hundred years later nobody yet has all the answers on this subject. The flying machine flew and the steam engine worked before hydrodynamics and thermodynamics had been elaborated. As a matter of fact, it is precisely the publication of the Origin of Species, the flying of the aeroplane and the chugging of the steam engine that give rise to their specific lines of understanding, in that they serve their purpose: to introduce new techniques and new concepts and direct further efforts towards new fields of endeavor.

Also, although a deep theoretical analysis of the subject may be presented in all its rigorous mathematical apparel, there is no guarantee that it is not quite wrong and will not be discarded, without ceremony, in the immediate future. It would be vindictive to give examples of this.

Thus, although a number of mathematical models are available which could be invoked to explain the behavior of the Electraflex signals and their responses, none, to the author's knowledge, is satisfactory. The signals used by Electraflex are transients, and not sine waves or DC and thus these models do not apply. The decay curves of the I.P. method are not relevant and

FIGURE 1



neither are the calculations based on M.T. or the Input method.

No doubt, the instrumentation and the conceptual tools are in existence today, which would be necessary to formulate a satisfactory explanation, but we are concerned only with the practical applications of the tool here. In presenting Electraflex, we have followed the traditional approach of mankind: first a thing is made and years later comes the explanation. Nobody has even prevented a man from throwing stones by pointing out his ignorance of Newton's laws of motion. This preamble should explain why the mathematics have so little place in this paper: they have not yet been worked out, it seems.

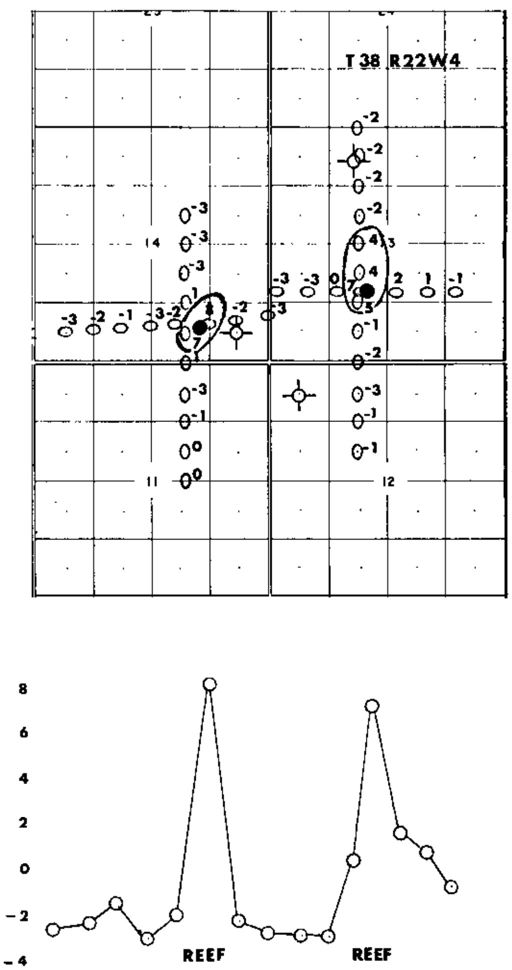
ELECTRAFLEX SET-UP

Figure 1 shows the essential parts of the Electraflex set-up. The truck carries the power source and the detection instruments. The power source is connected to the input dipole which is a half mile long and grounded at both its extremities. The instruments are connected to the potential dipole, which is also earthed at its extremities and is 500 feet long. The current and the potential dipoles are reversed at each half-cycle to avoid polarization. There is a gap between the inception of the signal anrd the start of the recording of the reflection; this allows the "first breaks" to sweep past the receivers, this also allows the I.P. effect to collapse at the receiver position and to get rid of the very shallow events which are of no significance to the purpose of the survey.

At each station, measurements are made on three different pulse rates. The returning signals undergo three stages of amplification, the first through electrical amplification ,the second through stacking in the instruments themselves and the third through stacking in a computer. The relative values recorded constitute the Electraflex output and these are the figures which are found on the maps and profiles presented below.

The distance between successive stations is usually one quarter mile, but it can be increased or decreased depending on the

FIGURE 2



definition required by the geological objective.

