New method helps to refine subsurface interpretations

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20-second summary

A recently developed electrotelluric surveying unit has proven successful in providing additional structural and lithologic information from any depth down to 40,000 ft. Surveying is done from the surface. A geologist with several years' experience with the tool discusses its proper applications and use. He is impressed by the amount of subsurface detail this tool can provide, better enabling an explorationist to eliminate or proceed with a project before drilling funds are spent.

RECENT ADVANCES in the application of plasma physics to resource exploration have resulted in the development of a passive geophysical instrument capable of determining various electrical properties of lithologies to depths of 40,000 ft, when used by a geologist trained to use the instrument and knowledgeable about the local geology. The surveying instrument is portable and can collect data at the Earth's surface from a selected range of depths. This technique requires no concurrent drilling and causes no environmental damage. Its ability to focus on a specific depth interval helps to eliminate the time and cost associated with drilling to a target lithology to obtain similar data. This is the author's opinion, as a geologist with no ties to the company that markets this tool, other than having the tool available without cost for some personal R&D projects. He further believes that this technology could initiate a new era in subsurface exploration because of its ability to aid a geologist in validating or eliminating prospects prior to drilling. Following is a brief explanation of the basics of the technique, a list of those criteria that the author believes are critical to the proper application of this new technology, and a discussion of what one can expect from the tool.

THE TECHNIQUE

The subsurface surveying technique discussed herein is based on known electrotelluric principles. The electrical field that is detected and recorded by the surveying instrument is generated by the interaction of solar radiation with the Earth's ionosphere. This plasma envelope causes electromagnetic pulses to pass into the Earth, and travel downward until they reach a change in conductivity caused by a change in lithological composition, porosity or mineral content. At that contact, a new electromagnetic pulse is generated that radiates to the surface, where it is detected by the survey unit. The frequency of the reradiated current is a function of the depth of the originating subsurface plane. The survey unit can be calibrated for this frequency and depth; hence, it can gather data from any other selected depth. The instrument then relays the characteristics of the detected current to the survey unit's operator (herein out called the surveyor), converting it to an audio signal. This is because the ear is the most sensitive recorder available.

TECHNIQUE'S CAPABILITIES

This electrotelluric surveying technique has been used successfully in numerous hydrocarbon exploration and production applications. In addition, it has proven effective in searching for coal, water, geothermal and hard mineral resources. It also may be employed for near-surface engineering, environmental and archaeological applications.

These electrotelluric surveys assist in identifying geological structures and lithologies, and, under ideal conditions, will detect the presence of oil and gas. Small-scale structures, structural displacements and lateral/vertical variations in lithologies can be defined. Collected data can be used for stratigraphic correlation, porosity geometries and, to some degree, reserve estimation. Geologic and isopach maps, three-dimensional stick diagrams, cross sections and other graphical analyses can be developed from the collected data.

THE INSTRUMENT

The surveying equipment developed to apply the previously discussed electrotelluric techniques is self-contained and is carried and operated by an individual geologist. Major components of the instrument include a power system, an electrical sensor, frequency filtration equipment for depth control, and an audio system for data collection. The survey units have various detection sensitivities and ranges that are tailored to specific applications and conditions, including shallow offshore exploration. The survey tool is provided exclusively by Geophysics International of Dallas, Texas, and is called the Petro-Sonde. It is battery operated and must be charged each night.

THE SURVEY

Each electrotelluric survey is carefully designed to meet specific project objectives. For example, the number and distribution of survey stations may be different for each exploration problem. Most surveys begin with calibration of the instrument for "true depth," using known lithologic or electric log data and topographic data. The surveyor scans through a range of frequencies calibrated for depth, listening for changes in the signal, which indicate the crossing of a resistivity boundary, or conductivity interface. Responses are classified as very low, low, medium or high. These are related to the relative resistivity contrasts. The data are logged on a Pro/Log graph, which is scaled to any available electric logs. Pro/Log graphs are similar, but not identical, to conventional downhole logs (Fig. 1).

Additional information regarding the fluid content of a formation, such as water, oil and gas, also is interpreted from associated signals. The content is not a quantitative analysis, but rather a potential indicator of the presence or absence of hydrocarbons and/or water. The reservoir fluid affects a formation's resistivity to some degree. The content signal can help in delineating the geometry of a hydrocarbon reservoir.

