ELECTRICAL LOGGING OF OIL WELLS

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In recent years the part science has played in the oil industry can best be realized by those who have been fortunate enough to have had a first hand view of them. From the "boom" days of the cable tool, the reckless fever to reach oil sand at any cost, and wide open production, has come, in vigorous contrast, the modern rotary rig with its thoroughly organized drilling and production program.

In the fields of geological and petroleum engineering careful studies of each and every formation traversed by the hole, analysis of structure and fluid content, and correlation with surrounding wells has replaced the careless "high-pressure" drilling methods of the past. Today's methods demand the working out of the subsurface of oil fields with as much care and exactness as in the engineering of a complicated machine. The knowledge gained in these studies has not only greatly improved the total oil recovery of wells but has facilitated in the location and drilling of "wildcat" wells for the discovery of new fields.

The problems brought about by the steadily increasing depth of wells have turned petroleum engineers and geologists wholeheartedly toward every available means of gaining knowledge of the subsurface. Mechanical coring of formations, the long reliable method by which small samples of cores are drilled and brought to the surface for analysis, was no longer infallible. In addition its cost, caused by extreme slowness of drilling, became excessively high when used for complete holes from the surface to the oil producing horizons. The advent of electrical open-hole logging provided just the information so ardently desired. By means of this device, a continuous log of the complete hole is obtained from which all of the data necessary for correlation as well as interpretation of formations is recorded with only one to three hours of time occupying the well. So vital has this service become to all well operators that, in a few short years, electrical logging has grown into an industry whose services are performed on over 95% of all oil wells drilled in the United States.

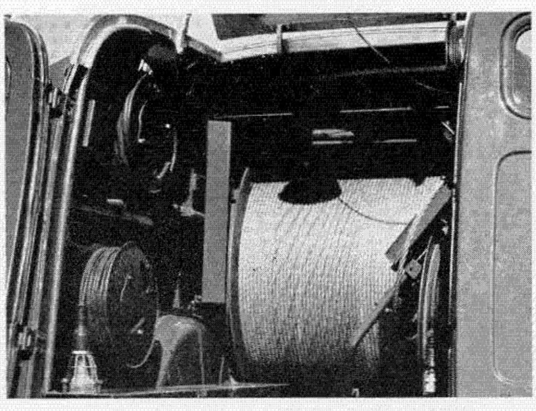

Fig. 1—Hoist truck equipped with 12,000 feet of five conductor cable.

EARLY HISTORY

Even prior to the year 1900 electrical measurements were being investigated as a means of locating conductive minerals or ore bodies lying under the surface of the earth. All such methods were based upon the changes of voltage or current at the earth's surface caused by, and thus indicating, the resistance of different subsurface formations to the passage of electrical current. Oil, having a relatively high electrical resistance, immediately became the object of many surface investigations which were only partially successful because of the depths involved.

It was not until the "twenties" that Conrad and Marcel Schlumberger conceived the idea of running electrical resistance methods in a bore-hole. By passing current from an insulated electrode out into the formation surrounding a bore-hole and picking up the impressed voltage on other suitably spaced electrodes, they were able to read the resistance of the fluid contained in these formations. Early trials were very discouraging from a practical viewpoint. But little by little it was found that false readings caused by measuring formation resistance close to the bore-hole were caused by drilling mud infiltration into the permeable formations. Measurements further back from the bore-hole were developed and comparisons of the shallow and deep values of resistance proved that formations might be closely identified by their electrical characteristics. By the use of these two curves in combination, not only could all sands and dense formations be distinguished from shales, but interpretations could be made to differentiate between the sand formations themselves. For the first time the electrical log could be used to differentiate between the oil sands, and the salt water sands usually associated with them.

NATURAL POTENTIAL

Along with the earliest developments in bore-hole resistance measurements came the discovery of a natural potential or voltage existing in the bore-hole opposite permeable formations such as sands. Immediate investigation into the cause of this voltage proved that it was the result of two phenomena. The first and foremost was that of electro-chemical or battery action between the bore-hole fluid and the natural fluid in the formations. The second cause proved to the result of the bore-hole fluid infiltrating into the permeable formation. Thus the Natural Potential Curve was found to be a valuable indication of the formation fluid content and, to some degree, its relative permeability. The modern electrical log is a compilation of two or more resistance or resistivity curves of different depth of formation pentration and the Natural Potential Curve. A

