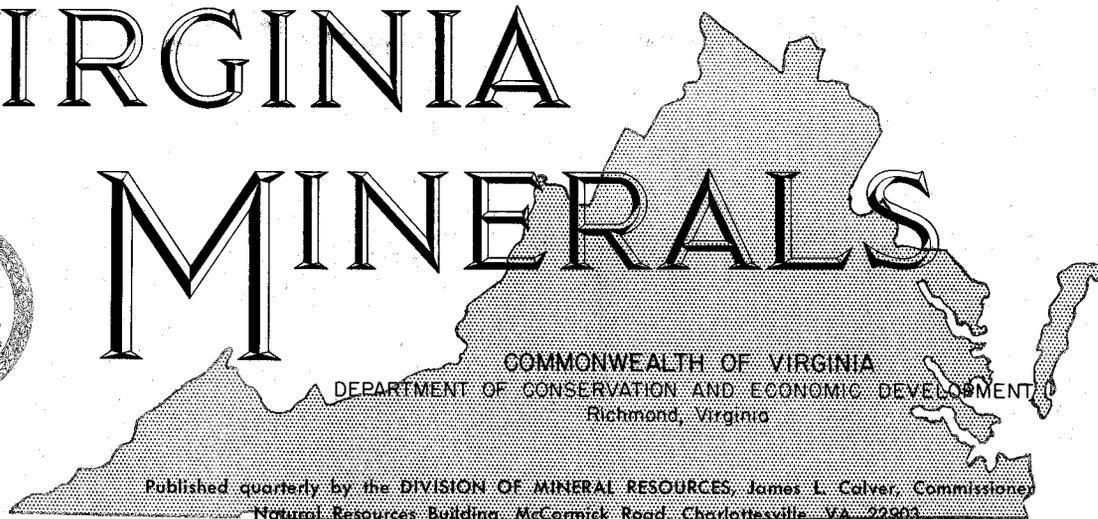


VIRGINIA



MINERALS



Vol. 16

NOVEMBER, 1970

No. 4

MECHANICAL WELL-LOGGING METHODS

Marshall S. Miller

INTRODUCTION

Mechanical well logging, mainly used by the petroleum industry, has progressed tremendously in scope and usefulness since the turn of the century. The greatest development of logging instruments has occurred in the past 20 to 25 years, resulting largely from intensive efforts of logging-company research centers. The tools and technology have evolved so rapidly that many methods are unfamiliar in areas of limited petroleum production such as parts of the Appalachian region.

The word "log" was first used in a geological sense by well drillers who kept a record of the rocks penetrated in a well as drilling progressed. The records, called drillers' logs, were usually very simple and often consisted of only a one- or two-word description for several hundred feet of rock. Later this type of log was supplemented by more-detailed descriptions, known as geologic logs, which were prepared by geologists through microscopic examination of rock cuttings. Although helpful in geological studies, the drillers' log and the geologic log are limited in descriptive accuracy and depth control because of physical problems involved in collecting samples. Contami-

nation or caving from overlying strata is the primary problem. Uncertainties also arise because the samples are collected at 10- or 20-foot intervals during rotary drilling or at irregular intervals during bailing of cable-tool tests. The electrical well log, using downhole instruments to record continuous data, was therefore developed to supply more-specific and much-needed information.

FIELD UNIT AND WELL LOG

A typical well-logging unit (Figure 1) consists of a truck that contains a winch and cable, sondes, power sources for AC and DC, a recorder with paper or film drive coupled to the cable motion, and developing and printing facilities. The sondes vary from simple insulated mandrels, with plain electrodes, to cartridges containing complicated electronic devices. Special sondes are used in holes less than 5 inches in diameter. The sonde is lowered into the hole by a cable that contains several conductor wires. A measuring device indicates the depth of the sonde and the recorder in the truck responds to the measurement being taken. The record is made with a pen on paper or with several specially designed galvanometers that trace their deflections on a moving film with light beams



Figure 1. Field unit in position for logging. (Photograph courtesy of Schlumberger Well Services.)

reflected from mirrors. A gear shift in the cable-to-film drive allows a choice of depth scales on the log of 1 inch equals 100 feet, 1 inch equals 50 feet, or other appropriate scales.

A hypothetical well log of a drill hole is shown in Figure 2. Several curves opposite the corresponding lithologic column represent the recorded measurements of the formation characteristics. Vertical straight "grid lines" represent the amplitude of the measurement and horizontal "grid lines" indicate the footage depth in the hole. The curves and grid lines constitute the final product of mechanical well logging. Log interpretation is then done by examining the intersections of the curves with the vertical scale lines and the hori-

zontal footage lines to: (1) determine accurately the thickness of rock units, (2) correlate units from well to well, (3) locate potential water-, hydrocarbon-, or mineral-bearing rocks, and (4) estimate producing characteristics of these rocks.

SPONTANEOUS-POTENTIAL LOG

The spontaneous-potential (SP) log records the naturally occurring potential differences between a surface electrode and an electrode in the hole, or more simply stated, the natural voltages in the hole. These voltages are basically due to the difference in salinity between the original water in the formation and the fluid in the borehole, including any fluid used as a drilling

medium. An imbalance of salinities between the formation water and the fluid in the borehole must exist before a potential can be created. One of two other conditions, however, must also be present before a potential exists: the "membrane potential", resulting essentially from movement of ions activated by shale within the drilled sequence of rocks; and the "liquid junction potential", resulting from permeability of the rock. The

slows down the mobility of the ions that initially produce the curve, causing it to decrease or deflect to the right. This curve may also be used in calculating the resistivity of formation water, because its amplitude depends on the imbalance of salinities of the two fluids and the degree of salinity.