A major advantage of this type of survey is the capability to analyze selected depth intervals of interest. Logging speed ranges from 90 to 400 ft/hr, depending upon the complexity of the geologic column and the resolution desired. Data are

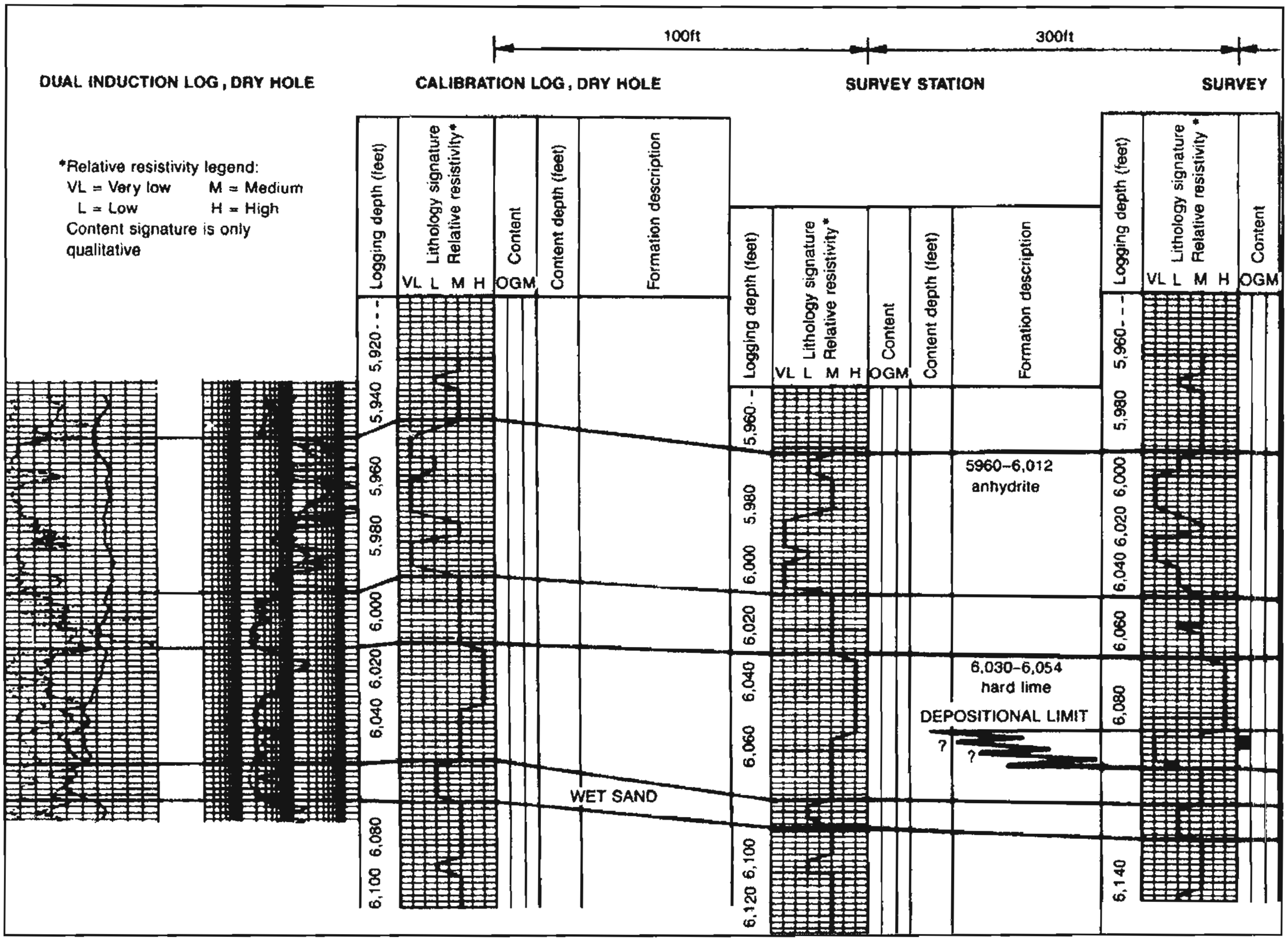


Fig. 1-Electrotelluric logs resulting from a Petro-Sonde survey are presented in Pro/Log form, which is obviously similar to, but less refined than, conventional downhole logs. The operating company's field geologist should designate the electrotelluric survey stations based on his/her knowledge of the local geology, such that ties to local wells can be made. Electric logs from the control wells are helpful in assuring accurate calibration of an electrotelluric survey.

