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NEW DEVELOPMENTS IN GROUND-WATER EXPLORATION

BY

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New Developments in Ground-Water Exploration

By Carl A. Bays

SPECIAL investigations of the ground-water geology of northeastern Illinois have been in progress during the past year. Certain of the methods used in these studies have been somewhat novel in their application to ground water although they include methods commonly used in scientific geological research and in petroleum engineering. Attention has been given to all the phases of the geology of ground water in the area, but the present discussion is restricted primarily to the deep wells that penetrate the sandstone aquifers of the region.

Geological Methods

In the past the primary service of the geologist in ground-water studies in Illinois has been to make careful studies of the drill-cuttings from wells. The correlation of these records and the records kept by drillers has permitted the identification and tracing of subsurface units and has thereby increased the understanding of geological conditions over broad regions. The subsurface data obtained have been used in many practical ways, such as in the estimation of depths to producing zones in new areas, in the outlining of casing and liner programs for wells and in many others.

During the past year a number of methods not normally used in the study of drill-cuttings have been employed to permit a better understanding of the regional geology and of the physical characteristics of the various formations. These have augmented the usual sample-study of formations and have given much valuable geological data. These special methods of study include:

1. *Insoluble Residues:* The carbonate rocks—limestone and dolomite—comprise a large proportion of the formations penetrated in northeastern Illinois. Insoluble residues of samples of these formations are made by digesting samples in hydrochloric acid. The determination of the character and percentage of the residue gives much valuable information on the character of the carbonate rocks. This method had been commonly used on well samples in Illinois and elsewhere for some time prior to these special studies, but particular value has been obtained from the correlation of these data with the data obtained from the other methods described below.

A paper presented on April 8, 1943, at the Illinois Section Meeting, Springfield, Ill., by Carl A. Bays, Special Geologist, Ground-Water Geology, Illinois State Geological Survey, Urbana, Ill.

2. *Heavy Accessory Minerals:* The sandstone formations are composed largely of quartz sand grains, more or less rounded and cemented; but in all these formations there is a small percentage of rare minerals. These rare or accessory minerals are diagnostic of many of the formations and indicate the sources of the sands. Most of the minerals are heavier than the quartz and can be readily separated from it by floating off the quartz in a high-gravity liquid, such as bromoform or tetrabromoethane. Studies of heavy accessory minerals have been widely used in many phases of geological work during the past decade, but were first extensively applied to well samples during the past year. They have proved useful in recognizing caving sands in wells and in tracing and identifying the sandstone-producing zones.

3. *Core Analysis:* In the oil industry, cores of the oil sands are usually taken and analyzed for permeability (usually measured in millidarcys) and porosity (usually reported as per cent by weight). Cores have not commonly been cut in water wells in Illinois in the past. However, cores obtained by the use of the Geological Survey's cable-tool core-barrel, as well as large caving fragments, obtained after shooting, and outcrop samples, have yielded samples large enough for core-analysis determinations of the porosity and permeability of all formations in northeastern Illinois. Thus, fundamental data on the character of the water-bearing strata have been obtained. It has been possible to indicate the physical limits of the rate of movement of ground water through the sandstones, to recognize that the carbonate rocks produce almost entirely from secondary crevice, cave or solution-cavity systems and not from the pore space in the rocks, and to establish from these and other data that the spacing between water wells is one of the most important factors controlling ground-water production.

4. *Size Analysis:* The use of mechanical or screen analyses of the size of grains in aquifers has long been a practice in water wells to determine screen sizes. Mechanical analyses also give data on the texture of sandstones. The data from size studies, from which sorting and other textural features are determined, indicate the permeability and porosity of the aquifers. The data may also be used for correlation of zones from well to well.

5. *Outcrop Studies:* The studies of the strata exposed at the surface of northeastern Illinois give much information as to the structural conditions which control the flow of water in that area. Studies of the producing strata which crop out in northcentral Illinois and southern Wisconsin give valuable information on the physical characters of the aquifers and the limits of rate of movement of water through them. Outcrop samples are carefully collected and compared with well samples. Insoluble residues, heavy mineral studies and porosity and permeability studies are made on outcrop samples.