RESISTIVITY LOG

The resistivity log, usually made simultaneously with the SP log, records the resistivities of subsurface formations and any fluids they may contain. Its design is based on electrical theory and instrumentation. The same basic principles are used in conventional resistivity logging as in spontaneous-potential logging. The resistivity of the rock formation must be measured in the uncased portion of the borehole. Current and measuring electrodes are mounted on a mandrel or sonde and lowered down the hole. Different spacings between electrodes allow resistivity measurements at different distances from the borehole into the rock formation. A short spacing between electrodes gives a radius of investigation of only a few inches into the formation; longer spacing measures a larger radius. Three simultaneous resistivity measurements, using different electrode spacings, are usually recorded. The resistivities at different radii of penetration are compared to indicate the true resistivity, which is modified to varying degrees near the borehole by the invasion of the drilling mud into the rock and the influence of the borehole itself.

The resistivity of a formation is a function of the amount, distribution, and kind of water within the formation. The few exceptions are metallic sulphides, graphite, and other substances that conduct electricity similar to metals. The amount of formation water depends on the porosity and the quantity of hydrocarbons present. Porosity is the amount of pore or void space of a substance as compared to its total volume. Porosities vary widely, but a rock must have a certain amount to be a reservoir for fluids. Dense limestones and anhydrites may have little or no porosity, well-consolidated sandstones as much as 10 to 15 percent, and unconsolidated sands as much as 30 percent or more. Shales and clays often contain over 40 percent liquid by volume, but are so fine grained that none of the fluids within the matrix will flow because the voids are not effectively interconnected. Porosity generally affects resistivity

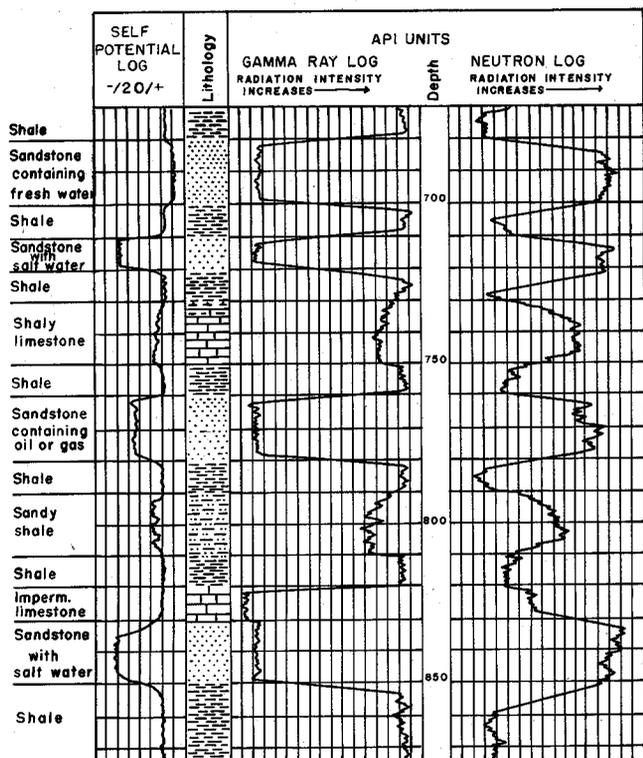


Figure 2. Schematic log showing correlation of spontaneous-potential, gamma-ray, and neutron curves with various rock types.

SP log must be run in the uncased portion of a hole that contains liquid. The current flows out of a shale having membrane potential into a more permeable formation containing liquid-junction potential. The impermeable formation tends to attenuate the lines of current. Thus, the SP curve records a base line to the right, opposite shale, and shows peaks to the left, opposite permeable formations. The curve readily identifies shale beds and indicates permeable zones.

The SP curve is useful as an aid in identifying oil in formations. Oil in a permeable formation

measurements inversely. As open space increases, the amount of water that contains the dissolved salts also increases, resulting in an easier current flow and lower resistivity. The distribution of water determines how easily the current passes through the formation. If the current must take a more tortuous path, the resistivity increases. The kind of water depends upon the amount of dissolved salts — the greater the salt concentration the more readily the current flows and the lower the resistivity.

The amount of hydrocarbon saturation, if any, varies inversely with the total amount of water in the rock pores, and thus affects the resistivity measurement. Saturation of the rock is the percentage of the pores and voids which is occupied by fluid. Usually the fluid is water, which conducts the electric currents. A formation which has 70 percent water saturation has 70 percent of its void space filled with water; the remaining 30 percent of open space can contain gas or oil. The greater the hydrocarbon content, the less the amount of water with dissolved salts to conduct electrical current, and the greater the resistivity.

The resistivity log indicates the three most important formation characteristics for estimating the presence of hydrocarbons: permeability, porosity, and water saturation. A considerable amount of research has brought about many combinations and spacings of electrodes to obtain the true resistivity of the formation. The result has been other resistivity logs: the laterolog, which is known for more accurate measurement of resistivity in thin beds; the displacement log, which records eight lateral curves from different radii of investigation; the induction log, which measures the conductivity (reciprocal of resistivity) of formations by means of energizing coils instead of electrodes; the microlog and the microlaterolog, which identify permeable formations by measuring the resistivity of the invading mud; and the most widely used resistivity log, the dual-induction laterolog, which utilizes two focused induction devices, a focused laterolog and an SP curve. Each of the logs is a specialized tool; the choice of one over another depends on the physical and geological conditions of the well and whether the measurements involve large or small volumes of material. All logs, except the induction log, must be recorded in the uncased portion of a hole and in a conductive mud or water. The in-

duction log requires an uncased portion of the hole, but no conductive liquid. Thus, it is useful in empty or oil-filled holes.