This example shows the delineation of a lenticular reservoir in East Texas. Specifically, a cross section between a Rodessa channel sand dry hole and a Rodessa producer is illustrated. The electrotelluric logs indicate that the dry hole was drilled about 300 ft beyond the depositional limit of the pay sand.

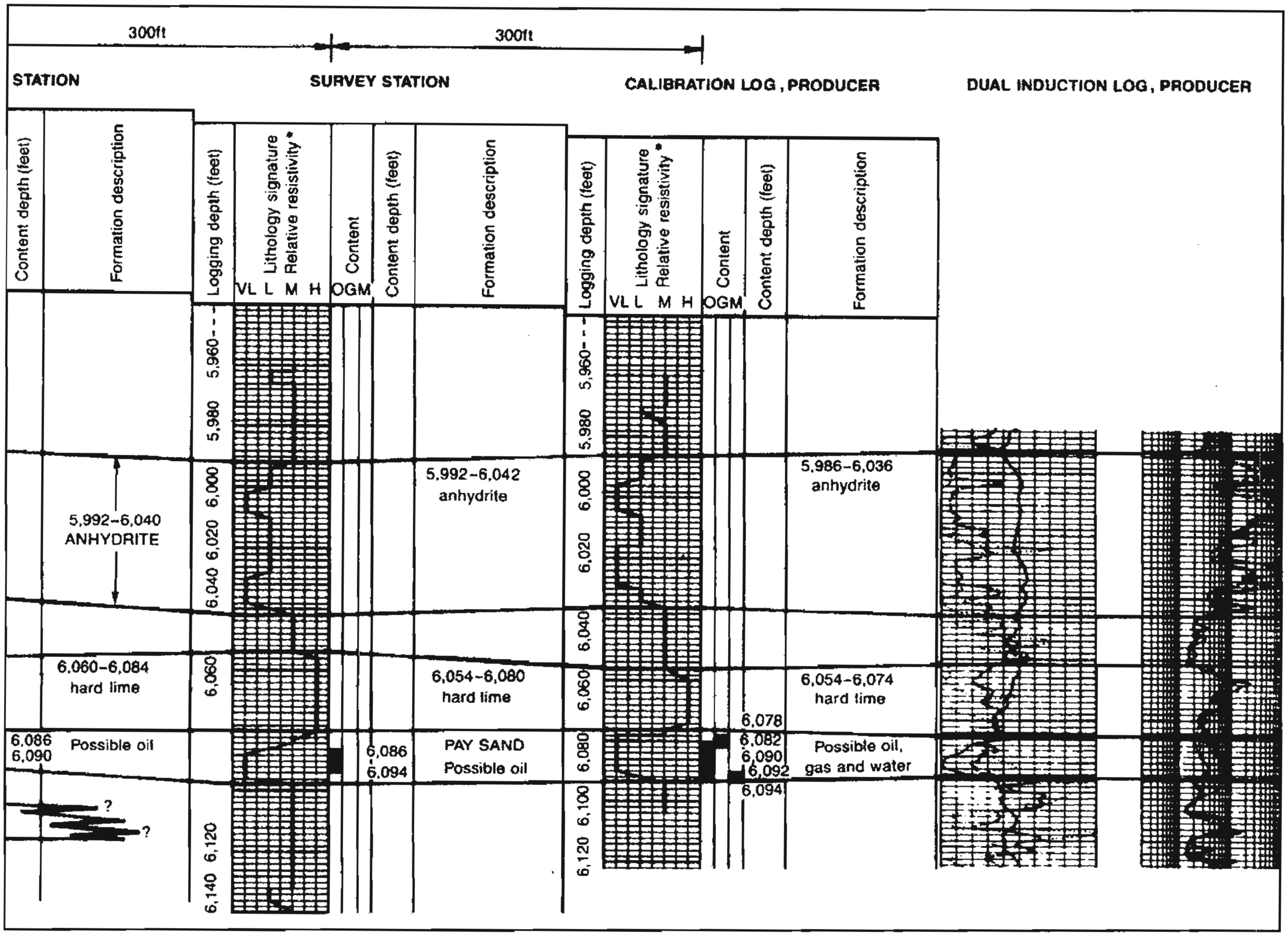
generated and available in the field, allowing for adjustments in exploration strategy as the survey progresses. Each station survey results in the equivalent of a rough resistivity and porosity log.