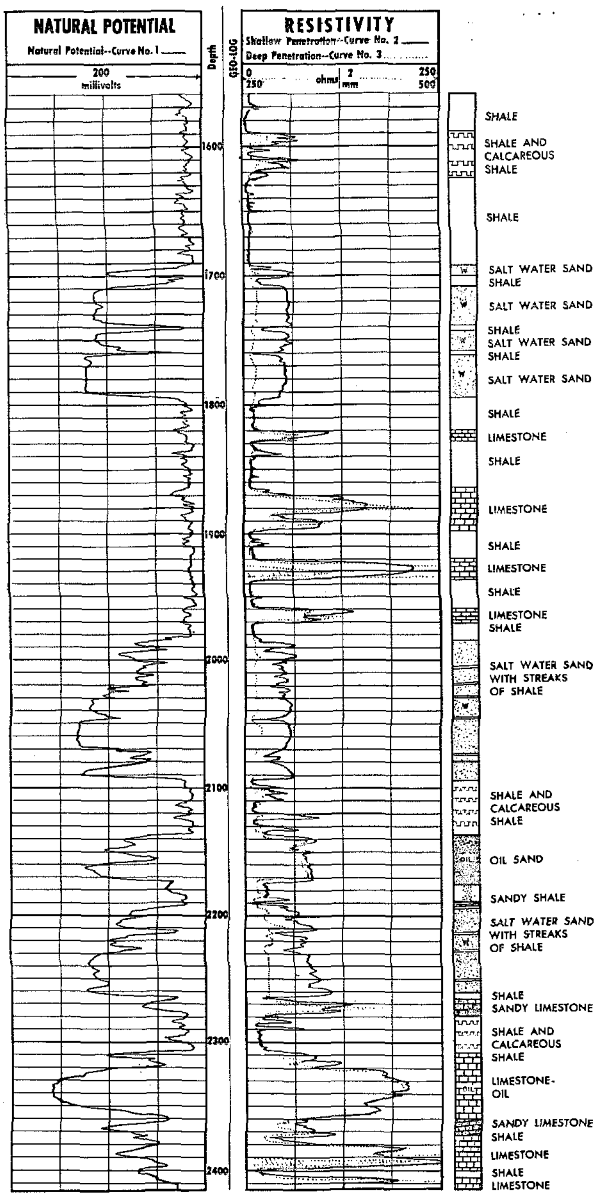

Fig. 2—Typical electrical log showing characteristic formation responses and method of presentation.

typical example, showing the electrical response of many of the most comomn formations and the manner of presentation is illustrated in Figure 2.

MANY USES

The uses of the electrical log are many. From it the geologist or petroleum engineer can determine the exact depth and thickness of all formations. From the depth, thickness, and the characteristic response of key formations correlations may be made to adjacent wells, faults located, and the general structure of whole oil fields worked out. Such extensive studies, now commonplace in all oil fields, have proved invaluable in the spacing of wells and determining drilling and production programs. From the response of all curves in combination, accurate interpretations of the nature of the fluid in the sands are made. The exact extent of the oil producing zones and the location of the undesirable salt water sands can be determined allowing the water to be cleanly shut out of the producing well. Other less important uses include the accurate location of lost or broken tools, lost strings of casing, and checking of the bottom of the casing set in the hole. The electrical log has not entirely replaced the older and more costly mechanical coring methods. It has, however, completely supplanted the older method for the long stretches above the oil horizons, and is carefully studied in comparison with the cores from producing horizons. In proven fields it often entirely replaces mechanical coring. Numerous instances could be recited wherein new producing zones, missed oil sands, or unexpected oil sands have been picked up by means of the electrical log often resulting in the discovery of new fields.

DESIGN PROBLEMS

The design and operation of the mechanical and electrical equipment necessary to carry on extensive electrical logging operations has presented many problems. Advanced drilling practices have resulted in greater average as well as extreme well depths. In 1939 the unheard of depth of 15,004 feet was attained and 12,000 to 13,000 foot wells are, at present, not at all uncommon. The development of electrical logging cables to withstand the high fluid pressures and temperatures encountered at such depths has required years of experimentation and involved great expense.*

To accommodate the higher recording speeds, as well as to eliminate the "human errors" involved in the extensively used but older hand-traced recording methods, all modern equipment utilizes photographic recording. The photo-recorder, illustrated in Figure 3, is a sensitive device which records as many as three curves continuously by means of mirror galvanometers reflecting beams of light on special photographic film. Simultaneously with galvanometer traces the ten-foot depth lines, depth numbers, and vertical scale lines are automatically exposed on the film, the operator having before him a visual screen continuously indicating all operations. Convenient controls on the photo-recorder govern all lamp intensities and allow for the selecting between any of three depth scales, one of which is a detail or "blown-up" scale used for increased accuracy over vital parts of the bore-hole. The films from these recorders, ranging in length from six inches to twenty feet, are developed on the job and become the master logs from which any desired number of prints are made. For added convenience a special portable printer allows a field print to be made and left with the company field personnel.

