LESSON

A HOME STUDY COURSE ISSSUED BY
PETROLEUM EXTENSION SERVICE
THE UNIVERSITY OF TEXAS AT AUSTIN

3

WELL SERVICING

WELL LOGGING METHODS

AESC

AND WORKOVER

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PETEX™ WELL SERVICING AND WORKOVER PUBLICATIONS

A Primer of Oilwell Service, Workover, and Completion

Well Servicing and Workover Series

- Lesson 1: *Introduction to Oilwell Service and Workover*
- Lesson 2: *Petroleum Geology and Reservoirs*
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Introduction

Sixty years ago, when people needed to know whether a well had struck oil in commercial quantities, the testing procedures they used were fairly unsophisticated. They simply drilled ahead until a show of oil appeared; then they pulled the drill stem and bit out of the hole and took a core sample. If the core indicated that the formation might yield commercial amounts of oil, operators usually ordered a drill stem test, or DST. In those days, a DST was not much more than a special pressure container, or bomb, made up on or near the bottom of the drill stem. Lowered to the depth of the formation to be tested, the bomb was opened to catch samples of formation fluid and then brought back to the surface for analysis.

By examining the samples, operators could readily determine whether oil had been encountered. The drawback, however, was that they could not tell how much oil might be present. Put scientifically, early DSTs were qualitative, but not quantitative. So, back then, if a DST sample showed oil, the operator usually set casing and completed the well. Unfortunately, no one could tell exactly how productive the zone was until the well actually began producing. Today, a well does not have to be completed to get an indication of how productive it will be, because modern drill stem tests yield qualitative *and* quantitative information.

In addition to core analysis and drill stem testing, today's operator can choose many types of well logs for evaluating potentially productive formations. A *well log* is a record of information, or data, about formations the wellbore penetrates. The term "log," however, can also refer to the tool used in obtaining the data. Thus, a log can be either the familiar long sheet of accordion-folded paper with several curves printed on it, or it can be the logging assembly that is run to obtain the curves.

Well logs can be broadly divided into mechanical and wireline. *Mechanical logs* include drilling-time logs, mud logs, and cuttings-sample logs. These last are usually printed on a mud log. Whereas wireline logs are available that use mechanical pads, arms, or springs that physically contact the borehole wall, the only type called a mechanical log is one obtained at the surface with sensors and other devices. Mechanical-log sensors detect and record such data as rate of penetration (ROP), type of rocks being drilled, and shows of oil or gas. Wireline logs are made by running special tools into and out of the hole on wireline. Wireline is wire rope with insulated wires beneath strands of cable. Wireline not only powers the logging tools and conducts data to the surface as the log is being run, but also provides a way to lower and raise the logging tools in the hole. Usually, the measurements are obtained as the logging tool, or *sonde*, is pulled out of the wellbore.

Mechanical Logging and Core Analysis

One common mechanical log is a drilling-time log. It is primarily employed for noting changes in formations as a well is drilled (fig. 1). Formation changes, when used with information obtained from other logs, can help in evaluating the well. More detailed and complete than a drilling-time log is a *mud log*, which is a mechanical log that includes a graph of the drilling rate, the sequence in which the formations were encountered, notations of oil or gas shows in the mud, and an indication of the amount of gas in the mud (fig. 2). The included cuttings-sample log reveals oil and gas shows in the drilled cuttings and an indication of the total gas in the cuttings.

While core analysis is not mechanical logging, if cores are taken as part of the well testing process, they are examined in a laboratory, and the results are included with the logs. In the laboratory, permeability, porosity, residual oil or gas, and water saturation of the core samples can be determined. Figure 3 shows a core analysis for a conventional core. Note that 20 to 52 percent water content is reported from 7,213 to 7,215 feet (ft), even though oil is predicted. This water is connate, or interstitial. (*Connate water* is water that was with the formation when it was originally laid down.) The figures listed in column *K* are values of *permeability*. The higher the *K* number, or the higher the permeability, the more easily a fluid can flow through the interconnected pores of a productive formation. The figures in the column headed by the Greek letter phi (ø) are percentages that show formation *porosity*—the amount of void space in the rocks—in relation to the total volume. It is in a rock's void spaces that connate water and oil and gas exist.

surveys, determine hole angle, direction, and formation dip, using mechanical and electrical measurements.

Wireline logging tools are designed for running either in open hole or in cased hole. In open-hole logging, data are obtained from subsurface formations before casing is set in the drilled hole. Electric, acoustic, nuclear, and borehole-contact logs, such as caliper logs, may be run. Further, open-hole logging can be done while the well is being drilled with measurement-while-drilling (MWD) or logging-while-drilling (LWD) techniques. MWD is the acquisition of downhole information during the drilling process. Just as radio waves send sound information through the atmosphere, waves, or pulses, in the drilling mud can send downhole information to the surface. Special MWD or LWD tools in the drill stem create small pulses that travel through the mud to the surface, where a computer picks up the data transmitted on the pulses. The computer translates the data to infor-mation that can be used to determine such downhole factors as hole angle, hole drift, formation resistivity, and formation porosity. Open-hole logging can also be carried out after a well is drilled to the depth of interest to determine whether the well will produce commercial amounts of hydrocarbons, and whether it will be worth the expense of completing. Moreover, open-hole logs can be employed for correlation.

