GEOPHYSICAL REPORT

Direct oil prospecting uses electrical transient reflections

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NORTH American explorationists are adding another dimension to the search for new oil and gas reserves: electrical transients. They serve as direct hydrocarbon indicators supplementing seismic and gravity. This approach has become practical due to more-sensitive equipment and greater understanding of the theory associated with electron wave propagation.

Data from millions of miles of geophysical coverage and 900,000 wells are available in North America today, but the easy and obvious plays and most of the large fields have already been found.

This situation is not accidental. Ever since the realization that oil may be structurally trapped in the subsurface, explorationists have mounted an attack on potentially lucrative structures. Ground mapping gave way to air photography, gravimetry, and seismic, followed by drilling. Stratigraphic fields were discovered, often by chance, and some large fields were discovered by random drilling. The clearest leads have been drilled and the largest fields discovered.

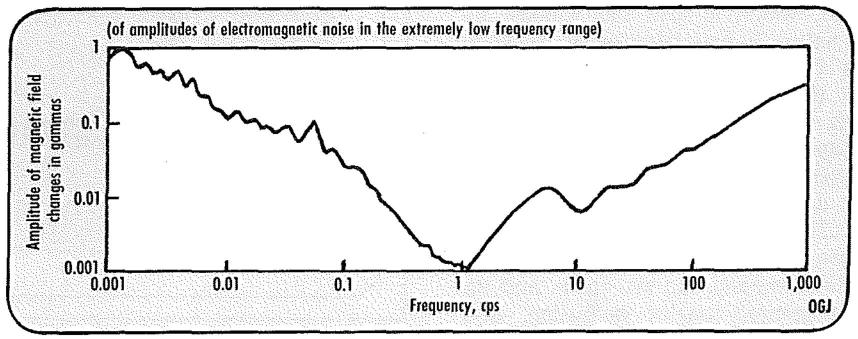
Electrical mapping. The principal geophysical tools of the explorationist have been gravity and seismic. Both look at the structure of the rocks in the subsurface and not the hydrocarbons.

Out of all wells in North America drilled to find the fairly modest objective of 1 million bbl of oil, only 1 in 60 is successful. The problem is that these tools look at the rocks which have some bearing on the occurrence of oil, but not at the hydrocarbons themselves.

There is a way to map hydrocarbons from the surface, as the following tabulation shows:

Fig. 1

Typical spectrum



Material	Resistivity, ohm/m/m[2]
Salt water	0.01
Fresh water	1
Shale	5
Sand	10
Carbonate	100
Coal	150
Anhydrite	200
Oil	300,000,000,000
Gas	Nearly infinite

The contrast of the order of a trillion to one between the resistivity of salt water and oil provides one answer to the explorationist's problem.

An electrical signal is generated from the surface and penetrates the sedimentary layers to a depth of several miles. This signal interacts with the hydrocarbon accumulations underneath and returns to the surface where it is unscrambled from the ambient electrical noise.

The transmitter is turned off to allow detection of the returns, a condition which dictates that the signal should be pulsed. The propagation of an electrical signal in the subsurface presents startling characteristics at first encounter.

According to one source on this subject:[1] "Application of electrical signals to geophysical prospecting invites investigation. This investigation has been carried out in detail starting from the general laws formulated by Maxwell. Certain revealing differences in behavior are at once evident. These are found in the absorptive and dispersive effect of the ground on the waves, and in the speed with which the waves travel in the ground.

"In the air, absorption is negligible. An electromagnetic wave, such as light, travels billions of wavelengths' distance without appreciable dimming by absorption. In the ground, low-frequency waves are almost completely absorbed in one wavelength distance of travel.

"In the air, dispersion is negligible; light of all wavelengths travels at the same speed. In the ground, dispersion is large. If the wavelength is doubled, the speed is cut in half. So it is somewhat meaningless to talk of speed of propagation unless the wavelength is specified.

"If investigation is confined to waves of appreciable wavelengths, say 10,000-20,000 ft, it will be found that the speed of propagation is surprisingly slow compared with 196,000 miles a second. It is, in fact, of the order of 40,000-20,000 fps."

Operation. This is how the system operates. The surface equipment sets up an electrical pulse which travels through the ground at velocities close to that of seismic waves. This electromagnetic wave (E) travels mainly through the groundwaters, the impedence of which (Z_1) is in the 0.1-0.01-ohm/m range.

If it encounters hydrocarbons with an impedance (Z_2) in the 300-billion-ohm/m range, part of the wave is reflected (E_r) towards the surface. Electromagnetic theory describes the phenomenon at the interface as:

$$E_r = (Z_2 - Z_1/Z_2 + Z_1)\,(E)$$

Most of the incident wave is reflected. This reflection is detected and measured at the surface. Fortunately the useful frequencies are in the 1-hz range, which is also the window in the naturally occurring noise. Without this coincidence it is conceivable that the method could never have been developed (Fig. 1).

Equipment. The method of using electrical transients to map hydrocarbon accumulations in the subsurface is used exclusively by Electraflex crews.

The company has six crews and an experimental marine operation, and although theory and solid-state electronics are necessarily involved, the method has been practically operational for a number of years. In the last 5 years in Canada, where most of the company's effort has been applied, 107 other companies have already used the system, 84% of them more than once.