The microlog and microlaterolog apply a different theory and arrangement of electrodes and physical conditions than the other resistivity logs. The apparatus consists of a rubber pad, on which three electrodes are spaced linearly one inch apart. The pad is pressed against the wall of the drill hole and the resistivity of a very small volume of material is measured. Two electrode systems are used in combination to provide two resistivity logs simultaneously.

The microlog and the microlaterolog are used for investigating very small volumes of material and for more accurate delineation of thin strata. The microlog provides a very detailed record of the formations, particularly of permeable zones. These zones are determined by the microlog because of the properties of the circulated mud in a borehole opposite such formations. If the rock is permeable, it admits drilling fluid, and a "mud cake" forms on the wall of the borehole opposite the formation as the mud filtrate passes into the rock. Under ideal conditions the shorter-spaced electrode system measures a resistivity that is primarily affected by the mud cake. The longer-spaced electrode system measures a resistivity that is affected less by the mud cake than by the properties of the formation. The mud cake, which is the less resistive material, causes the short-spaced system to indicate a lower resistivity than the longer spaced curve. The difference between these two curves is known as "separation", and it is called "positive separation" when the longer spacing gives the larger resistivity. A large amount of positive separation almost always indicates permeability.

When the microlog is applied opposite a low-resistive formation such as shale, which has no permeability and therefore no mud cake, both curves record the same low resistivity, and there is no "separation". Highly resistive, impervious rock is not invaded by fluid, and both curves therefore record high resistivities. Only in permeable rock does the mud filtrate enter the formation, forming a mud cake, and thereby causing "positive separation". Thus, the microlog sometimes indicates the formation resistivity and almost always identifies zones of permeability.

GAMMA-RAY LOG

The gamma-ray logging device consists of an electrically operated, downhole counter that detects naturally occurring gamma rays. The gamma rays are detected as pulses that are transmitted to the surface where they are converted to electrical voltages and recorded continuously on film as the sonde is pulled up the hole. The rays are emitted by the unstable elements uranium, thorium, and potassium, which are found in measurable amounts in all rocks. Shale generally contains the greatest concentrations of these elements, and typically is more radioactive than sandstone, limestone, dolomite, salt, or anhydrite. Gamma-ray logging is thus highly useful in distinguishing shale from other rock types.

Gamma-ray recording equipment is usually designed so that the curve deflects toward the right as radioactivity increases. On the gamma-ray curve shown in Figure 2 the deflection to the extreme right indicates shale. The parts of the curve with less deflection indicate non-shale lithologies such as sandstone and limestone. The gamma-ray log is used principally for bed definition, correlation, and determination of interfacies because of its shale-distinguishing characteristic. The high penetrating power of gamma rays permits logging in cased or uncased holes, regardless of the nature of the fluid, if any, in the hole.

NEUTRON LOG

The neutron log consists of an americium-beryllium or plutonium-beryllium source that emits fast neutrons, and a radiation detector placed close to the source. The emitted neutrons are electrically neutral particles that proceed outward from the source and penetrate into the adjacent rocks until they are captured by the atomic nuclei of certain elements after several collisions. When the neutron is captured, it is absorbed and one or more high-energy gamma rays are emitted. The induced gamma rays are of greater intensity and quantity than the naturally occurring gamma rays, thus permitting the measurements of the induced radiation without interference from the relatively weak, natural radiation. The atomic nucleus most successful in slowing down the emitted neutron is the hydrogen nucleus which has a mass almost identical to the neutron. When the hydrogen concentration is large, most of the neutrons are slowed down and

captured within a short distance. Due to the source-detector spacings commonly used, a high concentration of hydrogen allows only a few gamma rays to reach the detector. Because hydrogen is a common component of formation fluids, and rocks must be porous to contain these fluids, the intensity of the induced gamma rays indicates the amount of fluid and porosity. High intensity generally signifies nonporous rock, whereas low intensity signifies porous, fluid-bearing beds. Shale generally shows a high porosity on a neutron log because of the hydrogen chemically combined in its molecules or present in water in its pores. The porosity, however, is not "effective porosity", as the voids are not interconnected, and shale is usually impervious. Natural gas, which contains less hydrogen than oil or water, gives a higher counting rate and the neutron curve records low, inaccurate porosity.

The primary use of the neutron log is for porosity determination. It is also useful for delineation and correlation of formations. The log, like the gamma-ray log, can be made in either cased or uncased holes and requires no fluid. When used with the gamma ray, the neutron log may provide a quantitative record of shale and indicate porous and non-porous rock. Thus, it is particularly helpful in cased wells, for surveying old wells, and doing "workover" jobs. Gas-containing rocks may also be indicated.

Several other types of neutron logs are in use, including the thermal neutron log, epithermal neutron log, and "pulsed neutron log". The thermal neutron log has not been widely used, as it essentially has characteristics similar to the regular neutron log.