BACKGROUND AND ANOMALY

Figure 2 shows the data obtained over two pinnacle reefs in the Nevis area. The targets are Devonian D-3 reefs with an oil column. Due to the very small size of the objective, the stations have been spaced at 1/8th mile intervals. The numbers plotted as ordinates are computer stacked values and represent the power of the signals returning to the surface and detected by the potential dipole of the Electraflex set-up.

The stations situated away from the oil-bearing reefs collect very little energy reflected from the subsurface and define the barren background. The stations situated directly on top of the reefs record a large energy return;this strong return is represented by a sharp peak on the profile which defines the anomaly. The intensity of the anomalies is generally the same over similar reservoirs in the same area and this allows for positive identification of the anomalies.

The influence of casings on the Electraflex measurements is nil. This is due to the fact that they hang perpendicular to the wave front generated by the Electraflex set-up and their cross-section is negligible. This is illustrated by the profile which fails to record any indication of anomaly opposite the dry holes, although they too have surface pipe set.

LITHOLOGY AND HYDROCARBONS

The only clearly demonstrable response to lithological changes in the subsurface obtained to date has resulted from salt domes or their associated cap rocks and some completely cemented reefs in the Permian Basin of the U.S.A. It is conceivable that important lithological changes could be mapped by Electraflex but this effect has been completely overshadowed by the strength of the signal returned from hydrocarbon accumulations.

Figure 3 shows a profile across Turner Valley, a structural trap in the Foothills of Alberta. The spacing of the stations is one quarter mile. Surface equipment and access prevented the recording of stations right across the field. This example illustrates the subordinate role of the lithology, if any. At the right hand side of the section, the anomaly starts abruptly at the leading edge of the thrust sheet; from this evidence alone it is not possible to decide whether it is the hydrocarbons or the carbonate edge which causes the anomaly. At the left hand side of the section, however, the anomaly ends, just as abruptly, at the water table, there being no lithological change at this location, thus demonstrating that the anomaly is actually caused by the body of hydrocarbons.

BACKGROUND: THE ELECTRAFLEX NEGATIVE

Figure 4 shows a profile recorded over a prospect intended for drilling. It is situated in the Foothills belt of Alberta; for reasons which will be obvious the precise location of the survey has not been released by the owner of the data for general publication.

At the left hand side of the profile there is a very large anomaly which is caused by the Pincher Creek gas field, an important accumulation occurring at about 11,000 feet below the surface. This was recorded as a model since the prospect was situated on what was thought, from geological and seismic evidence, to be a similar thrust sheet. The Electraflex values, however, remained within the clearly defined envelope of the background. The well was drilled and was, as predicted by Electraflex, found to be dry, with no shows.

The files of Electraflex contain hundreds of instances of areas characterized by values representing barren background and which have subsequently been drilled. Whether wildcats or development, the ensuing wells have never been completed as producers.

The reason for the extremely reliable negative prediction is that, for hydrocarbons to be producible, they should occur as a continuous body in the subsurface and that such a body, having a resistivity of 300 billion ohm, will give an anomalous reflection of the Electraflex transient; therefore, no anomalous reflection, no hydrocarbon accumulation.

Other obvious uses of the barren background diagnosis are the recognition of wet reefs as opposed to those containing hydrocarbons, the differentiation between actual reefs and anhydrite "plugs", the delineation of stratigraphic accumulations and, of course, the checking of any area for hydrocarbons prior to drilling, or even prior to acquisition.

THE EXTENT OF THE ANOMALY

Since the anomaly corresponds to the hydrocarbons in the subsurface, the extent of the anomaly corresponds to the extent of the hydrocarbon accumulation.