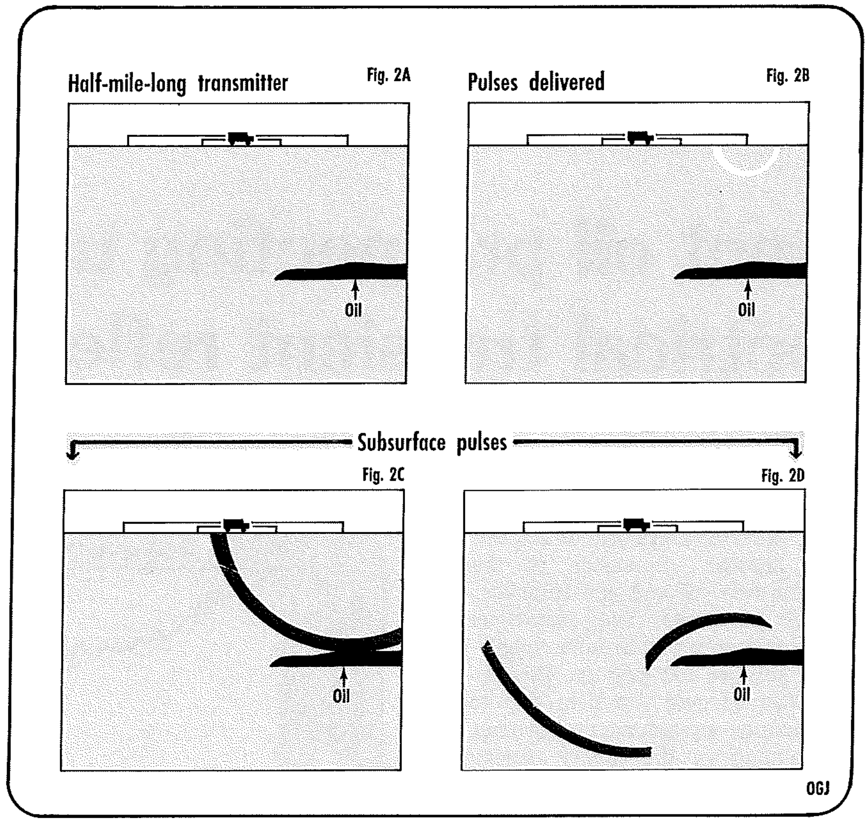
Fig. 2A shows the half-mile-long transmitter connected to a 4-kw electrical switch. The switch delivers a series of pulses to the ground; a commutator reverses the direction of successive pulses (Fig. 3).

The sudden discharge at the electrodes creates a pulse in the subsurface which expands in all directions, like the sonic pulse in seismic (Figs. 2A, B, C, and D). If a hydrocarbon accumulation occurs underneath, part of the wave is reflected and returns to the surface where it is detected through a 500-ft-long dipole.

The Electraflex measurement at a station reports the normalized amplitude of the signal returning to the surface. It expresses an absolute, dimensionless property of the station. Three different measurements are taken at every station, processed, and stacked into one single value by a computer. These are the Z-scores which are reported on the following illustrations:

Fig. 2

Transmitter, pulses



Low-frequency noise — a considerable amount of electrical noise occurs around dc or 0 frequency. For instance, the temperature at the electrodes is different and a thermocouple results. Invariably the electrodes are in different soils, with different ph and Eh, yet these potentials are unconnected with hydrocarbons.

The telluric currents are always present, but their distribution is irrelevant to the presence of hydrocarbons underneath. Unless solar flare activity is at a peak, the telluric currents are nearly dc. In the Electraflex approach, the dipoles are commutated, turning the dc into apparent ac and giving an easy means of balancing out the interfering potentials.

High-frequency noise — the 500-ft potential dipole is an antenna which picks up radio signals, radar signals, and 60-cycle power transmission. This pickup is quite large and masks the Electraflex returns in practically any place in North American unless it is filtered out. A typical "wide-open" recording of the potential dipole is shown on Fig. 4. The sophisticated electronic equipment used by Electraflex effectively filters out the high-frequency interference, and extracts the target reflection.

Returning signal — the signal which returns from the subsurface is weak and requires extremely sensitive detecting. The signal may have to travel several miles through a severely dispersive medium, turn around on the target hydrocarbon accumulations, and return to the surface.

Checking out the system. In practice, the working system is first checked out against models, under controlled conditions. The absence of hydrocarbons is the subject of the first test together with any influence of the casings which are left in dry holes. Theory predicts that well casings will not affect the Electraflex measurements since the casings hang perpendicularly to the wave front and their cross-sectional area is negligible.

Fig. 5 shows 6 miles of Electraflex line over ground proven barren by wells. There is little noise and no anomaly opposite the dry hole, which still has its surface casing.

The next test is run over hydrocarbons. Fig. 6 shows a section across the Cedar Valley "J" sand oil field. Only the discovery well had been drilled at the time of the survey.