The epithermal neutron log was introduced commercially in the early 1960's and has gained wide acceptance as an accurate porosity log. It detects epithermal neutrons, with an energy range of 0.1 to 100 electron volts, that result after fast neutrons have been slowed down by collisions with atomic nuclei, primarily those of hydrogen. The epithermal neutron log is influenced almost exclusively by the hydrogen content of the rock. It is not influenced by other rock constituents as are the neutron or thermal neutron logs. Also, the effects of borehole diameter and shape, fluid salinity, mud weight, and temperature are either suppressed by a directionally sensitive sidewall skid or corrected by the logging system.

The gamma-ray log is often run simultaneously with the epithermal neutron log, as it is with the neutron log. The epithermal neutron log greatly extends the application of neutron logging in uncased wells, and certain types of these logs that do not use the sidewall device may be made in cased holes. When combined with other porosity logs, epithermal neutron logs facilitate interpretation in complex lithologies.

Another logging technique that relies on neutron bombardment of formations is "pulsed neutron logging". A source is used to emit short, intense bursts of high-energy neutrons once every one thousandth of a second. After each burst, the emitted neutrons are quickly slowed to thermal energy and eventually captured or absorbed, producing high-energy gamma rays. This log measures the time that these thermal neutrons survive before being absorbed in the formation and its fluids. Of the common earth elements, chlorine is the strongest absorber of thermal neutrons. The log responds primarily to the amount of chlorine in the formation water, and identifies salt water and measures formation fluid saturation in either cased or open hole. Because the casing, the borehole size, the borehole fluid, and tool position have very little effect on the log, its utility is almost unlimited, especially in cased-hole logging, for determination of oil-water and gas-oil contacts and recovery efficiency, location of previously overlooked oil zones, and detection of oil migration between zones.

DENSITY LOG

The density log or "densilog" is a radioactivity tool, which is based on the response of the rock to induced, medium-energy gamma rays. The result is an approximate measurement of the bulk density of the rock. The bulk density, as used in well logging, is the number of grams or mass weight of a substance divided by its volume.

The tool (Figure 3) consists of a gamma-ray source and a detector mounted on a skid that is in contact with the borehole wall. Gamma rays, which are emitted by the source, are transmitted through the formation. The number that reach the detector depends on the abundance of electrons within the rock material. If many electrons are present, the gamma rays are quickly absorbed and only a few are counted. Conversely, if the

electrons are few, many gamma rays are counted. An increase in counting rate therefore indicates a decrease in bulk density.

The density log actually responds to electron density, but because the two densities are so closely related, the log is scaled in bulk density.

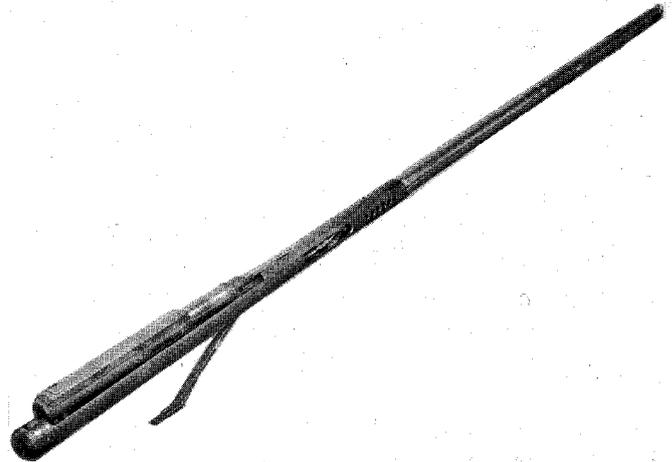


Figure 3. Formation density-logging sonde. (Photograph courtesy of Schlumberger Well Services.)

The important relationship between the electron density as recorded by the density log and the porosity of a formation is simple and direct. A formation with a considerable amount of open space offers little resistance to the progression of medium-energy gamma rays. Therefore, rock with good porosity has a low electron and bulk density, as indicated by a high count of diffused gamma rays.

The density log provides another method of direct porosity measurement. Oil and gas are less dense than water, which results in a lower density reading, and therefore, unlike a neutron log, their presence causes an indication of favorable porosity. When used to estimate effective porosity, the density log is not influenced as strongly by shale as the neutron log. The density log has many uses when combined with other porosity and resistivity logs.

SONIC LOG

The sonic log, or acoustical log, records the time for a sound wave to travel through a definite length of formation. The measurement of time is accomplished by placing a transmitter and two

receivers downhole as shown in Figure 4. The transmitter emits a sound pulse, which travels through the rock and is received by a near and a far receiver. A record is made of the time it takes the sound pulse to travel between the two receivers. The time interval is usually small and depends upon the matrix velocity or the speed of sound through a particular formation. The sonic velocity varies inversely with the recorded time interval. Thus, a hard formation has a high sonic velocity and transmits sound faster than a soft formation, which has a low sonic velocity. The dominant influence on sonic velocity variations is porosity. The higher the proportion of open space in a rock, the less the speed of sound and the greater the recorded time interval. Oil and gas that occur in the voids lower the speed of sound more than water, and higher porosity is sometimes indicated in their presence.

In addition to porosity evaluation, the sonic log is used for correlation and lithologic determination, for fracture location, and as an aid to seismic interpretation. Fracture porosity is approximated by comparison of a radioactivity log with the sonic log. The sonic log is influenced only slightly by fractures and vugs, whereas radiation logs record these features but do not distinguish them from normal intergranular porosity. The difference between the sonic-derived porosity and the nuclear-derived porosity may then be considered as an index of secondary porosity.