EFFECTIVE SURVEYS

Direct experience with this electrotelluric survey method during the past few years has shown that its successful use is as dependent on the field geologist as it is on the person operating the survey equipment, the surveyor. A well-planned survey that incorporates the knowledge of both parties will produce a more meaningful subsurface picture. The following are suggested approaches that have been found to improve the hydrocarbon-finding success of this surveying technique.

Provide adequate background data for calibration. Correlation errors can be avoided in several ways. The primary method of avoiding these errors is calibration of the instrument at key wells, using available electric logs and specific lithologic data. Providing this information in the beginning to the surveyor is *critical* for accurate data interpretation. This is emphasized because, as with other new technologies, company geologists frequently try to test the accuracy of this method by limiting the data provided at the start of a survey. It is important to recognize that careful calibration of the electrotelluric surveying instrument will ensure better data later on.

Surveyors are not electric log experts and cannot recognize lithologies from an electric log with any degree of expertise. Therefore, to allow the surveyor to refine the oil signal for a given pay zone, be certain that data are provided with regard to reservoir properties. For example, if the reservoir



has a known gas-oil contact and an oil-water contact, providing this information at the time of calibration will assist the operator in determining if these resistivity changes can be recognized. If they cannot, the client will be so informed. Also, it is advisable to have oil readings checked at several nearby producing wells, if the information regarding reservoir fluids is critical to the prospect.

The electrotelluric tools and methodology discussed herein are frequently modified as a result of ongoing research. At the present stage of development, the surveyors are working at the limit of the known capabilities of the tool; hence, the quality of data produced improves with the amount of data provided by the accompanying geologist. Where accurate and useful data are desired, it is advisable to work closely with the surveyor. An adversarial position, in which the surveyor is challenged to produce results while pertinent data are being withheld, will not optimize the quality of data collected and will minimize the cost-effectiveness of the survey.

Monitor Instrument calibration and data quality. Depth to various mapping horizons can be picked quite accurately with this electrotelluric surveying method. However, if the data are miscorrelated, any hydrocarbon readings are meaningless. The company field geologist should keep in mind that correlations are made with a relatively crude "resistivity" log that, while simple in format, differs in detail from conventional resistivity logs. Hence, geologists need to familiarize themselves with the interpretation and correlation of the type of log generated by this survey, called a Pro/Log (Fig. 1).

In making most effective use of this surveying method, the field geologist should check the accuracy of the resulting readings in every way possible. The best way to check the calibration is to continually tie to producing wells in the area, without providing the electric logs from those wells to the surveyor until the electrotelluric logging is completed.

Maximize survey effectiveness. When initially testing this type of electrotelluric surveying, it is recommended that it *not* be tried in areas of rapid facies or structural changes. While the instrument is capable of defining these variations, this type of surveying should be conducted only after the field geologist has become quite familiar with the strengths and weaknesses of the tool. Mixed or variable lithologies such as replacement chert in dolomite or limestone can cause problems for the surveyor and will result in miscorrelations.

A geological setting with uniform stratigraphy is the best learning location. Isopach intervals can then be checked, and corroborating readings up and down the hole can be obtained at each station. In areas with unpredictable stratigraphic and structural variations, it can be difficult to know if the instrument is delivering good, valid data. Consequently, the electrotelluric interpretation should be compared with any previous subsurface interpretation. For example, in reef environment exploration the electrotelluric survey should begin far enough above the reef to allow construction of isopach and contour maps for the overlying strata. The data should indicate drape over the reef.

There are many ways to check the effectiveness of the instrument, most of which require improvisation on the part of the field geologist in response to the requirements of the geologic environment. In no case is it recommended that a geologist other than the one who worked up the prospect initially accompany the surveyor into the field. If management then wishes to check the original electrotelluric interpretation, a different field geologist can be used after the critical resistivity parameters of the prospect are known. Don't try to resolve all unknowns at the same time!

