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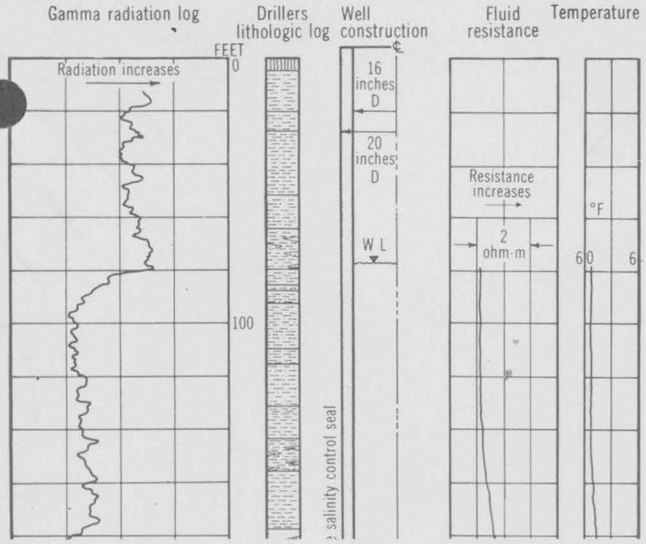

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DEPARTMENT OF THE INTERIOR

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GEOPHYSICAL LOGGING OF BOREHOLES FOR HYDROLOGIC STUDIES

JOHNSON

HYDROLOGIC LABORATORY

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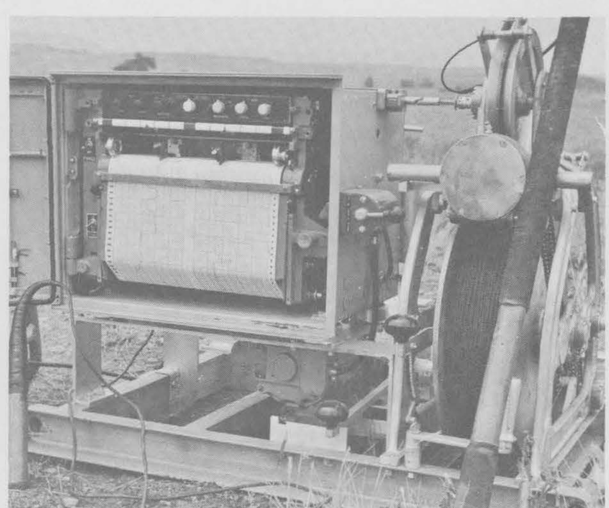

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By A. I. Johnson

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When the Schlumberger brothers made their first electrical survey of a borehole in France more than a quarter of a century ago, only one simple curve was recorded---resistivity. The early equipment was very simple but signaled the beginning of a whole new industry that has provided many useful tools in the solution of hydrologic problems.

The hydrologist has the problem of selecting the logging methods most efficient, technically and economically, for answering his particular need. Information on aquifer depth, thickness, extent and structure, as well as details of permeability, porosity, moisture content, and the chemical quality of the contained water, are often needed in hydrologic studies. Borehole geophysical logging methods now are available to provide the hydrologist with the data needed to give, through interpretation, all of the above information.

If funds are not to be wasted on unnecessary data, the logging methods must be chosen with due regard for the problem at hand. When there is doubt as to what type of log will give the information desired, logging experts in the hydrologist's organization or in the technical service centers of commercial logging companies should be consulted. In addition to a knowledge of the type of information desired from the logs, those logging experts probably would desire information on the following borehole conditions: depth, size, and condition of borehole; type of fluid in hole; classification and general thickness of formations; and quantity of fluid loss into formations. The technical consultation would be of even greater assistance if requested prior to drilling of boreholes.

It is the purpose of this paper to list various methods available for the geophysical logging of boreholes, and to briefly summarize the use which may be made of each log, as well as the specific borehole characteristics that provide conditions for optimum use of each method. (See table 1.) This paper originally was prepared as a handout for ground-water short courses and as a training aid for foreign participants, but now is presented in this form to provide greater availability. The information was compiled from the references at the end of this paper and does not necessarily represent the opinions of the author.