6. *Miscellaneous Laboratory Techniques:* A number of other methods of laboratory study of well samples occasionally find important usage in ground-water geology. Shape of grains is an important factor controlling the permeability of sandstone aquifers; and studies of shape must be used properly to interpret porosity and permeability conditions. Microscopic study of well cuttings in thin-sections made by special techniques also gives valuable data on the texture of the aquifers. In

the carbonate rocks, special stains may be used to differentiate limestone from dolomite. In many well cuttings microfossils, which may be identified and used for correlation purposes, are also present.

Application of Geological Methods

All of the geological methods are employed to obtain an integrated analysis of the regional ground-water geology. The data from well sample studies, heavy minerals, size analyses of the sandstones, insoluble residues and core analyses contribute to understanding the stratigraphy of the region and the variations in rock character. From these data the general conditions of structure, the folding and faulting of the strata may be interpreted. The lateral continuity and variations in permeability of the water-producing zones can be recognized. The various natural factors that control the amount of ground water and the circulation of ground water can be evaluated. The natural factors that control water levels and the character of the water produced can be determined in some cases. Although a regional picture is thus obtained, the producing conditions in any individual well still may be uncertain, because of the many local variations in geological conditions and the many differences in engineering and production practice.

Oil Well Practices

Oil-well production engineering has gone far in the exact science of determining the factors controlling production of oil and the conditions within oil wells. In the oil fields numerous tools have been developed to obtain the precise information needed properly to understand oil reservoirs and to produce oil with the maximum efficiency at lowest cost. Water is no less a valuable natural resource, but the water-well industry has not progressed as rapidly in the development of tools and instruments to get a more complete knowledge of the water well and to develop, thereby, the means to increase the efficiency of water-well operation.

During the past year a number of the special oil-field methods of investigation have been used in water wells in northeastern Illinois by the Illinois Geological Survey. This work has been done in co-operation with the Halliburton Oil Well Cementing Co. and the Schlumberger Well Surveying Corp.; the splendid co-operation of the staffs of both companies is gratefully acknowledged.

Geophysical Surveys

The term "geophysical logging" or "geophysical surveying" of water wells is applied to the special oil-field methods or to the modifications thereof used in water wells. A geophysical survey of any well includes the use of several logging devices (standard electric logging, temperature logging, caliper logging, resistivometer logging, current meter surveys) and the integration of these data into a composite geophysical log.

The standard oil-field electric log is run on most rotary drilled wells to obtain an accurate log of the formations present, to determine the presence or absence of saturation in commercial quantities, to obtain correct measurements and for many other uses. Usually this service is run from specially designed instrument and winch trucks which carry the instruments, the recorders, the line for running the instruments in the well and which are complete even to facilities for dark-