The purpose was to map the extent of the discovery before development. This survey turned out to be

Fig. 3

Input signal

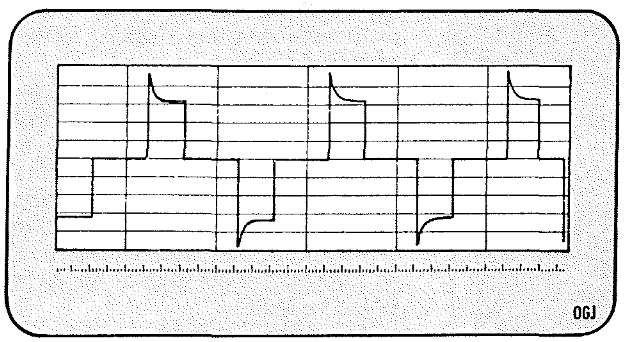


Fig. 4

"Wide-open" recording

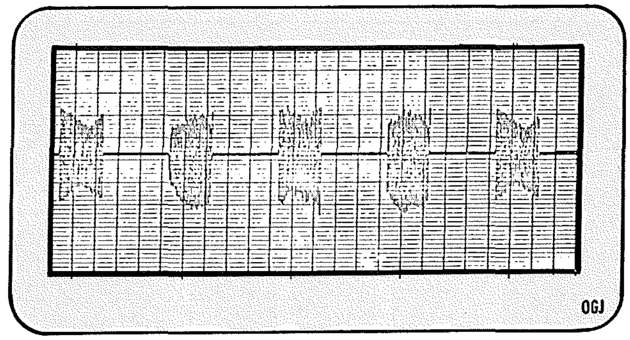
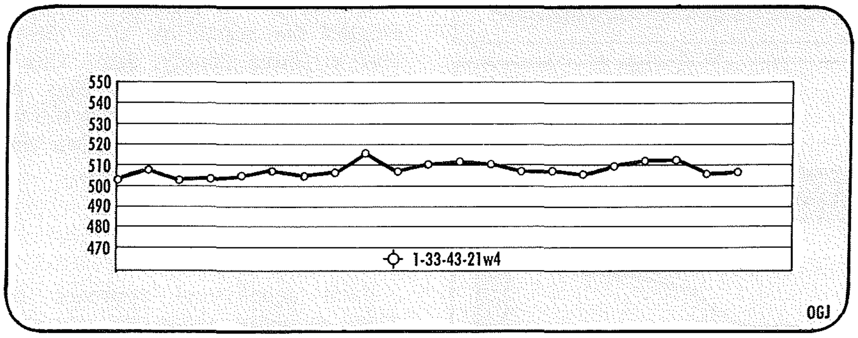


Fig. 5

Barren background and dry-hole check



a forecast successfully tested by drilling. The same vertical scale has been used as in the previous figure.

The section illustrates a very important characteristic of the system: the anomaly does not correspond to the structural attitude or the thickness of the sand. There is a good correlation with the thickness of the oil column, however.

The system can then be tested against control in oil and gas fields. Fig. 7-10 show four of 10 tests run by Tenneco with the oil company's own personnel operating the equipment. Traverses were run across edges of oil and gas fields at depths ranging from 2,000 to 9,000 ft. These experiments were uniformly successful in depicting the limits of the oil fields precisely.

The depth limit of the system is not established at this time. Fig. 11 is reprinted from the Bulletin of the South Texas Geological Society (Vol. II, No. 16) and shows a profile across the Fashing field, with the target Edwards lime at 10,790 ft. At that time the system noise was less than 5 units so it is clear that considerably deeper production could have been detected.

The deepest test is 16,000 ft in New Mexico, and it was successful. While it is clear that signals are attenuated with depth to target and that a practical limit exists with the present equipment, extrapolation of the information suggests that 20,000 ft should prove workable.

Finding oil

The proof of the system, however, lies in its ability to map production ahead of drilling. Following are three actual instances concerning a reef, an erosional outlier, and a channel sandstone.

Reef—Fig. 12A shows the drilling situation at the time of the survey. One oil well, flowing 700 b/d from a D-2 patch reef, had been completed and followed up with two dry holes; the first dry hole was an unlucky shot which just missed, the second well was cited on seismic evidence and was also dry.

The Electraflex survey is shown on Fig. 12B. The drilling followed the survey. The two oil wells were drilled on Electraflex evidence.

Erosional outlier — Fig. 13A shows the lone gas well which produces from Nordegg and Pekisko reservoirs, which occur directly superimposed in an erosional outlier. The total section is 40 ft, too small for the available seismic to pin down reliably; geology is of little help in predicting the shape of the outlier as demonstrated by the surrounding dry holes. Fig. 13B shows the Electraflex survey and the resulting gas well.

Shoestring sandstone — Fig. 14A shows the situation before the survey. The wells to the west produce from the Sunburst sandstone which dips to the north. The dry holes in that direction did not encounter the channel facies.

Fig. 14B gives the Electraflex survey which consists of a production check on the model well and on a dry hole. The successful well was drilled on the highest Electraflex station.

Condemnations. Since hydrocarbons in the subsurface give strong returns, the lack of such returns indicates the absence of hydrocarbon accumulations underneath.

A difficulty arises when hydrocarbon accumulations are present in the subsurface but are not of commercial interest. Such impregnations give reflections and provide a background which is different from the zero return which characterizes the truly barren areas.