Table 1.--Borehole geophysical logging methods

Method	Uses	Recommended conditions
Electric logging		
Single-electrode resistance	Equivalent to very short normal curve (1 or 2 inches). Determining depth and thickness of thin beds. Identification of rocks, provided general lithologic information is available, and correlation of formations. Determining casing depths.	Fluid-filled hole. Fresh mud required. Hole diameter less than 8 to 10 inches. Uncased hole only is logged.
Short normal	Spacing of 16 inches. Picking tops of resistive beds. Determining resistivity of the invaded zone. Estimating porosity of formations (deeply invaded and thick interval). Correlation and identification, provided general lithologic information is available.	Fluid-filled hole. Fresh mud. Ratio of mud resistivity to formation water resistivity should be .2 to 4. Log only in uncased portion of hole.
Long normal	Spacing 64 inches. Determining true resistivity in thick beds where mud invasion is not too deep. Obtaining data for calculation of formation-water resistivity.	Fluid-filled hole. Ratio of mud resistivity to formation water resistivity should be .2 to 4. Only uncased portion of hole logged.
Deep lateral	Spacing approximately 19 feet. Determining true resistivity where mud invasion is relatively deep. Locating thin beds.	Fluid-filled, uncased hole. Fresh mud. Formations should be of thickness different from electrode spacing and should be free of thin limestones.
Limestone sonde	Spacing 32 inches. Detecting permeable zones and determining porosity in hard rock. Determining formation factor *in situ*.	Fluid-filled, uncased hole. May be salty mud. Uniform hole size. Beds thicker than 5 feet.

Table 1.--Borehole geophysical logging methods--Continued

Method	Uses	Recommended conditions
Electric logging--Cont'd		
Laterolog	Investigating true resistivity of thin beds. Used in hard formations drilled with very salty muds. Correlation of formations, especially in hard rock regions.	Fluid-filled, uncased hole. Salty mud satisfactory. Mud invasion not too deep.
Microlog	Determining permeable beds in hard or well consolidated formations. Detailing beds in moderately consolidated formations. Correlation in hard rock country. Determining formation factor *in situ* in soft or moderately consolidated formations. Detailing very thin beds.	Fluid required in hole. Only uncased portion of hole is logged. Bit-size hole, (caved sections may be logged provided hole enlargements are not too great).
Microlaterolog	Determining detailed resistivity of flushed formation at wall of hole when mud cake thickness is less than 3/8 inch in all formations. Determining formation factor and porosity. Correlation of very thin beds.	Fluid-filled, uncased hole. Thin mud cake. Salty mud permitted.
Spontaneous potential	Helps delineate boundaries of many formations and the nature of these formations. Indicating approximate chemical quality of water. Indicate zones of water entry in borehole. Locating cased interval. Detecting and correlating permeable beds.	Fluid-filled, uncased hole. Fresh mud.

Table 1.--Borehole geophysical logging methods--Continued

Method	Uses	Recommended conditions
Radiation logging Gamma ray	Differentiating shales, clays, and marls from other formations. Correlation of formations. Measurement of inherent radioactivity in formations. Checking formation depths and thicknesses with reference to casing collars prior to perforating casing. For shale differentiation when holes contain very salty mud. Radioactive tracer studies. Logging dry or cased holes. Locating cemented and cased intervals. Logging in oil-base muds. Locating radioactive ores. In combination with electric logs, for locating coal or lignite beds.	Cased, uncased holes. Dry holes or hole filled with any fluid. Should have appreciable contrast in radioactivity between adjacent formations.
Neutron	Delineating formations and correlation in dry or cased holes. Qualitative determination of shales, tight formations, and porous sections in cased wells. Determining porosity and water content of formations, expecially those of low porosity. Distinguishing between water- or oil-filled and gas-filled reservoirs. Combining with gamma-ray log for better identification of lithology and correlation of formations. Indicating cased intervals. Logging in oil-base muds.	Cased, uncased holes. Dry holes or holes filled with any fluid. Formations relatively free from shaly material. Diameter less than 6 inches for dry holes. Hole diameter similar throughout.

Table 1.--Borehole geophysical logging methods--Continued

Method	Uses	Recommended conditions
Induction logging	Determining true resistivity, particularly for thin beds (down to about 2 feet thick), in wells drilled with comparatively fresh mud. Determining resistivity of formations in dry holes. Logging in oil-base muds. Defining lithology and bed boundaries in hard formations. Detection of water-bearing beds.	Uncased hole. Dry hole, or hole filled with fluid (preferably not too salty).
Sonic logging	Logging acoustic velocity for seismic interpretation. Correlation and identification of lithology. Reliable indication of porosity in moderate to hard formations; in soft formations of high porosity it is more responsive to the nature rather than quantity of fluids contained in pores.	Not affected materially by type of fluid, hole size, mud invasion.
Temperature logging	Locating approximate position of cement behind casing. Determining thermal gradient. Locating depth of lost circulation. Locating active gas flow. Used in checking depths and thickness of aquifers. Locating fissures and solution openings in open holes, and leaks or perforated sections in cased holes. Reciprocal-gradient temperature log may be more useful in correlation work.	Cased or uncased. Can be used in empty hole if logged at very slow speed, but fluid preferred in hole. Fluid should be undisturbed (no circulation) for 6 to 12 hours minimum prior to logging; possibly several days may be required to reach thermal equilibrium.