OTHER LOGS

The previously discussed logs are generally the ones most commonly used by the petroleum industry. Most other logging devices are beyond the scope of this article, such as those designed for production purposes or specialized work dealing with reservoir problems. Specialized logs frequently used, however, by the geologist and engineer include the caliper log, the temperature log, the dipmeter log, and the borehole televiewer log.

The caliper is an instrument which measures the diameter of a borehole. Measurement is made as several arms are moved along the sides of the hole. The caliper log is used for calculating the proper amount of cement necessary to fill space between casing and open hole, for locating tight spots in the hole, for evaluating perforations, for

determining acid and nitroglycerine treatment of holes, for selecting packer seats, and for more accurate interpretation of various electrical and radioactivity logs.

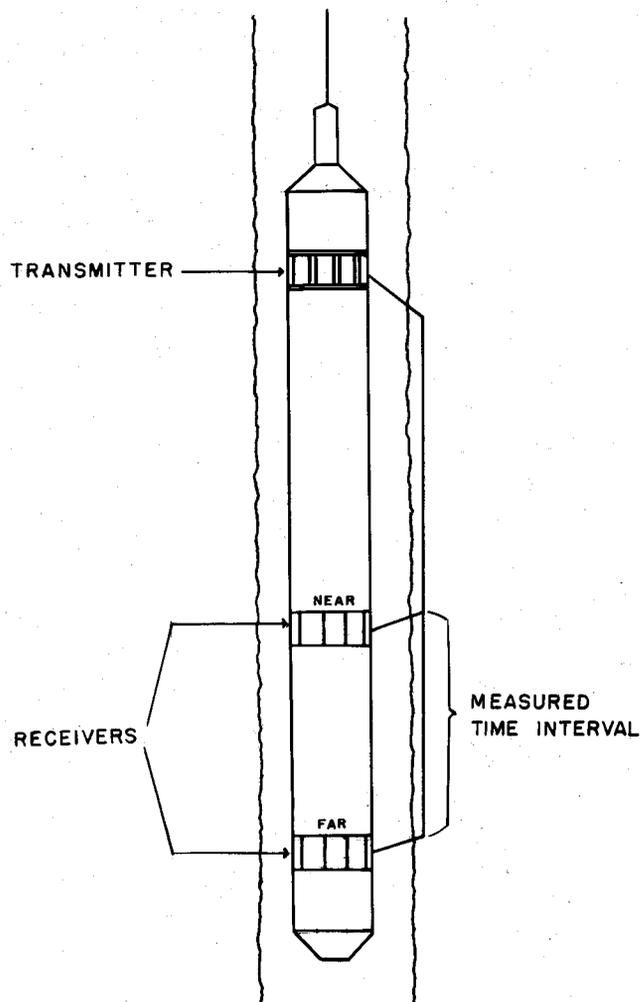


Figure 4. Diagram of a velocity sonde in operation.

A temperature log is obtained by measurements with a thermometer that has a sensing element. Temperature generally increases with hole depth because of the geothermal gradient, but the rate varies with location and heat conductivity of the rock. Also, chemical reaction, changes in hole size, movement of fluids, and the movement of gas can locally alter the temperature in a well. Thus, the temperature log is sometimes used to locate gas-bearing beds. It may also be used to determine the depth of lost circulation, such as excess loss of drilling mud into porous or cavernous strata.

Temperature surveys are also made in cased holes for locating the top of cement.

The dipmeter log supplies information on the magnitude and direction of formation inclination or dip across a borehole. Its primary application is the determination of structural attitudes and certain sedimentation features.

The recently developed borehole televiewer gives a direct and descriptive record of the borehole environment by taking a continuous acoustic picture in the form of a well log. The televiewer may be operated in a borehole filled with any homogeneous gas-free liquid such as fresh water, crude oil, saturated brine, or drilling mud, and in either the cased or uncased part. The log can reveal fractures, vuggy porosity, and the details of casing better than other logs presently in use.

GENERAL APPLICATION OF LOGS

The choice of logs to be made depends on the physical and geological characteristics of a well, such as the lithology, the presence of casing, the size of the borehole, the formation fluid, the fluid used while drilling, and the amount of mud invasion of the formation.

The use of a drilling substance other than conductive mud will usually complicate, and sometimes make impossible, the use of most resistivity logs. Holes drilled with gas or air contain no conductive liquid to provide a current-path for electrode devices, and consequently no resistivity logs depending on electrodes can be made. The induction log is the only resistivity-measuring device that does not require a conductive mud, and because of this versatility and its inherent accuracy, it has become the principal tool for evaluation of formation resistivity.

Possible oil or gas zones can be delineated by determining the amount of water saturation from resistivity and porosity-measuring logs. The greater the porosity and the less the water saturation, the better the chances are for oil and gas. Reservoir rock must also have sufficient permeability if it is to produce petroleum commercially. The permeability can be determined from the spontaneous-potential log or the microlog. Additionally, certain resistivity logs may be used for

ground-water investigation, such as the SP log, which can distinguish permeable formations, and may be used to estimate the quality of water and to show where to set screens to the best advantage.