FIGURE 3

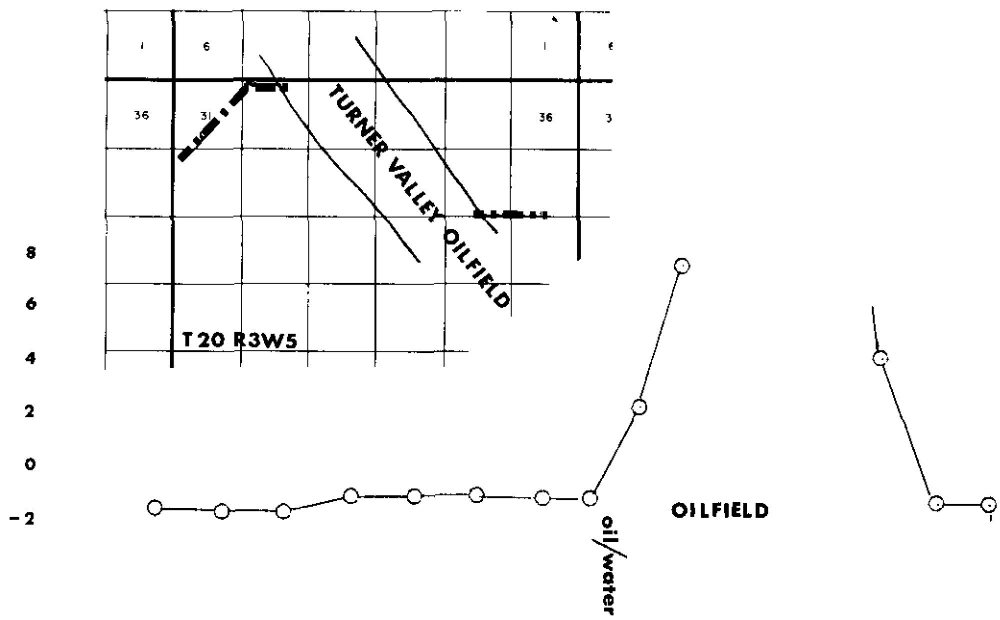
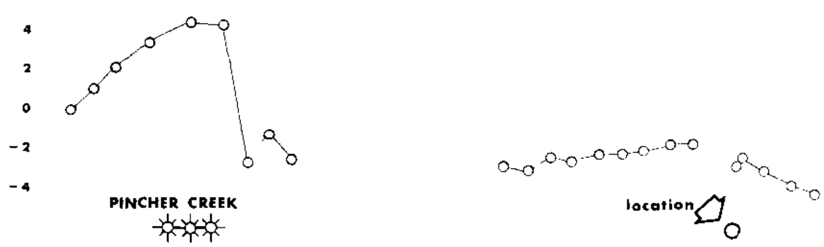


FIGURE 4



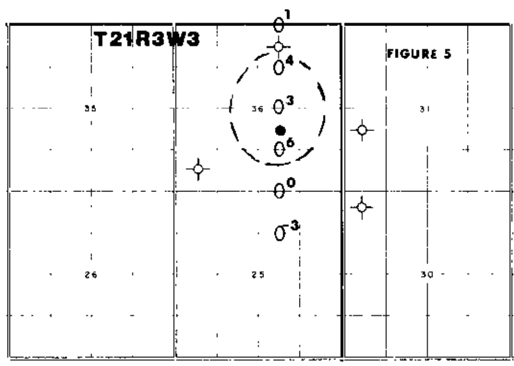


Figure 5 shows the situation around a well 7-36-3-21, W3M which produces oil from a thin Jurassic, Upper Shanavon sand in Saskatchewan. Several operators tried to extend the pool by outstepping from the producing well . Electraflex does not require dry holes to map the extent of the hydrocarbons and a short north-south line indicated the extent of the anomaly. The logic of this line is obvious. To have any commercial value the pool must extend southwards. To "calibrate" the Electraflex readings it is sufficient to record a line past a dry hole at 15-36-3-21 W3M into the oilwell at 7-36-21-3 W3M. This line should show the edge of the accumulation. If it does, it will show the other edge. The map shows that indeed, both edges of the accumulation were clearly seen and that the pool is small and would be uneconomic.

ELECTRAFLEX: POSITIVE LOCATION CHECK

Geological information may indicate the advisability of drilling at a certain location. It is sound practice to check the proposed location with an Electraflex station to insure that the geological conditions forecast have not undergone a drastic change, as could easily happen in the case of the Midale porosity, the objective in the next example.

A short line was first recorded off the known accumulation to obtain the background values. These are shown on Figure 6 with actual field readings being presented. A station was obtained on the producing well 11-27-8-11 W2M to serve as a model. Another station was then recorded on the location of the intended well 15-27-8-11 W2M. Since this was anomalous, the well was drilled. It was completed as a producer.

DELINEATION OF STRATIGRAPHIC TRAPS WITH ELECTRAFLEX

It is safe to state that the majority of stratigraphic traps now producing have been discovered by chance. The point is emphasized by any map of practically any stratigraphic field: it is delineated by marginal wells and dry holes. This demonstrates that the conventional methods are costly for determining pool limits.