* Pressures greater than 6,000 pounds per square inch and temperatures in excess of 320°F. have been recorded at extreme depths. At present cables having as many as five insulated conductors and breaking strengths of 17,000 pounds are being used commercially. In addition to good electrical properties such cables must be designed to provide acurate depth measurements. Depth accuracies to within a foot are demanded for most oil horizons necessitating the careful study of cable behavior under operating loads. To this end the cable tension as well as the cable speed are continuously indicating during runs. The recent improvement in cables and cable performance studies have increased running speed *from fifty feet per minute to upwards of 200 feet per* minute, materially reducing the time necessary to record a complete log.

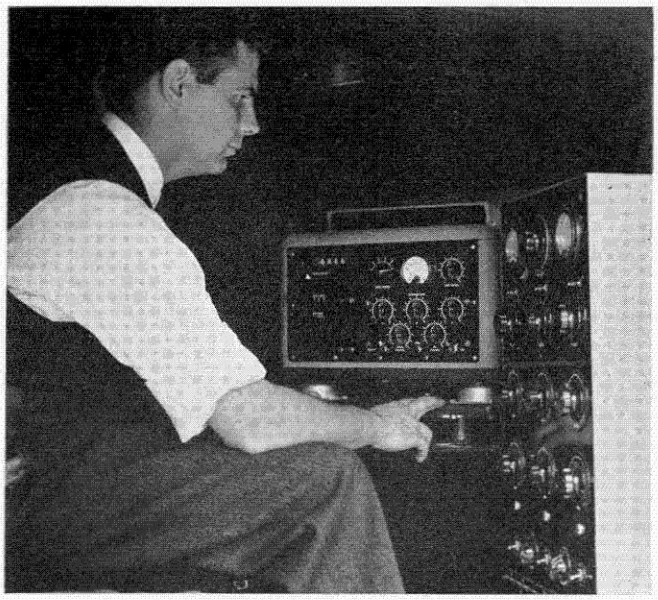

Fig. 3—Photo-recorder which continuously transfers the electrical responses onto a permanent photographic film.

CARRIED IN TRUCKS

The apparatus is carried in two trucks. A heavy duty hoist unit contains up to 15,000 feet of logging cable, electrode assembly, additional electrode weights, and associated apparatus. The main electrical power supply, consisting of a 1,000 watt gasoline driven generator is also on this unit. Power from this unit supplies the lighting loads as well as the Selsyn or self-synchronizing motors by which the cable measuring sheave wheel drives the measuring odometers and the photo-recorder. When operating two multi-conductor cables connect the instrument truck with this hoist unit. The instrument truck carries all of the electrical control apparatus including the control panel, photo-recorder, recording power supply, and is convertible into a complete photographic darkroom.

The adaptation for field use of laboratory equipment capable of measuring accurately sensitivities to fractions of a millivolt has required careful design. Electrical logging apparatus is subjected to the very worst atmospheric temperature and humidity variations, being in daily use from the extremes of Canada to the swamps of the Gulf Coast region. The maintaining of overall sensitivity standards varying by only a very few percent, requires frequent check tests utilizing special test apparatus. To this end each field office has become a self-sufficient laboratory in itself. As a result the logs obtained from well to well and from area to area are entirely comparable and contain only the variations present within the well bores themselves.

RECENT EXPERIMENTS

Interesting variations from routine electrical logging are continually arising. Recent experimental drlling with oil base mud to eliminate drilling mud invastion of oil sands, has necessitated the design of special electrodes capable of continuously contacting the formations to allow the electrical current to enter the strata in spite of the highly non-conductive oil within the bore-hole. High angle drilling, developed to allow closer surface spacing of wells, often produces holes with a deflection from the vertical of over 45°. The added friction to the passage of electrodes down such a hole often cannot be overcome by just adding weight and a practice has been devveloped by which a special small electrode is run inside of the drill pipe, the latter being raised to just above the portion of the hole to be logged. This type of logging is finding increasing use, also, in the deeper wells where excessive caving, bridging, etc., of the hole are present.

Personnel for field operations are carefully chosen. Recording operators must not only be entirely familiar with the intricacies of their apparatus, but must have a substantial knowledge of the geology of the region in which they work. Thorough studies of the methods used in electrical logging have only recently been instituted by many oil companies. Accordingly the burden of analysis and interpretation has often fallen on the individual logging operators and district field personnel.

FUTURE BRIGHT

The future of electrical logging looks as bright as its past. Studies of the effects of logging under varying fluid pressures and depths of penetration have opened the possibilities of predicting total and daily well production. The quest for methods to successfully accomplish logging through casings continues. Recently commercial methods have been made available which show promise in this direction. There appears to be no end to the possibilities of adapting science to the oil well. Thanks to the ever increasing cooperation between the outstanding oil companies and the independent service companies on whose shoulders falls a large portion of the burden of research and development electrical logging will continue to offer new benefits to the industry.