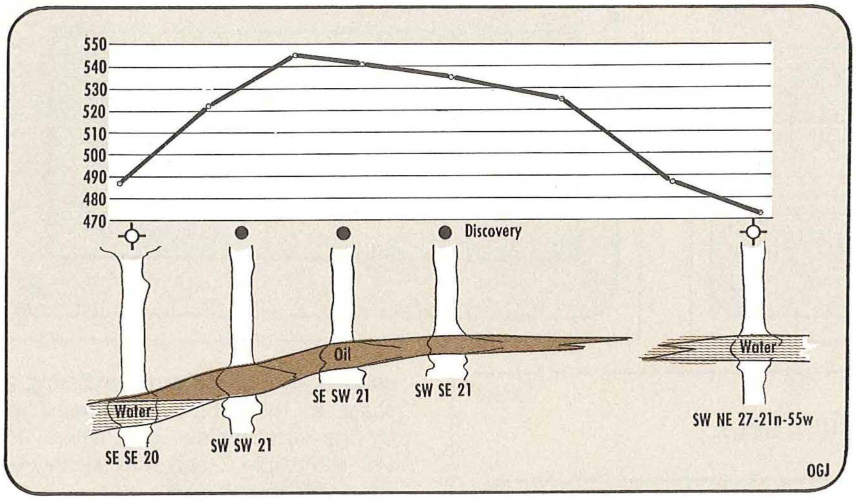
When regional impregnations are present, the accumulations which are the real targets of the Electraflex surveys stand out by virtue of the signals being additive. Absolute condemnations are no longer possible under such circumstances since what is not commercial at today's prices may prove worthwhile in the near future and the instruments have no means of discriminating.

In the history of Electraflex, there has been no producer drilled on a condemnation, although the sample counts many hundreds of wells. On investigating the very few apparent exceptions to this statement, it was found that the station had not been recorded on the location of the well, but some distance from it.

The other case concerns extremely narrow reservoirs, 300 ft or less, oriented at right angles to the di-

Fig. 6

Cedar Valley field



Figs. 7 - 10

Tenneco tests

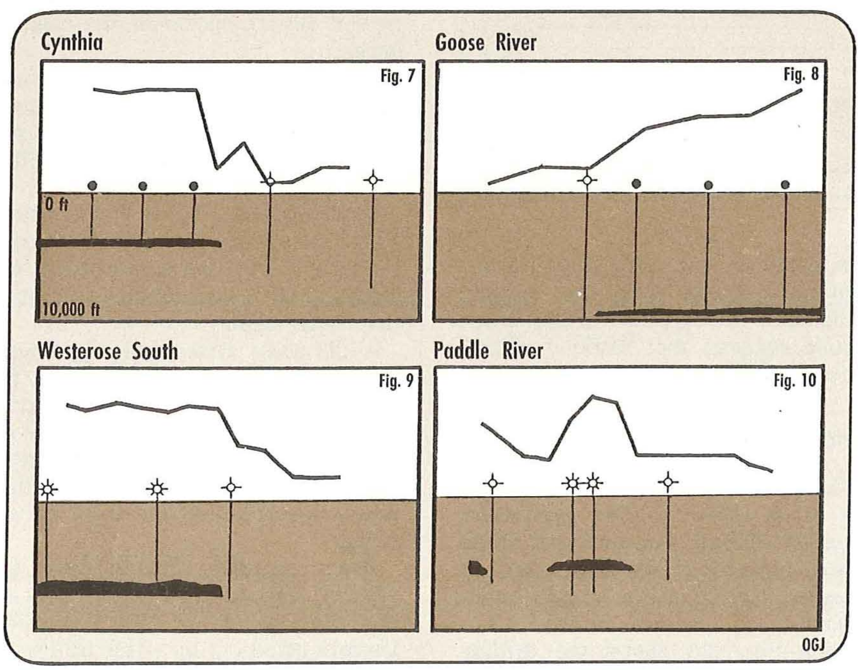
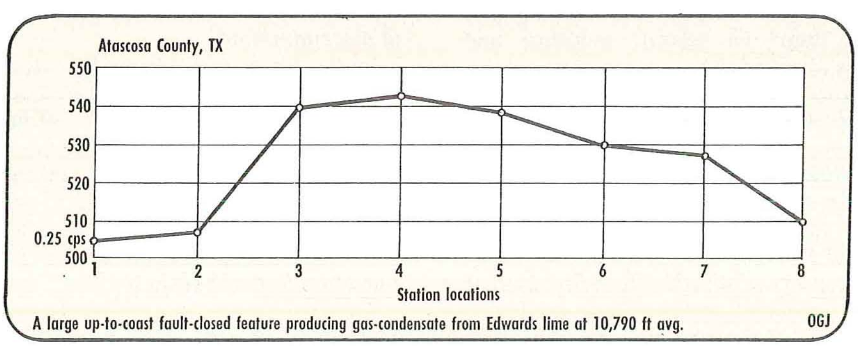


Fig. 11

Fashing-field profile



A large up-to-coast fault-closed feature producing gas-condensate from Edwards lime at 10,790 ft avg.

poles: their contribution may be so small as to make if difficult to tell them from the background. On checking with the dipoles parallel to the reservoirs, they were clearly detected on each occasion.

Structure — Pincher Creek is an 11,000-ft-deep thrusted structure in the foothills of Alberta. Seismic had indicated a similar structure in front of Pincher Creek. Over and above uncertainties with the testimony of seismic in this particular instance, there was, as always, the question of the content of the structure.

The survey started on the known field to obtain the model and then proceeded to the location intended for drilling. Figs. 15A and B show the survey and the resulting condemnation. The well was drilled and was dry.

Reef play — A geological study indicated the possibility of a Canyon reef in Garza County, Tex. This is shown by the contours on Figs. 16A and B. A line was run across the feature which condemned it. Two wells drilled subsequently were dry.

Combination of geophysical tools

Each geophysical approach provides evidence about the subsurface from its own perspective. Clearly a combination of the geophysical approaches should compound benefits from each. Some examples of the combination of the various lines of evidence follow.