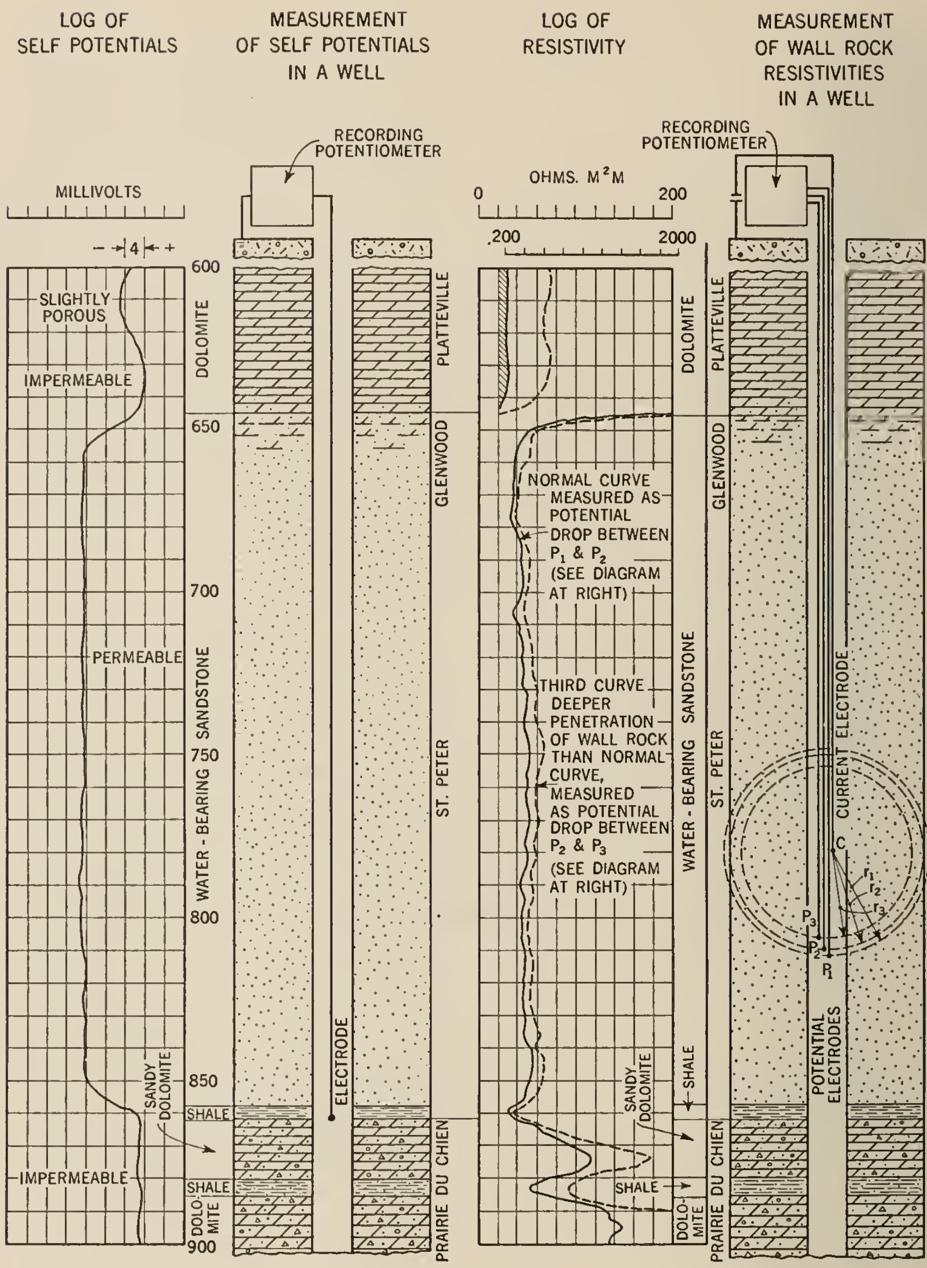

Fig. 1. Electric Logging of Water Well

room work. All observations are recorded as logs, or continuous curves, photoelectrically recorded on film or sensitized paper by very sensitive galvanometers which are motivated by the electrical circuits involved. All of the other instruments used in geophysical logging have been designed so that they may be run by the same trucks, and the data from them are recorded in the same fashion as the regular electric log.

Electric Logging: The regular electric log consists of two types of curves. Potential curves (Fig. 1) are the natural or spontaneous potential charges on the various rock formations in a well. The variations in potential curves largely reflect the porosity or permeability of the wall rock, but some other factors (such as circulation of water) which cause potential currents influence these curves. In general, high potentials (negative) indicate high porosity or effective permeability and low potentials indicate impermeable or tight zones.

The resistivity curves are made by applying current to the formations and measuring their resistivity to the applied currents. Different spacings of the electrodes which measure the resistivity are used so that different spheres of current are applied and thereby different depths of penetration are recorded. Generally, limestones and dolomites have very high resistivities, shales have low resistivities and sandstones have intermediate resistivities, dependent in part upon the character of the fluid content of the pores of the sandstone. Deep penetration curves reveal the zones of high or low salinity in sandstones, although the water in the well bore is of different composition.

Special modifications of the regular electric-log curves are made to obtain particular information on water wells. The potential curves recorded in many water wells lack relief and the sensitivity of potential measurements in some wells may be greatly increased by adding salt to the water in the well bore. Also it has been found that increasing the head of a well by keeping it filled with water during logging of the potential curve will give greatly increased values in potential in the porous zones.