Table 1.--Borehole geophysical logging methods--Continued

Method	Uses	Recommended conditions
Fluid-conductivity logging	Locating point of entry of different quality water through leaks or perforations in casing or opening in rock hole. (Usually fluid-resistivity is determined and must be converted to conductivity.) Determining quality of fluid in hole for improved interpretation of electric logs. Determining fresh-salt-water interface.	Fluid required in hole, cased or uncased. Temperature log required for quantitative information.
Fluid-velocity logging	Locating zones of water entry into hole. Determining relative quantities of water flow into or out of these zones. Determine direction of flow up or down in sections of hole. Locating leaks in casing. Determine approximate permeability of lithologic sections penetrated by hole, or perforated section of casing.	Cased or uncased holes, fluid filled. Injection, pumping, flowing, or static (at surface) conditions. Flange or packer units required in large diameter holes. Caliper (section gage) logs required for quantitative interpretation.
Casing-collar locator	Locating position of casing collars and shoes for depth control during perforating. Determining accurate depth references for use with other types of logs.	Cased hole.
Caliper (section gage) survey	Determining hole or casing diameter. Indicates lithologic character of formations and coherency of rocks penetrated. Locating fractures, solution openings, and other cavities. Correlation of formations. Selection of zone	Fluid-filled or dry hole, cased or uncased (in cased holes does not give information on beds behind casing).

Table 1.--Borehole geophysical logging methods--Continued

Method	Uses	Recommended conditions
Caliper (section gage) survey--Cont'd	to set a packer. Useful in quantitative interpretation of electric, temperature and radiation logs. Used with fluid-velocity logs to determine quantities of flow. Determining diameter of under-reamed section prior to placement of gravel pack. Determining diameter of hole for use in computing volume of cement to seal annular space. Evaluating the efficiency of explosive development of rock wells. Determining construction information on abandoned wells.	
Dipmeter survey	Determining dip angle and dip direction (from magnetic north) in relation to well axis in the study of geologic structure. Correlation of formations.	Uncased, fluid-filled hole. Carefully picked zones needing survey, because of expense and time required. Directional survey required for determination of true dip and strike (generally obtained simultaneously with dipmeter curves).
Directional (inclinometer) survey	Locating points in a hole to determine deviation from the vertical. Determining true depth. Determining possible mechanical difficulty for casing installation or pump operation. Determining true dip and strike from dipmeter survey.	Uncased hole. Dry or fluid-filled hole.

Table 1.--Borehole geophysical logging methods--Continued

Method	Uses	Recommended conditions
Magnetic logging	Determining magnetic field intensity in borehole and magnetic susceptibility of rocks surrounding hole. Studying lithology and correlation, especially in igneous rocks.	Uncased hole. Dry or fluid-filled hole.

References:

Dakhnov, V. N., 1962, Geophysical well logging: Colorado School Mines Quart., v. 57, no. 2, 445 p.

Guyod, Hubert, 1952, Electrical well logging fundamentals: Houston, Tex., Well Inst. Developing Co., 104 p.

_____1957, Electric detective: Water Well Jour., Mar., May, 7 p.

Jones, P. H., and Buford, T. B., 1951, Electric logging applied to ground-water exploration: Geophysics, v. 16, no. 1, p. 115-139.

Jones, P. H., and Skibitzke, H. E., 1956, Advances in geophysics: New York, Academic Press, v. 3, p. 241-300.

LeRoy, L. W., 1951, Subsurface geologic methods--a symposium: 2d ed., Colorado School Mines, p. 364-455.

Runcorn, S. K., ed., 1960, Methods and techniques in geophysics: London, Interscience Publishers, Ltd., v. 1, p. 62-103.

Schlumberger Well Surveying Corporation, 1958, Introduction to Schlumberger well logging: Houston, Tex., Schlumberger Well Surveying Corp., Schlumberger Doc. 8, 176 p.