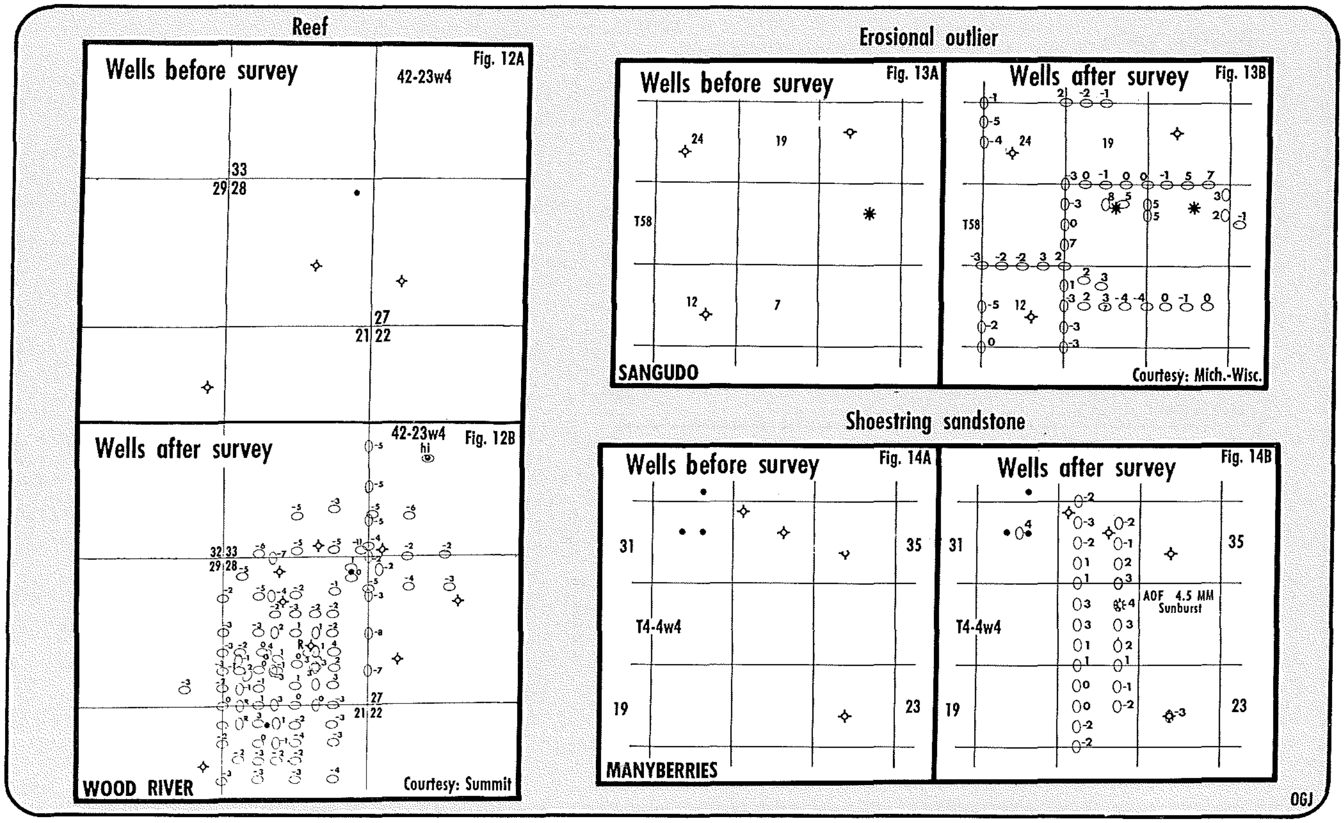
Electraflex and gravimetry. Gravimetry has an advantage over many other geophysical approaches in that the securing of data is easy and can be accomplished almost anywhere. It is sometimes ambiguous and may, in the case of pinnacle reefs, confuse them with near-surface features.

It cannot tell which reefs are "salted out" or "wet." Fig. 17 shows an Electraflex profile over a gravity profile run across a reef. Electraflex confirms the reef and shows the hydrocarbons inside.

Electraflex and well logs. Well logs are often difficult to interpret accurately in new areas. This difficulty results in the testing of many unproductive zones. This is not serious. The real catastrophe unfolds when downhole equipment does not show any promise, no tests are run, and a discovery is missed.

In such instances, the knowledge that the well is sited on an Electraflex anomaly provides the analyst with information that significant hydrocarbon accumulations are present, and leads him to introduce this evidence in his interpretation.