Temperature Logging: A special electronic thermometer which will record temperatures of fluids as a continuous graph has been adapted for well use (Fig. 2). Temperature surveys indicate circulation conditions within water wells. Normally, anomalies are obtained in zones where water is entering the well, as from behind the casing, or where water is being lost, as in crevices of thieving zones. The temperature curves are used to locate the zones of production of water of various temperatures, and with temperature data on the production of any well, it is possible to use the temperature log to evaluate the quantities of water produced from various zones.

Caliper Surveys: The hole caliper, an instrument which is run on the standard electric logging line, consists of four movable arms which motivate a resistance so calibrated as to measure the average hole diameter. The instrument is run into the hole with the arms bound and they are released by electrical detonation of a small powder charge. The tool is then run up the hole and the log is recorded from the diameter measured by the four arms (Fig. 3).

Caliper logging has given valuable data on the effect of shooting of the sandstones, on the caving zones, on the relative hardness of various formations and on the condition of casing and liners.

Resistivometer Surveys: The resistivometer or salinity meter is used to measure the resistivity of the fluid in a well bore (Fig. 4). Measurements reflect the variations in salinity of the water. It is possible from resistivometer logs in many wells to understand the circulation conditions and to recognize the zones that produce waters of different composition.

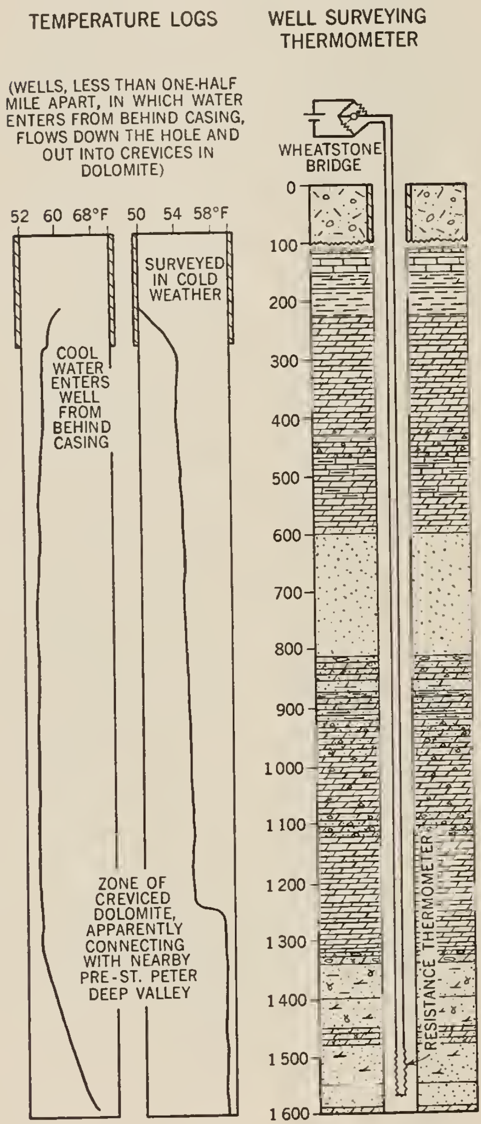

Fig. 2. Temperature Logging of Well

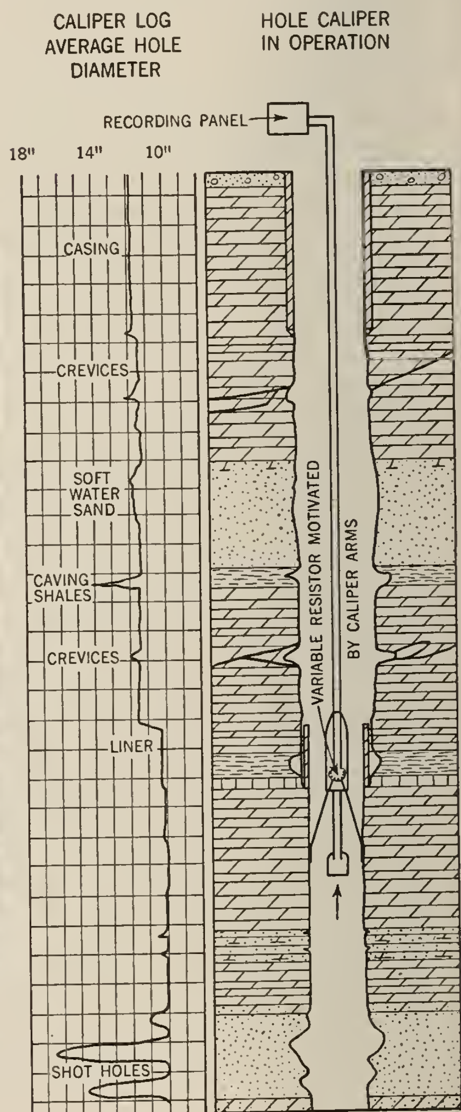

Fig. 3. Caliper Logging of Well

A technique has been developed for a fairly even distribution of salt within a well bore. After salting a well, a resistivometer survey is used to note the effect of circulation on the salt within a well. Usually the zones giving water into the well bore dilute the salt added, but in the zones where water is leaving the well bore, there is a high concentration of salt. These conditions are readily recognized.

Current Meter Surveys: The current meter is used to measure the rate and indicate the direction of move-