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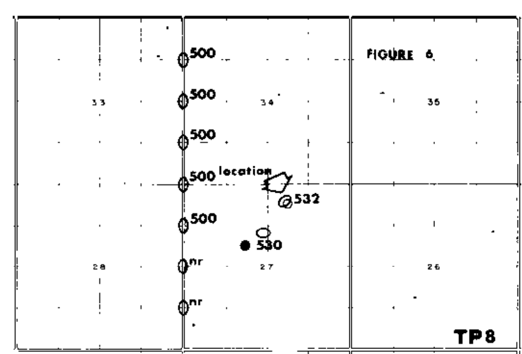

Figure 7 shows one typical instance of the application of Electraflex to the delineation of a stratigraphic trap. The key well has a gas section in the Nordegg and the Pekisko. The trap is an erosional outlier capped by Cretaceous sediments. A number of dry holes drilled prior to the Electraflex survey attest to the inability of the conventional methods to deal with this type of problem. Electraflex mapped the precise outline of the outlier except to the southeast, where a large lake did not allow access. The well which followed the survey drilled at the recommended 10-18-58-6 W5M location was completed in the Nordegg.

COMBINATION OF ELECTRAFLEX AND SEISMIC

Electraflex and seismic combine to form a very powerful tool in the prospection for hydrocarbons. This applies both to the conventional seismic and to the modern off shoots such as "bright spot." The first side-by-side "bright spot" and Electraflex surveys are now under way with Electra-