Reef, erosional outlier, shoestring sandstone



Structure, reef play

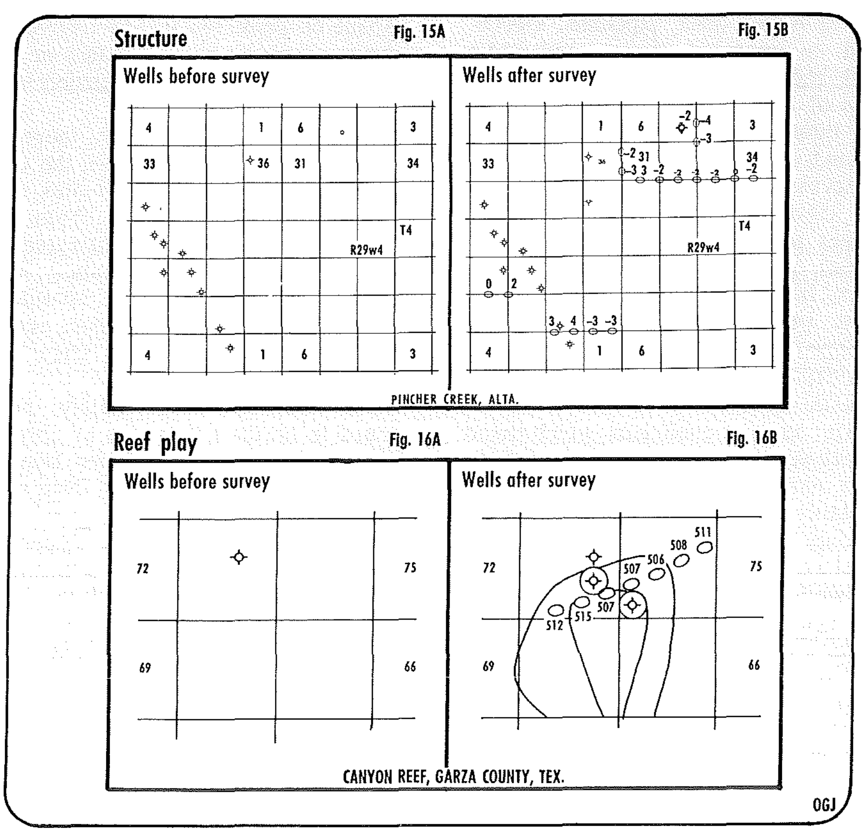


Fig. 18 shows the section of a well drilled specifically to test an Electraflex anomaly. The 11-10 well objective was a deep reef. When it was clear from the well tops that the high reef could not be present, the well was abandoned short of the Cooking Lake platform. This left the possibility that a hydrocarbon-bearing reef toe could still be present at the location of the well.

With this in mind, a further well was drilled a quarter mile away—14-10. No reef was present, but then the log analyst had to face the task of explaining the strong Electraflex anomaly.

The Glauconitic sand section (Fig. 16) calculates SW = 100% and Ro = 0.7 ohm. This does not warrant testing the sand. In this case, the knowledge that a strong Electraflex anomaly existed at the location of the well leads the analyst to the correct line of reasoning.

The Glauconitic bears oil, gas, or salt water in Alberta, not fresh water. The logs showed fresh water nevertheless: it must have been drilling water, having invaded a very porous, gas-bearing sand.

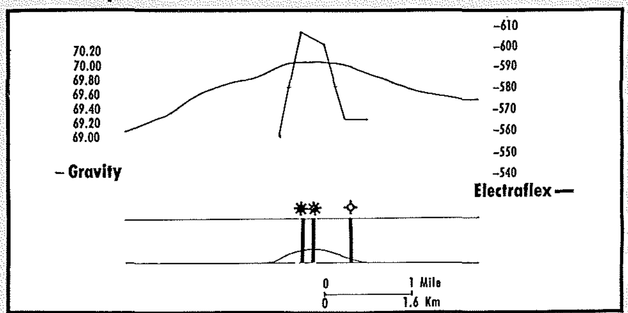
This was confirmed by a test which recovered first 2,200 ft of fresh water and then gas and condensate. Now it

Combination of geophysical approaches

Figs. 17 - 19

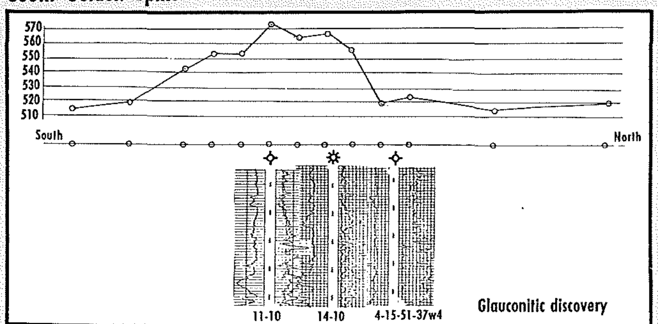
Electraflex profile

Fig. 17



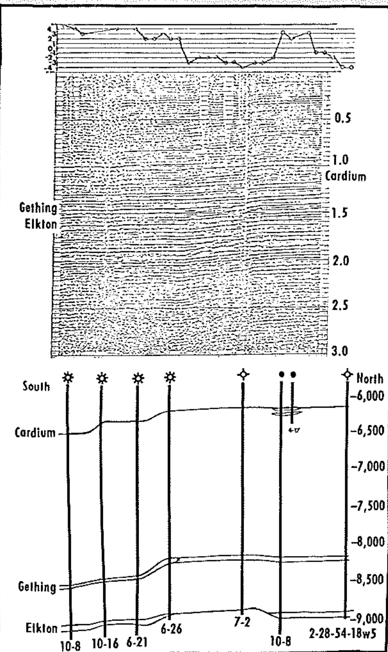
South Golden Spike

Fig. 18



Edson profile

Fig. 19



OGJ

is clear that the original well 11-10 also suffers from water invasion and has, in fact, gas and condensate as well.

Electraflex and seismic. Seismic provides information about structure, which Electraflex does not do. Electraflex provides information about hydrocarbons which land seismic, in most cases, is unable to do. The combination of both gives the explorationist an extremely useful tool to conduct his search for reserves.

In this context, Electraflex is used as the hydrocarbon indicator and is physically superimposed on the seismic information. Fig. 19 shows the superimposition of Electraflex, seismic, and geological evidence. This figure is reprinted by courtesy of Caravel Exploration which ran true amplitude seismic sections over seven gas fields in Alberta to assess the possibility of obtaining "bright spots" from such targets, side-by-side with Electraflex.