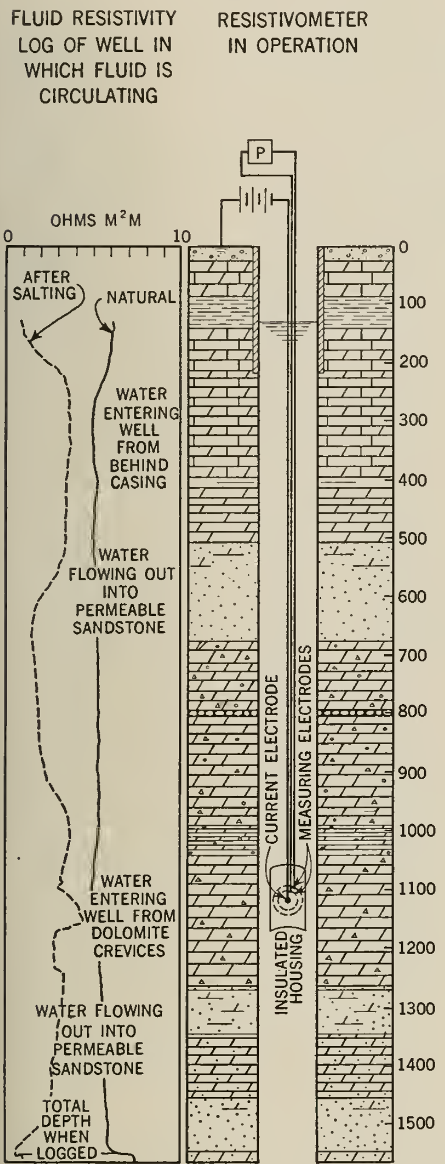

Fig. 4. Resistivometer Survey of Well

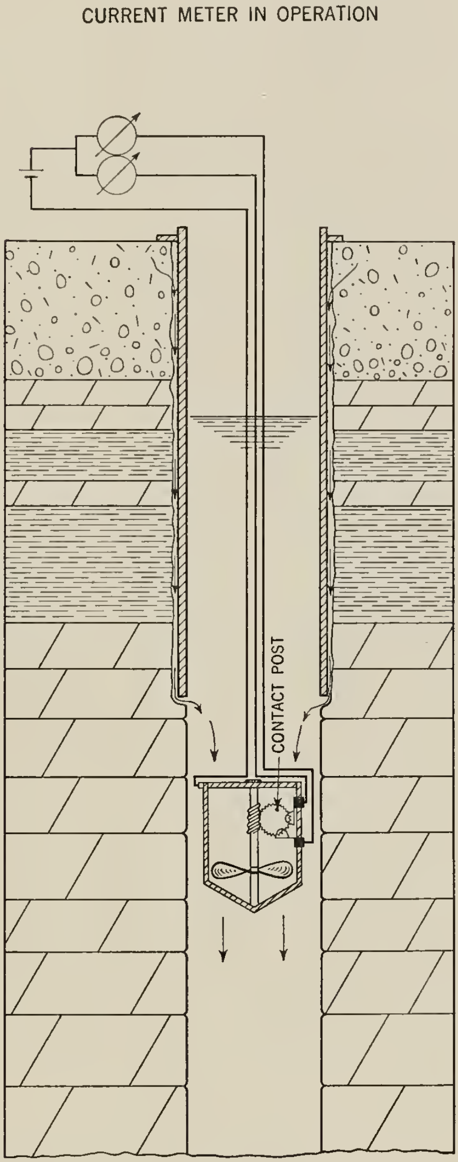

Fig. 5. Current Meter Survey of Well

ment of water within a well bore. Two types have been developed. One is a propeller meter (Fig. 5) which is so constructed as to measure rate of flow by signals received from the turning of the propeller. At each revolution