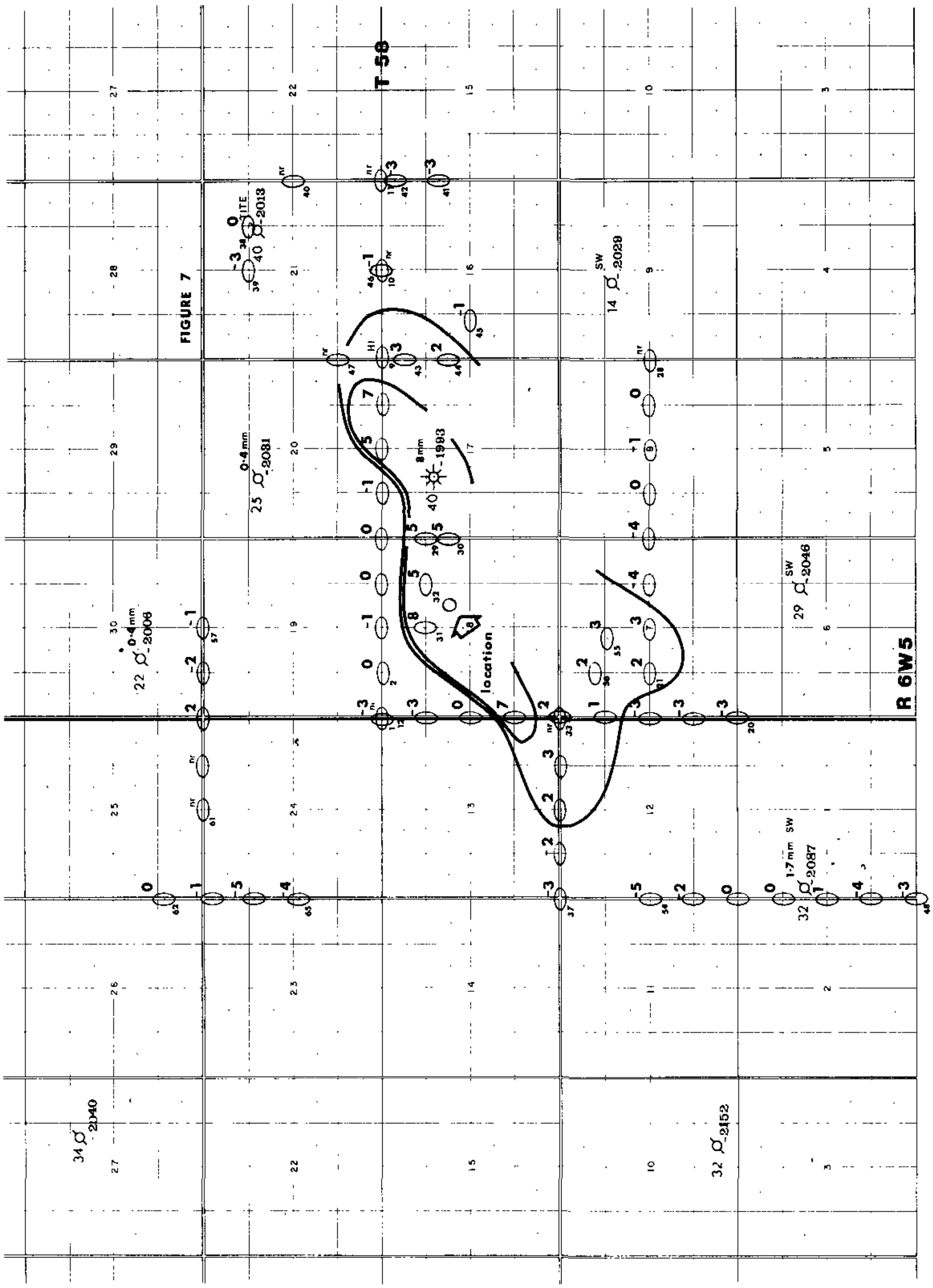
FIGURE 7
T 58
R 6W5
location

flex providing positive hydrocarbon identification for the "bright spot" anomalies and the "bright spot" providing, in turn, positive depth identification for the Electraflex anomalies.

The conventional seismic method provides *information about the structure of the* strata in the subsurface and says nothing about hydrocarbon content. Electraflex provides information about the distribution of the hydrocarbons in the subsurface and says nothing about the structure of the reservoirs which contain them. Obviously, the combination of both lines of evidence is a great step towards finding commercial accumulations of hydrocarbons with great probability of success.

Reefs and other structures by seismic can be proven to be hydrocarbon - bearing and, by the same token can be distinguished from anhydrite "plugs" by the combination of both these methods.

LIMITATIONS OF ELECTRAFLEX

Fundamentally, the limitations of this method of prospecting for hydrocarbons stem from the fact that it maps reliably two parameters and gives some indication of the third of the four parameters desirable in the pursuit of hydrocarbons. Thus, the width and length of the deposit are mapped as accurately as the circumstances require by reducing the spacing between *consecutive stations. At this time,* only a semi-quantitative indication of the thickness of the reservoir is available and only a suggestion of the depth of the accumulation is provided by the readings of Electraflex, in the cases where the deposit is very shallow and where it is extremely deep.

In Alberta, the evidence from about 50,000 wells and countless mile of seismic has identified most of the relevant models. Thus, the shape of the anomalies mapped by *Electraflex is, in most cases, sufficient* to identify the hydrocarbon bearing reservoir. Thus, elongated anomalies several miles long and one mile or so across with a distinctive trend, would clearly represent marine Cretaceous bars. The channels are portrayed as such and also are related to specific horizons from information available in every geologist's files. Pinnacle reefs have a distinctive shape and are confined to the D-3, and can easily be confirmed by seismic. Extensions of known fields are obvious, since the Electraflex survey starts on the known accumulation which provides an automatic model. Outliers are easily identified by their characteristic shape even in the absence of any other line of evidence.

In the final analysis Electraflex is just another geophysical tool that maps hydrocarbon accumulations in the subsurface. As such, it has to be integrated with all the other techniques available to the Industrry in its search for economically viable hydrocarbon deposits. Failure to use the available evidence will often result in outright failure since the extent of the accumulation is not the only relevant factor in successful exploration.

For instance, in a marine environment, thick sand bodies are restricted to the vicinity of the shore line. Mapping anomalies ten miles seaward from a stable strand line is futile since the reservoirs will be thin, silty and shaly and non-economical. In pinnacle reef country, a small anomaly may represent a reef but could also represent a small accumulation in the overlying sequence; unless a model is available in the neighborhood there will be no way of deciding which case applies on the basis of Electraflex alone, however, a critically situated seismic line will solve the problem. Drilling on the edges of Electraflex anomalies will creat disappointment if the reservoirs which give rise to such anomalies are sands or erosional outliers which pinch out at their edges and only offer a small reser*voir thickness at such locations.*

Another limitation of the Electraflex approach is the number of hydrocarbon bearing horizons present in the section. Usually, the results are clear with even three super*imposed reservoirs which all can be identi*fied provided adequate controls are available. Should more reservoirs be present in the section, they merge to constitute a "cummulative" anomaly which cannot be resolved by this method alone, as only the edges can be usefully mapped.