Limitations of electrical transients

All physical tools have limitations. The limitations met by Electraflex fall into two categories: the survey cannot be carried out or the survey fails to give the desired results.

Failure to carry out the survey can be generally traced to close proximity to power lines, pipelines, electrified or grounded fences, and radio and radar stations. A new generation of instruments with more-powerful filtering capabilities is planned to remedy this situation.

Access can prevent doing the work. To circumvent this, the Electraflex crews are using four-wheel-drive vehicles, all-terrain vehicles, marsh buggies, tracked vehicles, and helicopters. Portable crews have been developed and development is being carried out on water-borne surveys in coastal waters.

The surface conditions which would preclude the recording of a survey are related to excessive surface resistance which prevents sufficient energy to be transmitted to the subsurface. Such conditions are evidenced by frozen ground; thus, winter operations require drilling through it for a few feet.

Exceedingly clean and dry rocks high above the water table create difficulties. Adverse surface conditions are encountered less than 1% of the time and are not considered a serious factor.

Anomalies do not always yield producing wells for a number of reasons which are detailed here.

Thin pay. The thickness of the pay cannot be predicted to any degree of accuracy from the sole basis of an Electraflex survey unless models are available.

In a particular reservoir, there is a general correlation between the values of the Electraflex anomalies and the reservoir section as is shown on Fig. 20. In the instance illustrated in Fig. 20, the Electraflex anomaly was indeed drilled at the most favorable location—on the highest station, and a respectable distance away from the edges of the anomaly.

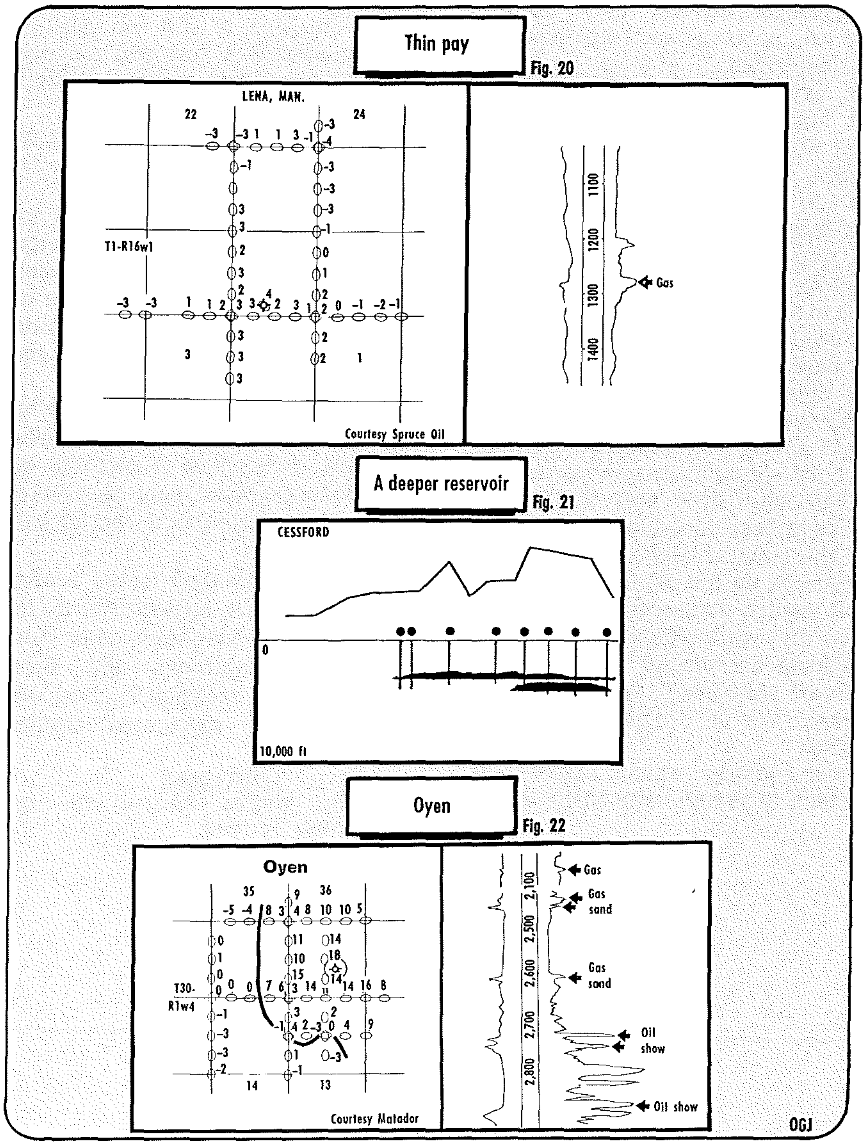
The reservoir, unfortunately, happened to be the Greenhorn or Second Specks in a development too thin to be of commercial interest. The well was abandoned.

Superimposed thin pays. Superimposed hydrocarbon-bearing reservoirs give signals which are additive. This property allows a deeper reservoir to be mapped through a blanket deposit overhead. Fig. 21 shows how a deeper reservoir (the basal quartz) is mapped through the shallow basal Colorado sand. In this case, both reservoirs are of commercial interest.