In effect, every reading is equivalent to drilling a well at a specific location, to a targeted depth interval, in a rapid and cost-effective manner. It is very exciting for a geologist to have the ability to "drill and log" 10 or 15 wells per day at a nominal cost. The author has found that the fine detail provided by this survey technique usually produces more detailed geologic maps and sections than can be constructed using well data alone. With conventional methods of subsurface evaluation, even on 40-acre spacing, there are usually not enough data on which to draw truly accurate subsurface contours and isopach maps.

Evaluate the prospect's geological parameters. When the surveyor is satisfied that the distinctive audio signals for an area have been identified through calibration, the field geologist should start out by locating stations fairly close to a calibration well (within roughly 300 ft) in a pattern that will allow evaluation of the geological parameters of the prospect (Fig. 1). The surveyor should *not* see the contour and isopach maps. Rather, the field geologist should plot the data in the field to determine whether the survey unit is verifying existing geological interpretation. This check is critical in effective use of the tool. In most instances, if a prospect is well conceived, analysis of the survey data will result in generation of cross sections and maps that will be more detailed than the subsurface interpretation. If a prospect is based on erroneous premises, the electrotelluric survey will often indicate the inaccuracy of the geological interpretation early in the survey. This provides the field geologist with an opportunity to terminate the survey (if no prospect is found to exist), or to restructure the survey to collect data for use in reformulation of the initial hypothesis.

Understand instrument limitations. It is important to recognize that there is a human element involved in the recording of electro telluric data, and that there is potential for the most experienced surveyor to make mistakes. When a reading is inconsistent or appears wrong, the geologist should alter the planned program to determine the cause of the discrepancy. This requires taking intermediate readings until the problem is resolved. The problem may be caused by variations in solar intensity, which seldom lasts long but does result in weakened or misinterpreted signals. Occasionally, the surveyor will draw a blank. This can happen when readings are taken over a fault, or when atmospheric conditions result in a sharply reduced signal. Distant lightning can severely alter a survey. However, the surveyor should be able to distinguish a geological problem from an atmospheric problem by moving on to a new station.

If a fault is encountered, and the displacement is fairly well known, the field geologist can assist the surveyor by defining an appropriate search interval. This will often enable the surveyor to measure the actual fault displacement. When these data are not available, the search will be less productive and will produce data with a lower degree of reliability.

It is recommended that a second surveyor validate any prospect generated from an electrotelluric survey. This is particularly important when dealing with complex prospects, or where the original survey results differ substantially from a field geologist's original premise. The resurvey should verify the original survey. If the two do not agree, a third field check should be made. The cost of repeating a survey is insignificant when compared with the cost of drilling a dry hole. Even more important, one would not want to eliminate a valid subsurface prospect, which can happen if the electrotelluric tool is not working properly.

Interpret the data correctly. Main emphasis should be placed on lithological breaks and the relative conductivity changes detected by the surveying *tool-not* on the detection of hydrocarbon content signals. However, if the surveyor can determine the extent of a reservoir by crossing back and forth across the oil-water contact, it can lend credence to Pro/Log correlations.

A good electrotelluric prospect should show closure, and should justify drilling without relying too heavily on hydrocarbon readings. Oil readings alone, obtained in the absence of substantiating subsurface geologic data, should be ignored unless the economics of the prospect justify a high-risk wildcatting operation. While this surveying technique does provide data on relative porosity, it provides no information pertaining to permeability, and some organic-rich shales have been mistaken for oil and gas zones.

CONCLUSION

When properly used, as a supplement to drilling and other technologies, this electrotelluric surveying method provides fast, accurate and cost-effective data concerning subsurface conditions. It is a good compliment to seismic as it is not velocity dependent and provides a new, independent variable. Use of this innovative technology could mark the beginning of a new era of exploration and production in the author's opinion, especially in this time of depressed product prices. This technology should permit a much larger percentage of exploration budgets to be spent on checking geology, with a resultant reduction in the cost of drilling dry exploratory holes, since it enables the recovery of subsurface data previously available only by drilling a well. While good exploration geologists will continue to be needed to locate the prospects to be checked, this technique will allow a geologist to more accurately validate or eliminate prospects prior to drilling, which is more cost effective. It might even save a geologist's job.

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