of the gear, which is driven by the propeller, the contact post com-

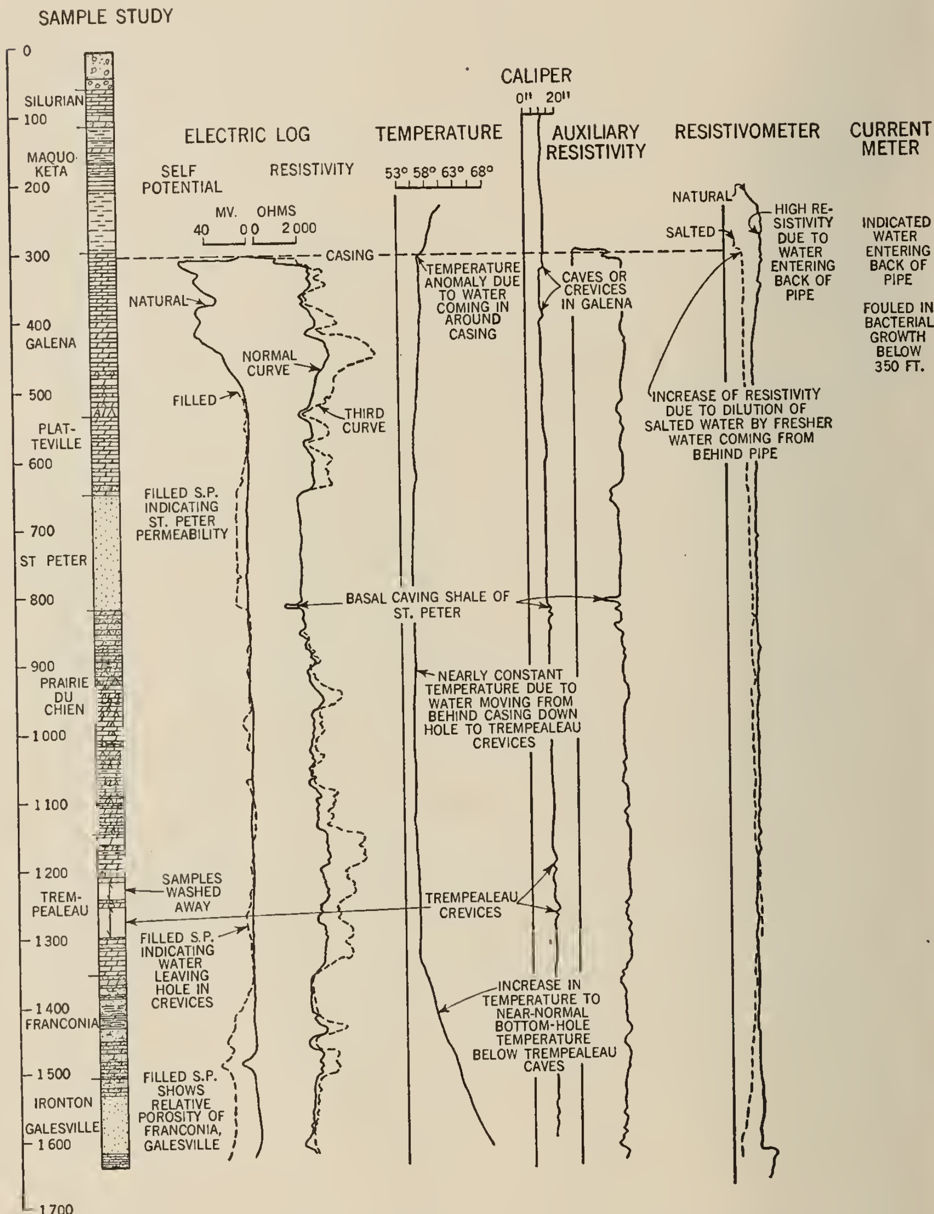

FIG. 6. Composite Geophysical Log of a Well in Will County, Ill.

pletes two electrical circuits, producing two different signals at the surface. The sequence of the signals indicates the direction and the frequency indicates the rate of fluid movement within the well.