It may happen, however, that although reservoirs are present and

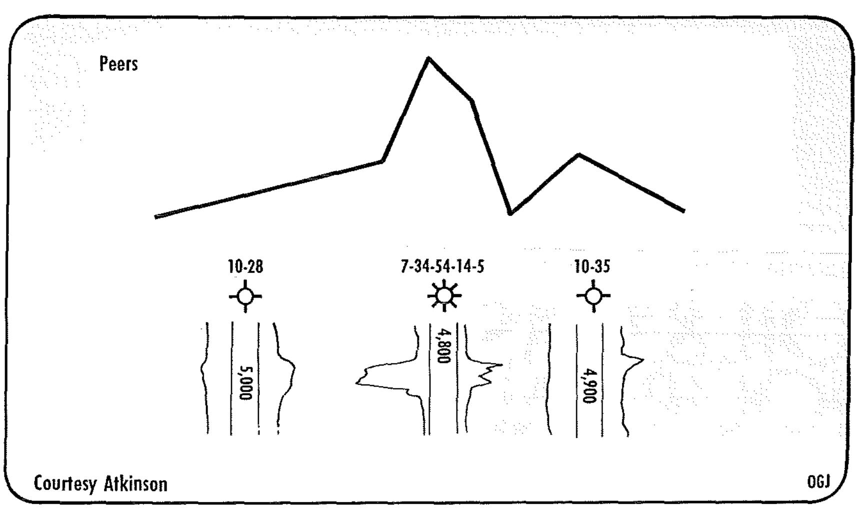
Noncommercial anomalies

Figs. 20 - 22



Solving a riddle

Fig. 23



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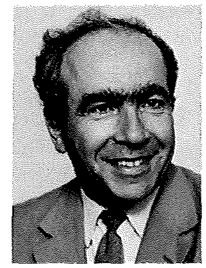

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represent superimposed zones, they are unable to hold sufficient reserves or produce at sufficient rates to merit further interest. (Fig. 22). The well was situated at the center of the anomaly but none of the seven oil and gas reservoirs proved capable of commercial production.

A reservoir too thin to be commercial, and thin pays substituting for a thicker target section are the main sources of disappointment with the results of a survey. Other factors militating against commercial production and which cannot be identified by this method are heavy oil, for which there may be no market, viscous oil which will not flow at reservoir temperatures, sour gas distant from existing treatment facilities, excessive amounts of CO_2 or nitrogen in the gas, high water saturations in the reservoir which give a significant cut, or low permeability despite satisfactory porosity.

Electraflex does not mislead about the existence of such factors, simply it fails to provide information about them.

Applications

Electraflex surveys have been used in conjunction with other tools on a number of engineering problems. For instance, reservoir-pressure decline curves have indicated that a stratigraphic trap which was being produced was more extensive than indicated by the drilling evidence available. Subsequently, the additional lobe of the reservoir was mapped by Electraflex.

A survey was carried out on a gas-storage reservoir when it was realized that the reservoir was leaking. The survey established that the sands used to store the gas were connected to the main field, 2 miles away, from where the gas was being produced.

For waterflooding operations, engineers need the exact shape of the reservoir to design the most-efficient sweep pattern. This was critical in the particular instance of bar sandstones, where Electraflex was employed.

General uses. Electraflex can only provide one equation in the search for petroleum reserves: a return from the hydrocarbons underneath. This is not the only equation that needs be solved to obtain success in exploration, but it is an essential element of better success. Mapping oil and gas directly, independently from structure, gives the explorationist a new and very powerful tool for his work.

Fig. 23 shows one instance where Electraflex was used to help solve a geological riddle. The geologist interpreted the two wells as having missed a Cardium gravel bar to both the land and sea sides. Four miles separate both control wells. The bar is about ½ mile across. Should it be drilled? Where?

The bar may not exist, it may be closer to one well than to the other. The Electraflex section confirmed the existence of the bar and pinpointed its position. The pay section measured 41 ft, and initial production of the discovery well was 10 MMcfd.

This instance is typical of the combination of two lines of evidence which complement each other. Seismic may depict a pinnacle reef, but the question remains, is it infilled with salt or is it water-bearing? In the same manner, gravity, geochemistry, or photogeology may provide a lead, and Electraflex can be used to check its validity, and if affirmative, detail it.

In the case of subsurface geology, it is found that even if the existence of a trap is indicated by available information, the controls are usually far enough away, perhaps a mile or so, that the precise position of the postulated trap cannot be established. The Electraflex survey not only can verify the hypothesis of an accumulation of hydrocarbons but can also pinpoint the optimum location for a test.

Other specialized uses of the survey have been to evaluate the potential of a tract of land, before bidding, or tying it up for cash or a commitment, on the philosophy that mineral rights are worth nothing or a fortune depending on whether there are any minerals underneath. A farmout or a prospect can be evaluated in such a manner.

Land holdings which require the payment of rentals may make a substantial dent in an explorationst's budget. Often the original idea which prompted the acquisition has been modified or somewhat downgraded by new evidence. This follows a situation where the land is still too good to give up without a test and too poor to merit immediate drilling. Electraflex can make the difference.

Further developments. The first experiments at sea have indicated that the method is workable offshore.

Full scale experiments are now being conducted offshore with a marine cable. The solid-state instruments used for land work will have to be redesigned to permit recording information from a vessel in continuous motion.

This experimental work is expected to yield new equipment and understanding, from which a depth to the targets underground may be extracted by methods similar to that of seismic.

It is also envisaged that a scaling up of operations consecutive to the tool opening up vast reserves of stratigraphic hydrocarbons will bring about different techniques of recording to satisfy specialized requirements.

Reference

1. Lewis, William Bradley, The Oil Weekly, Aug. 13, 1945.

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