The most useful applications of well logging can often be achieved through combinations of several logs. The three main porosity tools, the sonic, neutron, and density logs, all have a basic response to porosity. A combination of more than one type of porosity log, however, allows certain quantitative and qualitative results that cannot always be achieved by any single log. The combination of porosity logs is often effective in determining formational characteristics because the various logs respond differently to matrix and mineral variations. Because of their different response to the presence of hydrocarbons, porosity logs are also helpful in identifying gas deposits. Porosity logs may be used with resistivity logs to yield a variety of information: (1) the rock units and their correlation between wells can be pinpointed within less than a foot; (2) the lithology can be described and percentages determined of silica, limestone, dolomite, anhydrite, gypsum and shale; (3) minerals such as sulfur, potash, and trona can be identified and percentages of bulk volume in place estimated; (4) porosity may be measured within one percent, and the amount of effective porosity established; (5) primary and secondary porosity can be determined; (6) water can be defined and the percentage of water and hydrocarbons within the porosity can be measured; and (7) an estimate of residual and moveable hydrocarbons can be made.

If the lithology is known to be essentially homogeneous, the porosity can be determined with any one of the three main porosity logs. When the formation is composed of a single but undetermined rock type, any two porosity logs will usually identify the lithology and accurately define the porosity. When the formation is a mixture of two known rock types, two porosity logs will determine porosity and the percentage of each. All three porosity logs are usually run if the borehole and formation characteristics are not known. When two or more porosity logs are made, the data are cross-plotted to resolve both the porosity and matrix. Recent technical innovations include compilation of data on digital tape, and use of computers to finalize the results.

The best combination of logs is the one in which the greatest resolution is possible. Because each porosity log reacts with different sensitivity to certain rock parameters, the best choice of logs is the one that shows the most contrast between the lithologies to be encountered. Field experiments and actual tests have established a few general relationships that simplify the decision of log combinations. Density logs plus either sonic or neutron logs are most effective for sandstone and shale, or limestone and shale sequences. The sonic log, however, is necessary when the hole is caved or a thick mud cake is present. The neutron log should be used with the density log for shallow unconsolidated formations, where the hole contains gassy mud or water, or is empty. The epithermal neutron is preferred for the latter conditions, as it is corrected for such and also gives a more predictable value in shale. In limestone and dolomite sequences the density and neutron logs are usually the best combination. Although the sonic log provides a good contrast between limestone and dolomite, the indicated porosity tends to be too small if vugs, fractures, or reef-type porosity are present. Therefore, neutron- and density-derived porosity is compared to sonic-derived porosity to identify such non-homogeneous types of openings. In sandstone-dolomite sequences any two of the three porosity logs give good resolution. Other complex logging methods provide even more detailed information for petroleum exploration. The interpretation methods involved are also complex and usually machine computation is required.

Certain well logs also identify various mineral substances. Coal beds show a high resistivity and may also be indicated by the gamma-ray and neutron log. Because carbon is a good moderator of neutrons, the neutron log indicates a high porosity opposite coal beds. The gamma-ray log response depends on the amount of shale in the coal. The sonic log may indicate coal beds by high transit time because coal has a relatively low matrix velocity, which is related to rank and quality. The density log generally records a relatively low density for coal beds because significant mineral impurities have higher densities than the coal. By comparison of several logs the depth and thickness of coal beds can be determined within inches and the percentages of moisture, ash, and carbon estimated. An evaluation of lithology sur-

rounding coal seams can be made and the strength index determined. As the value and importance of coal continues to grow, more detailed and quantitative evaluations may be developed.

Oil shales can be identified and evaluated by a combination of several logs. The gamma-ray log shows a high radioactive response, but generally less than most shales because of the higher percentage of organic matter present. The resistivity is high largely because of the low water content and the high organic content. The density and sonic logs provide an estimate of the amount of oil yield. Sulfur, potash, and trona may also be evaluated by well logs. Each porosity log exhibits a different response to these materials, making it possible to evaluate the presence of concentrations of each. Potassium compounds, phosphates, and uranium can be determined through use of the gamma-ray log, because of the natural radioactivity associated with these minerals. Evaporite minerals may often be identified and evaluated by the combined use of gamma-ray, neutron, and density logs. The gamma-ray log indicates the amount of potassium in certain evaporities, as potassium emits natural gamma rays. The neutron log, which is dependent upon the hydrogen content, indicates the amount of water of crystallization, and the density log responds to the wide range of densities of the evaporites. Thus, evaporite minerals such as carnallite, sylvite, halite, kainite, gypsum, polyhalite, langbeinite, and anhydrite can be identified. As the well-logging industry continues to progress, other natural resources will undoubtedly be studied and evaluated by new and improved methods. The use of these new methods will depend on the importance of the minerals and the limitations of the probes.

Although man cannot physically place himself thousands of feet into the earth through the small hole made by a drilling rig, he can see into the depths with the help of the mechanical well log. The ability of the geologist or engineer to understand the subsurface of the earth continues to improve with the technological advances of the well-logging industry in combination with other scientific methods.

ACKNOWLEDGEMENTS

The writer would like to express appreciation to the well-logging companies and the staff of the

Virginia Division of Mineral Resources for their cooperation and assistance in this report. Appreciation is particularly extended to R. P. Alger of Schlumberger Well Services, P. A. Wichmann of Dresser Atlas, and D. C. Le Van of the Division's staff for their critical review of the manuscript.

✕ ✕ ✕

AIPG MEETS

The Virginia Division of Mineral Resources and the Virginia Section of the American Institute of Professional Geologists served as co-hosts at the Section's annual meeting, held in Charlottesville on September 25, 1970. A guided tour of the Division facilities was conducted during the afternoon as part of the activities in order to acquaint participants with its programs and services. Guest speakers at the evening meeting were Mr. J. A. Wheeler, Vice President of the Institute, and Dr. R. G. Wayland of the U. S. Geological Survey. Dr. James L. Calver, State Geologist and Commissioner of Mineral Resources is President-elect of the Virginia Section for the coming year, and Mr. D. C. Le Van of the Division will continue as editor.