Cased-hole logging is accomplished after casing is set in the hole. Because steel casing would short-circuit any normal type of electric log, most cased-hole logs are acoustic, nuclear, or borehole-contact logs. In general, cased-hole logging (also called production logging) is used to evaluate old wells for recompletion possibilities; to determine whether casing is adequately cemented in a well; to locate casing collars, or joints, for accurate depth determination; and to evaluate a well's performance while it is producing.

Whether wireline logs are run in open or cased hole, and whether they are electric, acoustic, or nuclear logs, their primary function is to help operators evaluate formations the borehole has penetrated. Mechanical, wireline, and special logs obtained by MWD and LWD methods, constitute the permanent records of a well, which are useful throughout its life. These records can be invaluable when planning a workover, repair, or recompletion, for example, and are an essential part of any well's history.

Electric Logging

Wireline electric logging is possible because electric current can pass through salt water that exists in formations. In short, formation salt water conducts electricity. Electric logging uses electrodes on the logging tool and on the surface or other location that emit and receive current. How the current is affected as it flows into the fluid in the wellbore, through the wall cake, or mud cake, and through the formation is measured and recorded. The recording, or log, can be interpreted to reveal much about the formation and its fluid content.

As current flows through a formation, it meets resistance because formation fluids and the material of which the rock is composed may not be good conductors of electricity. The formation's *resistivity* can be measured and is a basic concept of electric, or resistivity, logging.

Just as weight and length have units of measure—feet and pounds in the United States—resistivity has a unit of measure: ohms. On well logs, resistivity is measured in ohms per unit of volume. The unit of volume is a one-meter cube; so, resistivity is usually expressed on the log as ohm-meters, which may also be shortened to ohm-m^2/m, OHMM, or a similar variation.

The resistivity of any formation depends on (1) the amount of water in the formation, (2) the salinity of the water, and (3) the temperature. At top in figure 4, an electric current is passing through a container of water. If the cross-sectional area of this container were doubled, the resistance to the current flow would be one-half as much. Further, the saltier and hotter the water, the lower its resistivity, which is shown by the graph at bottom in figure 4.

When sand grains are added to the container, the amount of water is reduced and the resistivity is increased (fig. 5). If more sand is packed into the container, more water is displaced and resistivity increases further. Thus, a formation with low porosity has less water and higher resistivity than a high-porosity formation, which has more water. Because oil, like sand, is a nonconductor of electricity, adding oil to the container displaces water and further increases the resistivity of the contents of the container. Like resistivity in the container, formation resistivity varies with porosity, water salinity, temperature, and hydrocarbon content. The fact that resistivity varies with into the formation. As a result, dielectric constants are being obtained in the flushed zone, which is filled mainly with mud filtrate. Further, the log can be obtained only in holes filled with water-base muds; it does not work in holes drilled with oil-base muds or air. In spite of these limitations, however, dielectric constant logs can be very helpful in evaluating zones that contain fresh water.

Acoustic Logging

Several types of acoustic logging device are in use today. Two of the most popular are the acoustic, or sonic, log, which is used for formation porosity determination, and the cement bond log, which is used to evaluate the integrity of the cement in the annular space between the casing and the wall of the hole. Two other acoustic logs are available: a well velocity survey (also known as a seismic check shot velocity survey), and a vertical seismic profile (VSP) survey. All use sound energy to measure certain aspects of the formation or the cement behind the casing.

Sonic Logging

The acoustic, or sonic, log was first recognized in 1954 as a porosity-measuring tool. It was originally developed as an aid for interpreting seismic exploration data, but proved so effective in determining porosity that it became the standard porosity-measuring tool in many areas. An *acoustic log* measures the time it takes for a sound impulse to travel through a given distance of rock at a given depth. How fast sound travels through a rock depends on the rock's composition and the fluids it contains. For example, limestone transmits sound much faster than shale, while sandstone transmits sound faster than shale, but more slowly than limestone. Because sonic transit time varies with relative amounts of rock and fluid, porosity can usually be determined with good accuracy by means of acoustic logs.

Table 1 gives the sonic velocities and corresponding travel times, in microseconds per ft, for various fluids and solid materials. Travel time, which is abbreviated as Δt, refers to the time it takes for sound to travel from one receiver on an acoustic sonde to another receiver on the sonde. A microsecond is one-millionth of a second (sec) and is often abbreviated as μsec. Some of these values are averages and may vary with the depth of the formations.

An acoustic log must be run in a liquid-filled open hole because mud is required to provide an acoustic coupling between the tool and the formation. If the mud is gas cut, the coupling is weakened and the log may be inaccurate; it is impossible to obtain an acoustic log in a gas- or air-filled hole. One type of

TABLE 1

Material	Sonic Velocity (ft /sec)	Travel Time, Δt (microsec/ft)
Air	1,088	919.0
Methane	1,417	706.0
Oil	4,300	232.0
Water or mud	5,000–5,300	200.0
Neoprene	5,300	189.0
Shales	6,000–16,000	167.0–62.5
Rock salt	15,000	66.7
Sandstones	up to 18,000	55.6
Anhydrite	20,000	50.0
Limestones	up to 23,000	43.5
Dolomite	24,500	40.8