INTERFERENCE

There are several conditions which may interfere with the recording of Electraflex data in the field but their influence is local. Pipelines, power lines and grounded fences fall into this category. The influences of these bodies is greatest when they lie parallel to the Electraflex dipoles and minimum or nil when they are perpendicular. In almost every case, moving away from the disturbing body a hundred yards or so removes the interference; the exception being extremely high voltage overhead power lines which require more clearance.

Cased wells, whether they contain surface pipe only or the long string as well, never constitute an interference as they simply are "invisible" to the method. This comes from the fact that casings lie perpendicular to the field created by the Electraflex signal and that their effect is nil. This is the reason that Electraflex "models" can be run, without fear, over fields already drilled.

Telluric currents constitute an interference which is routinely dealt with. Prior to the recording of any Electraflex station, the telluric currents are balanced out, and the measurements are concluded before any appreciable drift of the telluric currents could take place. An exception occurs when extreme solar storms occur; then the telluric currents undergo violent and rapid changes on a time scale comparable with the recording of the Electraflex measurements; in such cases no work can be done. But such extremes are a very infrequent occurrence and our records show such conditions only once in three years (autumn 1972).

REPEATABILITY AND REPRODUCIBILITY

The repeatability and reproducibility of Electraflex readings have been tested a number of time by re-recording at the same stations. The experiments were, of course, conducted under "blind" conditions. It was found that the repeatability followed a Gaussian curve, the normal expectation for instrumental errors and that 75% of the deviations of successive measurements were three units or less. This roughly translates into the instrumental error amounting in most cases to 0.5% to 10% of the anomalies sought for or, in other words ,a signal to noise ratio of between 10:1 and 200:1 at individual stations. This means that the instrumental errors can be neglected altogether and are never a factor in the interpretation of the results.

Specific experiments have also been conducted on the effect of a long period of time elapsing between successive readings over the same location with the objective of detecting the influence of longer term climatic conditions on the measurements. It was reported that there was a small drift between both the surveys, or a change of "base-line" and this was interpreted to be caused by changes in the conductivity of the soil.

POTENTIAL APPLICATIONS OF ELECTRAFLEX IN NORTH AMERICA

It is otiose to speculate on what would have been the history of petroleum exploration, had the Industry recognized the potential of electrical transients when the method was first put forward. It is not too late today. The "obvious" prospects for the conventional methods have been drilled and this activity has resulted in a wealth of information in the form of geological and geophysical data. Thousands of leads are contained in this information and Electraflex is a most appropriate method to evaluate their validity. The dramatic decline in the success of the conventional methods of prospecting clearly shows that their limits of application have been reached and that the leads must be supplemented by additional lines of evidence. What is required, now, is not additional ransacking or reprocessing of already ransacked and processed information, but a radically new line of evidence to supplement it.

For instance, thousands of wells have encountered hydrocarbons in stratigraphic traps, the extent of which is not known and which have been abandoned after a few unsuccessful extension attempts. Electraflex can map the area covered by such traps and not only provide new wells but, by proving additional reserves, help bring into production the shut-in potential of already discovered hydrocarbons. Electraflex can evaluate seismic anomalies and direct the operators to those which should be drilled and those which should be forgotten. The reallocation of exploration dollars towards the features with real potential rather than to those which will "obviously" by dry should have a great impetus on exploration.

Electraflex also puts into the reach of prospectors such objectives as channel sands, which up to now have had to be discovered by chance and can only be extended with considerable risk, or subtle porosity traps, the extent of which cannot otherwise be predicted. Electraflex can also liberate millions of dollars now locked into paying rentals on land that will never yield production by evaluating its potential without recourse to the drill, a traditional dilemma.

ACKNOWLEDGEMENT

Electraflex wishes to thank the Petroleum Industry, represented by its various clients, for having given this empirical method the chance to prove its claims and also for having released for publication some of the results of the association. The readers will appreciate, in view of the extremely competitive aspect of the exploration field, that some of the most economically significant successes are not available for general release. Finally, Electraflex wishes to record its appreciation to the Canadian Society of Exploration Geophysicists for having opened its pages to the exposition of this thoroughly unconventional method.

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