✕ ✕ ✕

STAFF CHANGES

In September of this year the Division established a geophysical activity that will be a phase of its investigatory work in geologic studies and mineral resource development. Mr. Stanley S. Johnson who has been engaged in geophysical projects has been promoted to supervise this activity on a full time basis. Initially he will have the responsibility for magnetic and gravity surveys in which a network of control points are being set up throughout the State for the first time.

Mr. Philip T. Stafford joined the Division staff on September 16, 1970 as editor of publications and reports. He received his B. S. degree in geology from the University of Kentucky in 1949. Mr. Stafford was employed as a geologist by the Fuels Branch, Geologic Division, United States

Geological Survey for eight years in Kentucky, Texas, and Arkansas. He worked nine years as an exploration geologist and supervisor in petroleum and mineral exploration for Standard Oil Company of New Jersey in Libya, Australia, and New Zealand. During the past four years, he has been a consulting geologist in Australia, New Zealand, Tennessee, and Kentucky. He is married and has three children.

Mr. Ernest B. Nuckols III was employed by the Division on July 15, 1970 and is assisting with the preparation of a geologic report for the Shenandoah National Park area. After attending the University of Miami (Florida) for two years, Mr. Nuckols transferred to Virginia Polytechnic Institute where he received his B.S. degree in geology in 1970. His interests are structural geology and oceanography.

✕ ✕ ✕

NEWS NOTES

The Riverton Lime and Stone Company, Incorporated, opened a quarry in May 1970 near Luray, Page County, for the production of crushed stone from carbonate rocks.

The Appomattox Lime Company is operating a quarry and crushing plant for the production of agricultural stone near Oakville, Appomattox County. The facilities were utilized by State Lime Grinding Plant Number 2 of the Commonwealth of Virginia from 1937 until August 1970.

The Martinsville Stone Corporation transferred quarrying and plant operations in early 1970 from near Collinsville, Henry County, to a new location south of Fieldale in the same county. Crushed stone is being produced from gneiss at the new quarry.

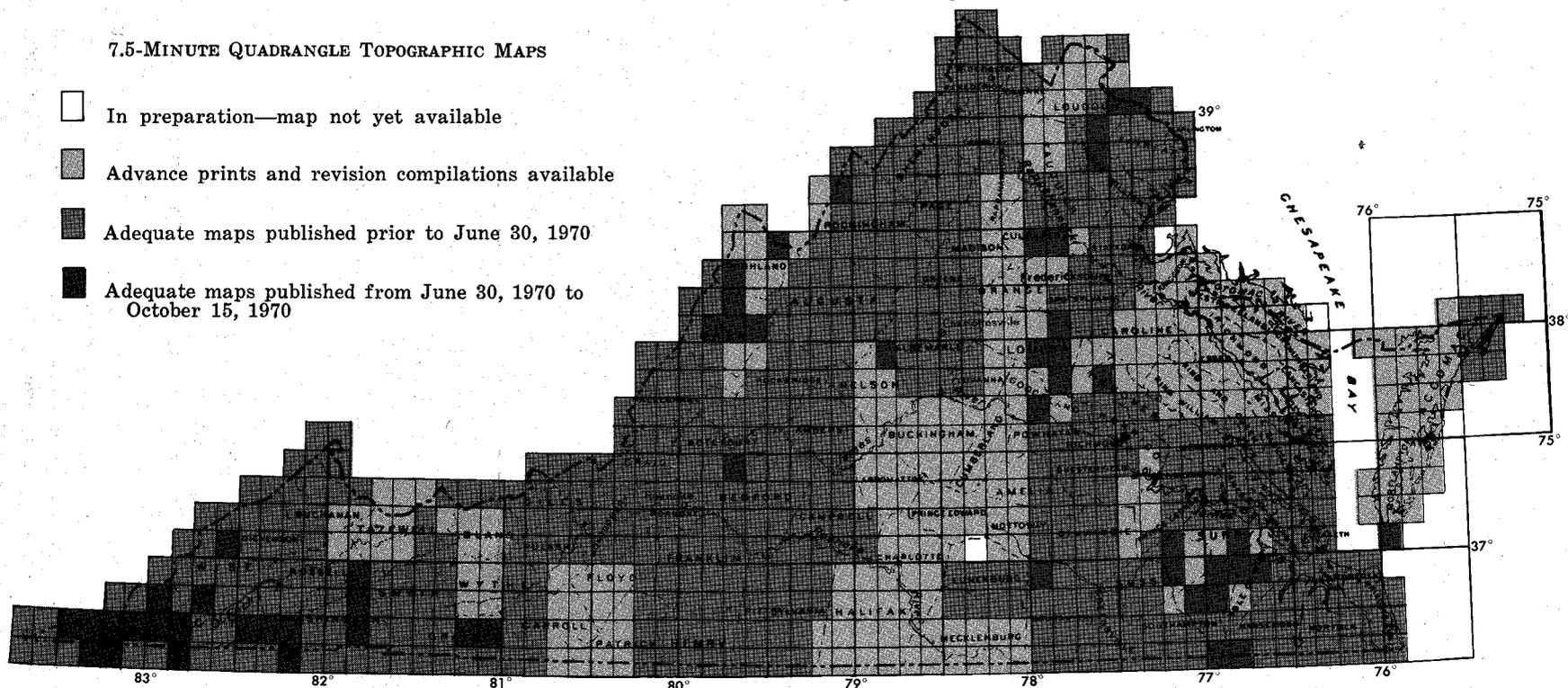
Operations of the Virginia Glass Sand Corporation and Shenandoah Silica Company, Incorporated, near Gore, Frederick County, have been consolidated under a new owner, the Unisil Corporation. The new company will continue the mining and processing of sandstone for glass sand and other industrial uses.