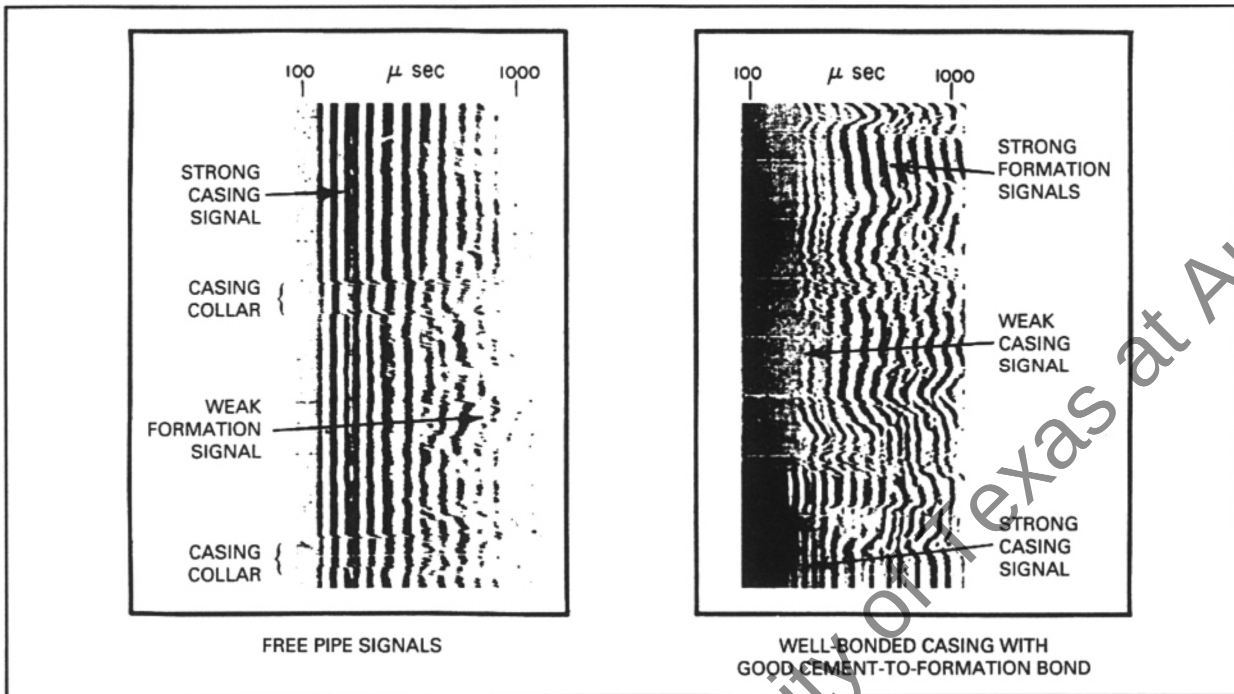


Figure 31. Cement bond log acoustic signals.

to the seismic source to provide a precise time break measurement and to provide wave train signature monitoring; and a downhole tool equipped with one or more receivers, called hydrophones, to detect the acoustic signal after it travels through the formations.

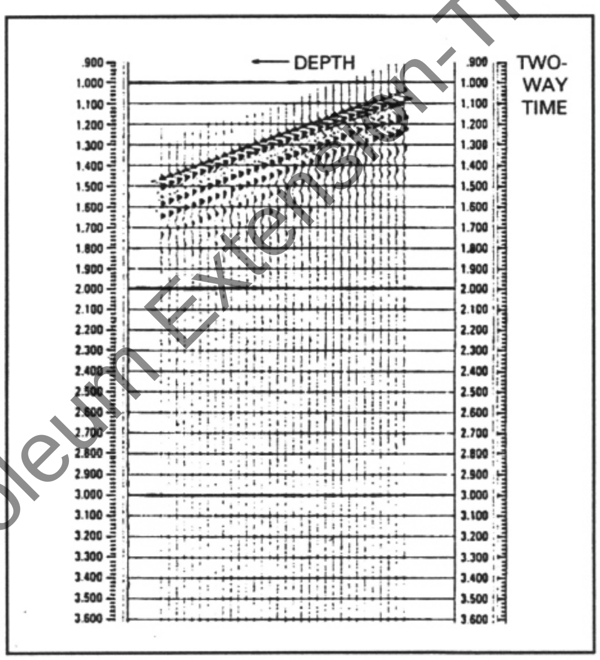


Figure 32. Vertical seismic profile.

Nuclear Logging

When rocks in the earth were deposited, they contained not only the material making up the bulk of the rock, such as sand or clay, but also certain amounts of nuclear material, such as potassium, thorium, and uranium. Virtually all rocks contain traces of nuclear minerals and, as a consequence, emit radiation that can be measured with nuclear logging tools. This radiation is emitted in the form of alpha, beta, and gamma particles, or rays. Alpha, beta, and gamma rays emanate from nuclear substances as these substances decay. Alpha and beta rays have low penetrating power, and are readily stopped by relatively thin material. Gamma rays, on the other hand, can penetrate several inches of steel; thus, a properly shielded logging tool responds only to gamma radiation. The intensity of gamma ray emissions varies in different sedimentary rocks. These variations can help distinguish shales from sandstones and carbonate rocks that could bear hydrocarbons (fig. 34).

Other nuclear well logging devices depend on neutron radiation. Since rocks do not naturally emit neutron radiation, a logging tool that emits it is used to bombard a formation and then measure and record the formation's reaction to the bombardment.

because depth must be correlated with an electric or other type of log taken before setting casing. To obtain accurate depth information, the depth to the bottom of a well is carefully checked when logs are run. Also, the height of the formation of interest from bottom is observed. This distance can then be converted to the number of joints of casing from the bottom of the well; thus perforation depth control can be related to the nearest casing collar.