The other type of meter consists of a counterweighted vane which is deflected by water movement. The vane motivates a resistance so that a continuous record of water movement in a well may be made by running the instrument at known rates of speed and deflection.

Composite Geophysical Logs: In general, the various tools used in geophysical logging give separate lines of evidence for understanding the many different problems and conditions within a water well. Together, they present a complete picture of the information that can be determined and these data should be inter-related. Also water-level data, pumpage data, sample study and other geological data are of aid in integrating the data from geophysical surveys. All of the results are grouped in a single composite geophysical log, such as is shown in Fig. 6.

Results of Geophysical Logging

Geophysical logs have permitted the assemblage of the most complete data possible on the deep water wells in northeastern Illinois. It has been found that the log of a new well forms a valuable record for the well owner's use in the operation and understanding of the production of the well. More benefit, however, has been obtained by use of geophysical surveys in older wells in which operation difficulties, pollution or contamination, or other conditions have rendered them inefficient or useless. Such wells when reconditioned by proper engineering practice usually are greatly improved.

The following specific results have been obtained in various wells surveyed:

1. A complete detailed log of all the formations not cased in the well is made.

2. The exact measurements of the position of the casing and liners are obtained and some knowledge of the condition of the pipe is usually learned in old wells.

3. The water-producing zones are located and their comparative importance within a well is evaluated. These studies have led to recognition that the producing portions of any formation are restricted in thickness and that the entire sandstone sections of the aquifers do not produce water equally.

4. A record of the salinity of the water within the well bore is obtained and the zones of production of less saline waters are usually recognized.

5. The caving zones that are not cased off within wells are readily located.

6. The thieving zones, that is, zones through which quantities of water are leaving the well bore, either under static or producing conditions, are located.

7. The circulation conditions within a well are recognized.

8. The source beds of waters of different temperature are located.

9. A number of special conditions such as water coming from behind casing, partially collapsed casing or liners, production of water from caves and crevices and similar matters may be recognized from geophysical logs.

10. The effect of shooting is evaluated by logging before and after.

11. In wells where tools have been lost or other special conditions such as parted liners, etc., occur, it is possible

to locate the iron in the hole and in some cases to give information that will permit the ready solution of such problems.

12. Exact measurements of fluid levels are made during geophysical surveys under conditions of thieving in the well and producing conditions in nearby wells, so that much valuable information on the relation between wells and causes of variation in water levels is obtained. In conjunction with geophysical logging valuable data have also been obtained by use of the echometer, an instrument for determining fluid levels by sonic reflection which can be used to measure fluid levels in pumping and non-pumping wells in which no air lines or other measuring devices are available.

13. From geophysical studies and observation of nearby wells during surveying, the relations between wells as to interference and zones of connection can be recognized. From these data conclusions as to well spacing can be reached.

Thus it is recommended that in northeastern Illinois spacing of wells to the Galesville formation should exceed 6800 ft. for optimum water level and production conditions with normal high summer pumpage and low winter pumpage. It is recommended, too, that wells to the St. Peter sandstone should be at least 4800 ft. apart under the same conditions. Where there are special pumpage conditions, variations in optimum spacing may be calculated from the geophysical survey and other data by use of formulas derived from basic laws of transmission of fluids through permeable media.

Benefits of Studies

During the period of the special studies of ground-water geology of northeastern Illinois, the geological and geophysical techniques here described have brought new understanding of the problems of ground-water production and control. Economies have been effected in water works operation by war industries and by municipalities in reconditioning or completing wells after the information was available from geophysical surveys. The results of the investigation suggest that a number of new practices may be formulated to improve the quality of water and promote more efficient use of ground-water supplies.

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