TOPOGRAPHIC MAPS

- | | | |
|---------------------|-------------------|----------------|
| Arcola | Elk Creek | Mustoe |
| *Back Valley | *Ewing | Pendleton |
| Bath Alum | Fishermans Island | *Plum Grove |
| *Ben Hur | Fort Seybert | *Pound |
| Brierpatch Mountain | Gainesville | Raynor |
| *Bristol | Gates | Riverdale |
| Buckner | Germanna Bridge | *Rose Hill |
| Burnsville | *Glade Spring | Runnymede |
| Contrary Creek | Greenfield | *Saltville |
| Cow Knob | Green Valley | Sedley |
| Culpeper | Hanover Academy | Seneca |
| Dabneys | *Hilton | Smithfield |
| *Damascus | *Hubbard Springs | *Sneedville |
| *Danieltown | Ivor | Sterling |
| Disputanta South | *Keokee | *Stickleyville |
| Doe Hill | Littleton | Vicksville |
| *Duffield | *Mendota | *Wallace |
| *East Stone Gap | Montvale | Warm Springs |
- * Updated map

7.5-MINUTE QUADRANGLE TOPOGRAPHIC MAPS

- In preparation—map not yet available
- Advance prints and revision compilations available
- Adequate maps published prior to June 30, 1970
- Adequate maps published from June 30, 1970 to October 15, 1970



ADVANCE PRINTS AND REVISION COMPILATIONS

Advance prints and copies of revision compilations are available at 50 cents each from the U. S. Geological Survey, Topographic Division, 1109 N. Highland St., Arlington, VA 22210.

PUBLISHED MAPS

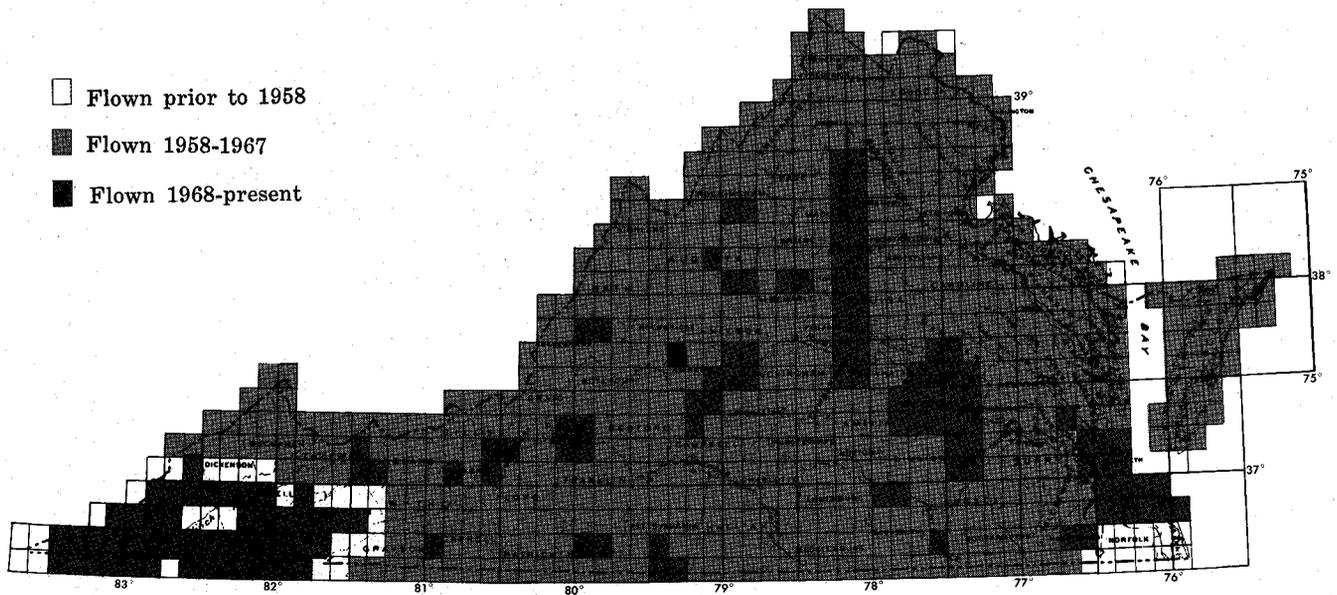
State index is available free. Updated maps, on which recent cultural changes are indicated, are now available for certain areas of industrial, residential, or commercial growth. Published maps are available at 50 cents each from the Virginia Division of Mineral Resources, Box 3667, Charlottesville, VA 22903.

Virginia Division of Mineral Resources
Box 3667
Charlottesville, VA 22903

Second-class postage paid at
Charlottesville, Virginia.

Return Postage Guaranteed

AERIAL—MAPPING PHOTOGRAPHY



Information concerning availability of Virginia photography may be obtained from the U. S. Geological Survey, Map Information Office, Washington, DC 20242.