Depth control for perforating is usually obtained with a neutron or gamma ray log that is run in conjunction with a casing collar survey. Such a log is a perforation depth control (PDC) log (fig. 47). In most cases a neutron log or a combination gamma ray and neutron run is used as the perforation depth control log.

In any case, accurate correlation of nuclear logs with open-hole logs that were run before casing was set establishes the desired perforating interval. If the depth control log is made on a separate trip into the well, the proper shooting depth is determined on the perforating run by recording a second collar log with the collar locator attached to the perforator. If a combination perforating gun and gamma ray is used, all of the equipment for depth control and perforating is run on a single trip into the well. Various types of collar locators are now in use. Some of them are sensitive enough to locate old perforations in casing. A collar locator can also be used to locate the casing shoe in open-hole completions, or liner overlap inside casing.

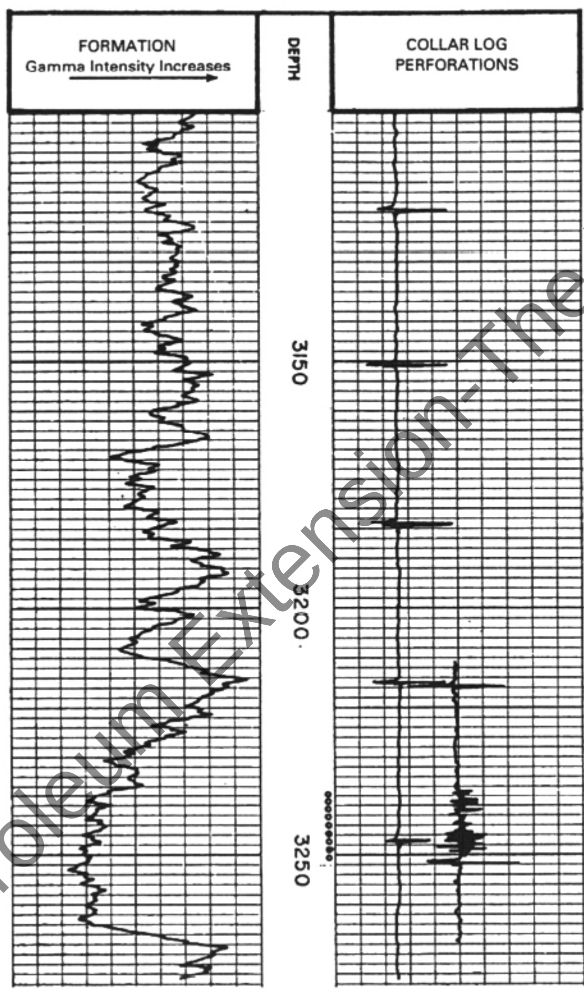


Figure 47. Perforation depth control log.

Nuclear logs of all types have become valuable tools for determining porosity, lithology, and water and hydrocarbon content in both open and cased holes. They also have other uses, such as perforation depth control and tracer surveying. As technological advances are made, it is safe to assume that more sophisticated nuclear tools will be developed to assist operators in finding and evaluating oil and gas reservoirs.

Temperature Logging

Temperature in the earth increases with depth. The rate of increase averages about 1° F per 60 ft of depth and is known as the *geothermal gradient*. Deviation from the average depends on the location and the heat conductivity of the geological formations. Temperatures in holes that can be circulated through drill pipe or tubing depend not only on the natural geothermal gradient, but also on the circulation of the fluid in the well. In a well that has been thoroughly circulated, the fluid will tend to have a uniform temperature. If drill pipe or tubing is pulled out of the hole and the mud in the well is allowed to remain stationary, the mud will gradually attain the temperature of the formation around it.

Most temperature surveys are made during the transition period before the fluid has enough time to reach thermal equilibrium with adjacent formations. A survey is made by lowering the instrument into the hole slowly so that the temperature-sensing element has time to reach the temperature of the surrounding fluid. Measurements are made going down, thus eliminating the perturbing effect of the logging cable. If another run must be made in the hole, it is necessary to wait six to twelve hours so that stabilized temperature conditions may be reestablished.

magnitude of the pressure drop. For example, small amounts of gas under high pressure can cool off a lot, whereas large amounts may not cool much if the pressure drop is small. Large-capacity wells may make temperature surveys difficult to interpret.

Production Logging

Production logs can be run in injection wells and in producing wells. Injection wells may be receiving water as part of an improved recovery project, or sometimes water is disposed of by injecting it into a well. Water is not the only fluid that may be injected. At times, the injection medium may be liquid hydrocarbon, gas, air, or a combination of liquid and gas. Whatever the injection fluid, the main purpose of a production log is to determine an *injection profile*—that is, to assign specific volumes or percentages to each of the intervals taking fluid. It is also important to check for casing or packer leaks, bad cement jobs, and fluid migration between zones.

In many instances, relatively high injection rates—1,000 barrels per day (bpd) or more—make a device called a continuous spinner flowmeter a highly suitable tool for obtaining an injection profile. Where a continuous spinner flowmeter is not suitable, a packer flowmeter can be employed; under certain circumstances, nuclear tracers can be used. Temperature surveys are commonly run in conjunction with spinner flowmeter logs or nuclear surveys.

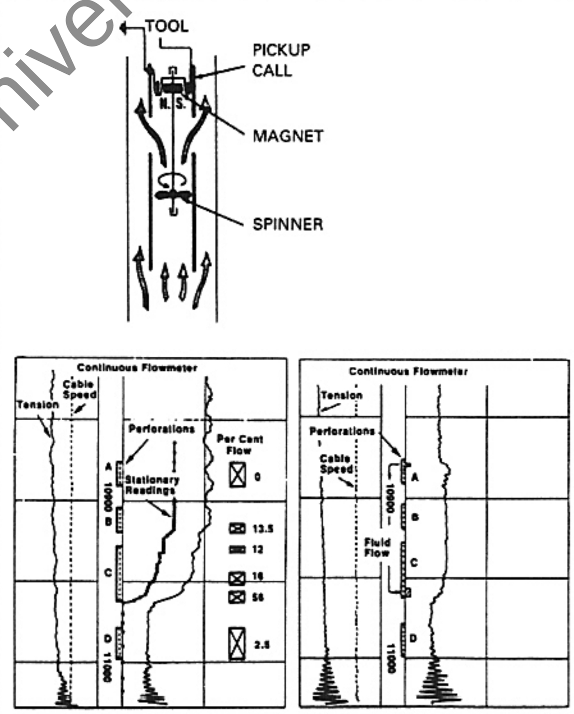
Since both oil and water are usually present in a producing well, a different approach is used in a single-phase injection well. If well conditions and flow rates permit, spinner flowmeter logs can be used to determine gross flow rates. The use of a water-soluble nuclear tracer has proved satisfactory to define the interval or intervals of water entry in the presence of moderate quantities of oil. The nuclear tracer permits measuring the water flow rate at selected depths to obtain a water rate versus depth profile. In addition, the soluble nuclear tracer can be spread over a selected vertical interval, so that the dilution of formation water can provide qualitative assessment of the entry amounts.

The temperature survey is the most common means used to evaluate a static well. If a temperature log does not produce meaningful results, then it may be necessary to run a tracer survey to identify fluid migration from one zone to another, a not uncommon problem in static wells. Occasionally, the conventional approach may not give enough information, so special techniques may be required. One example is the use of a single-electrode conductivity tool to determine an oil-water interface or to identify downward movement of water through an oil column.

Continuous Flowmeter Logging

Sometimes called a spinner survey, the *continuous flowmeter log* is used to determine the contribution of each zone to the total production or injection. These surveys can be used to indicate changes in the flow pattern versus changes in conditions at the surface, time, type of operation, or after stimulation treatments. Depending on the size of the tool employed and the pipe size involved, very high flow rates can be measured—up to 60,000 bpd. It is particularly useful for measuring gas well flow.

Figure 50 is a schematic diagram of the tool and logging records taken on an example well. The recordings



Logged while injecting water.

Logged with well shut in at the surface.

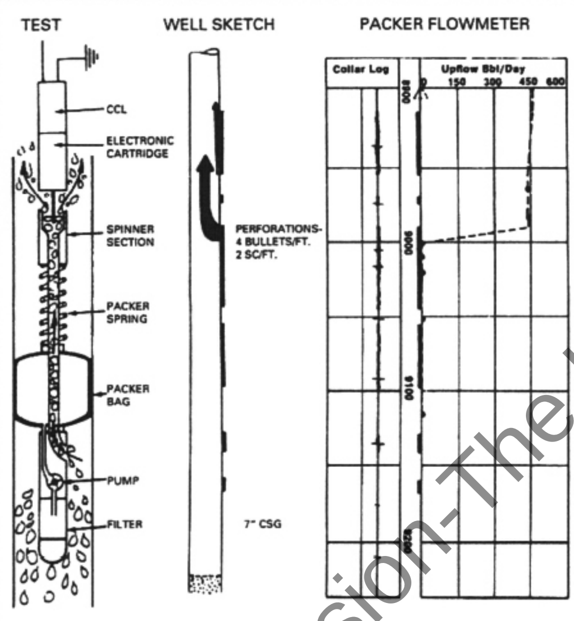
The Continous Flowmeter run during water injection showed Zone C to be taking 84% of the injected water. Zone A was taking none. When injection was stopped the Continuous Flowmeter indicated a crossflow with Zone A producing into Zone C.

Figure 50. Continuous flowmeter logging device and record.

show a profile for either up- or downflow (on track 2), cable speed, and tension on the cable.

Packer Flowmeter Logging

A packer flowmeter employs an inflatable packer that ensures that all the fluid passes through the measuring devices built into the tool. Since all fluid passes through the tool, fluids can be identified at each point in the well where the tool is set. This tool can be used to make a record of production or an injection profile with specific fluid identification. Flow rates up to 800 bpd can be handled through a 2⅛-in. tool. Figure 51 is a diagram of the tool, an example flowmeter recording, and a sketch of a well showing paths of fluid movement.



Production often comes from only a fraction of the total intervals perforated. This flow profile shows 97% of the production entering the casing in one ten-foot zone.

Figure 51. Packer flowmeter logging device, recording, and well diagram.

Computer-generated Logging

New radiation detectors, downhole minicomputers, truck-mounted computers, and central computing facilities allow modern well logs to yield more information than ever before. A computer in the truck backed up to a land rig, or one in the logging house on a remote or offshore rig, can handle very large amounts of information transmitted from the downhole sonde. The computer stores information, makes corrections where needed for the downhole conditions in which the logging tool is being run, does complex calculations, and prints out various log formats. Meanwhile, it keeps track of the depth at which the logs are being obtained and warns the logging operator if a malfunction occurs. Moreover, logging data that are obtained at the site can be transmitted to a central facility, where even more powerful computers are available to process the data further.

Well-Site Computer Logging

An important use of well-site computer logs, which are also called quick-look logs, is to help an operator decide whether to complete a well. One on-site computer log, for example, uses resistivity, nuclear, gamma ray, SP, and caliper measurements to determine water saturation and porosity in the formations logged. From these readings, hydrocarbon saturation can be calculated (fig. 52). The values displayed on the log are corrected for the effects of temperature, borehole size, and weight and salinity of the mud.

Computing Center Data Processing

Even though computers at the well site are becoming more and more powerful and are thus able to yield very sophisticated and refined logs on-site, it may be desirable to have logging data interpreted at a computer center. In many cases, logs generated by computing centers are more accurate than well-site logs, because center computers are more powerful, the programs in the computers are more advanced, and more complex correction factors can be used than those that can be used in well-site computers.

Computing center logs employ a different format from well-site logs. Computing center logs may place the depth track to the left (fig. 53). Track 1, which is labeled formation characteristics, shows a gamma ray curve, an apparent grain density curve, and the formation's intrinsic and effective permeability to water and to hydrocarbons. Track 2 has two parts: hydrocarbon analysis, and porosity analysis in percentage of bulk volume. Note that hydrocarbon saturation is shown by the blackened parts of the curves. In addition, a caliper curve is shown. Track 3 displays a bulk volume analysis of the entire formation. It is divided into dry clay, bound water (water that is associated with the dry clay), silt, matrix, and effective porosity of the rock to fluids. These logs may also be produced in color.

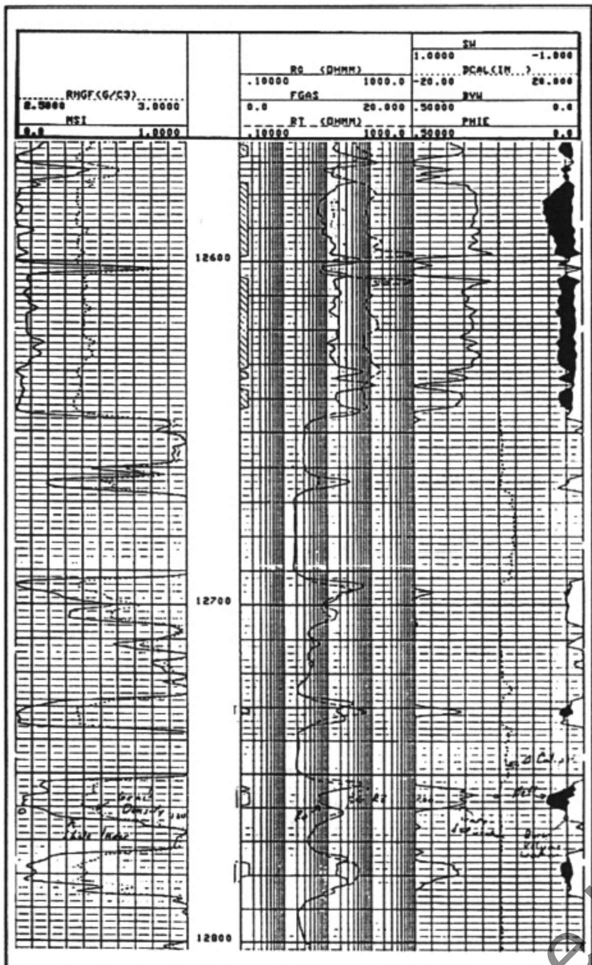


Figure 52. Well-site computer-generated log showing several curves. Most important are the blackened areas at extreme right, which indicate hydrocarbon saturation.

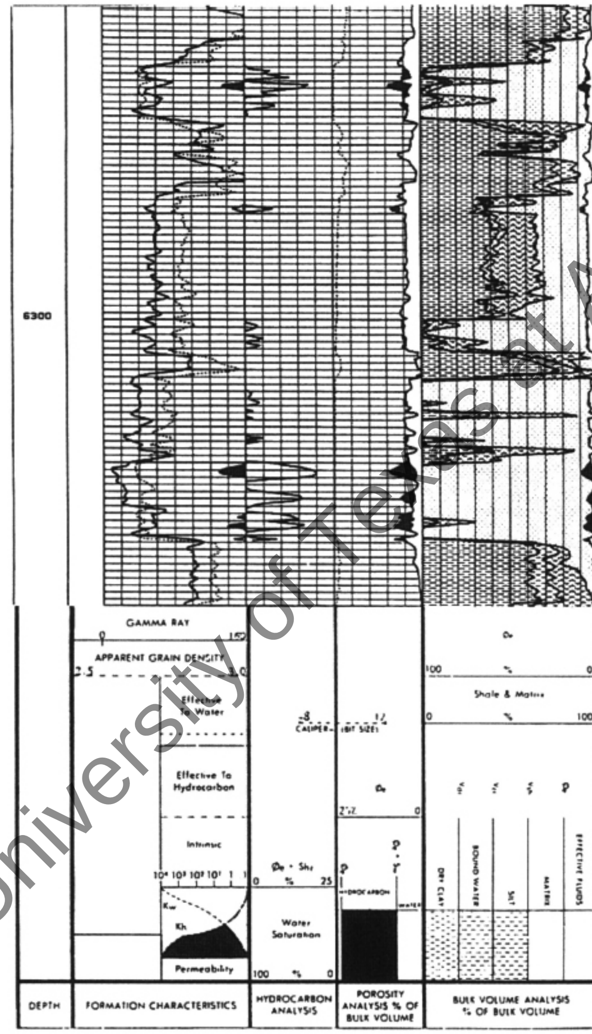


Figure 53. Computer center log.

Another log generated at a computing center is shown in figure 54. Called a Faciolog by the company that generated it, the log identifies various sediments, or facies. It displays the sediments to the right and describes them with abbreviations such as SH for shale, SST for siltstone, and LS for limestone. Also displayed on the readout are the raw log data and a lithology-analysis log. The raw log data show that gamma ray, caliper, induction, neutron, and dipmeter logs were originally run on the well.

Conclusion

Well testing has come a long way since the days of lowering a primitive pressure bomb into the well in the hope of catching a good sample of formation fluids. Determining whether a well contains an ample amount of hydrocarbons in a formation that makes it possible to economically produce them, is easier to determine now than ever before. Sophisticated well logs taken both during and after a well is drilled, make the often difficult decision of whether or not to complete a well a little easier.

Further, advances in open-hole logging, cased-hole logging, and production logging provide excellent records of a well's formation characteristics and performance as it is produced. When wireline logs are combined with core samples, DSTs, and mechanical logs, and when these valuable records are properly stored for rapid access, a well's history can be displayed for analysis. By analyzing well records, decisions about its future can be confidently made.

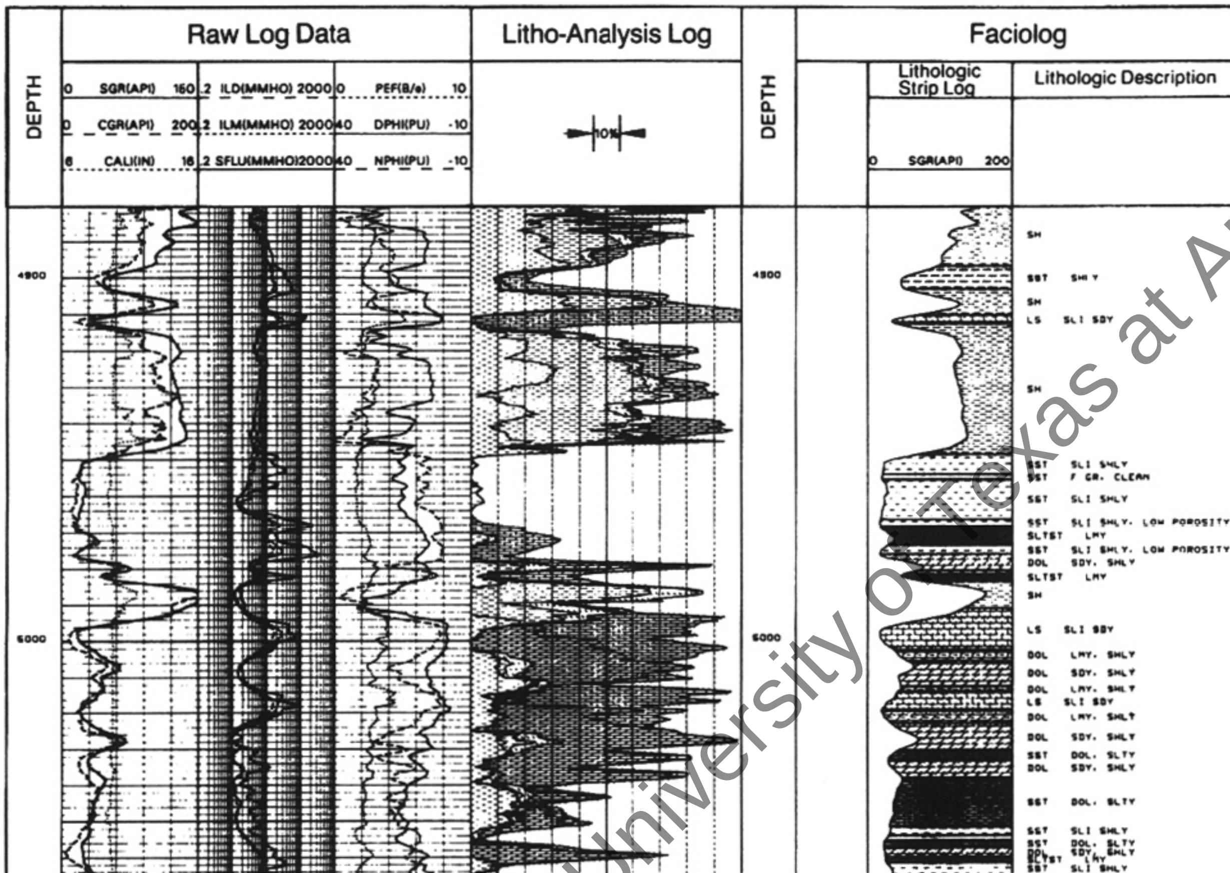


Figure 54. A Faciolog identifies various sediments.

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GLOSSARY

A

acoustic survey *n*: a well logging method in which sound impulses are generated and transmitted into the formations opposite the wellbore. The time it takes for the sound impulses to travel through the rock is measured and recorded. Subsequent interpretation of the record (log) permits estimation of the rock's porosity and fluid content.

acoustic well logging *n*: the process of recording the acoustic characteristics of subsurface formations, based on the time required for a sound wave to travel a specific distance through rock. The rate of travel depends on the composition of the formation, its porosity, and its fluid content. Also called sonic logging.

alpha ray *n*: one of the extremely small particles of an atom that is ejected from a nuclear substance (such as radium or uranium) as it disintegrates. Alpha rays have a positive charge.

amplitudes *n pl*: shapes and heights of the peaks on a log as recorded by a logging instrument.

angle of formation dip *n*: the angle at which a formation dips downward from the horizontal.

B

bedding plane *n*: the surface that separates each successive layer of a stratified rock from the preceding layer. It is here that minor changes in sediments or depositional conditions can be observed.

beta ray *n*: one of the extremely small particles emitted from the nucleus of a nuclear substance such as radium or uranium as it disintegrates. Beta rays have a negative charge.

bomb *n*: a thick-walled container, usually steel, used to hold devices that determine and record pressure or temperature in a wellbore.

borehole-contact log *n*: any logging device whose operation depends on a portion of the logging tool touching the wellbore.

bulk density *n*: the density of the rock and the fluids in the pores of the rock.

bulk density log *n*: a continuous record of variations in the density of the lithologic column penetrated by the borehole.

C

caliper log *n*: a record showing variations in wellbore diameter by depth, indicating undue enlargement due to caving in, washout, or other causes, or indicating a decrease in diameter where wall cake builds up. The caliper log also reveals corrosion, scaling, or pitting inside tubular goods.

capture gamma ray *n*: a high-energy gamma ray emitted when the nucleus of an atom captures a neutron and becomes intensely excited. Capture gamma rays are counted by the neutron logging detector.

carnotite *n*: see *nuclear tracer*.

cased-hole logging *n*: logging inside a portion of the wellbore that is lined with casing. Also called production logging.

cement bond log *n*: an acoustic logging method based on the fact that sound travels at different speeds through materials of different densities. Because sound travels faster through cement than through air, this fact can be used to determine whether the cement has bonded properly to the casing and the formation.

collar locator *n*: a logging device for depth-correlation purposes, operated mechanically or magnetically to produce a log showing the location of each casing collar, or coupling, in a well. It provides an accurate means of measuring depth in a well.

compensated densilog (CDL) *n*: see *density log*.

compensated formation density log *n*: see *density log*.

compensated neutron log *n*: a neutron log in which there are a source and two detectors. The ratio of the count rates from the two detectors is processed by a small computer, which calculates apparent limestone porosity. The compensated neutron log has fewer borehole effects than any other type of neutron log.

conductivity *n*: an electrical logging measurement obtained from an induction survey, in which eddy currents produced by an alternating magnetic field induce in a receiver coil a voltage proportionate to the ability of the formation to conduct electricity. Compare *resistivity*.

connate water *n*: water retained in the pore spaces, or interstices, of a formation from the time the formation was created. Compare *interstitial water*.

contact log *n*: any log in which the logging sonde must be put into contact with the walls of the hole or casing to obtain the log.

continuous flowmeter log *n*: a log used to determine the contribution of each zone to the total production or injection. These surveys are used to indicate changes in the flow pattern versus changes in conditions at the surface, in time, in type of operation, or after stimulation treatments; particularly useful for measuring gas well flow.

Review Questions
Lessons in Well Servicing and Workover
Lesson 3: Well Logging Methods

True or False

Place a *T* in the space if the statement is true and an *F* in the space if the statement is false.

____ 1. The term "log" applies not only to the data obtained by the logging tool but also to the tool itself.

____ 2. According to the text, the only types of log called mechanical logs are those obtained at the surface with sensors and other devices.

____ 3. There are three types of wireline log: electrical, acoustic, and nuclear.

____ 4. Open-hole logs are obtained in wells in which casing has been run.

____ 5. An electric current passed through a container of salt water meets more resistance than an electric current passed through a container of fresh water.

____ 6. In general, the less porous a formation is, the higher is its resistivity.

____ 7. Oil is less resistant to the passage of electricity than water.

____ 8. With a conventional electric log, resistivity measurements deep within the formation were obtained with lateral logging devices.

____ 9. A spontaneous potential (SP) curve is usually obtained by passing a low-voltage current from electrodes on the sonde into the formation opposite the sonde.

____ 10. A shale line and a sand line can often be established with an SP curve.

____ 11. A focused electrical log—also called a conventional log—measures the natural resistivity of a formation.

____ 12. An induction log may be obtained in wells in which either freshwater mud, saltwater mud, or an oil mud is being used to drill the well.

____ 13. Induction logging measures the conductivity of a formation; however, the log often displays the conductivity measurements as resistivity curves.

____ 14. Caliper logs often measure hole diameter through two axes to determine hole geometry.

____ 15. Electromagnetic propagation tools measure the dielectric constant of water and oil several feet into the formation opposite the wellbore.

____ 16. It is impossible to obtain an acoustic log in an air- or gas-filled hole.

____ 17. In general, sound travels more slowly through porous rock than it does through nonporous rock.

____ 18. A cement bond log's primary purpose is to determine the top of the cement behind the casing.

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