EXPERIMENTAL DRILL HOLE LOGGING IN POTASH DEPOSITS OF THE CARLSBAD DISTRICT, NEW MEXICO

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60-84

U. S. GEOLOGICAL SURVEY

Released to open files

January 5 1960

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ABSTRACT

Experimental logging of holes drilled through potash deposits in the Carlsbad district, southeastern New Mexico, demonstrate the considerable utility of gamma-ray, neutron, and electrical resistivity logging in the search for and identification of mineable deposits of sylvite and langbeinite. Such deposits are strongly radioactive with both gamma-ray and neutron well logging. Their radioactivity serves to distinguish them from claystone, sandstone, and polyhalite beds and from potash deposits containing carnallite, leonite, and kainite. These latter strata and deposits are radioactive with gamma-ray logging but yield no radiation with neutron logging. Porous beds, such as sandstone strata, and solution cavities, such as those commonly formed in potash deposits by rotary drilling of evaporites, are less resistive than other materials. Low resistivity provides a means for differentiating between potash deposits and polyhalite beds on electrical resistivity logs of holes drilled with fresh-water and salt-base muds.

INTRODUCTION

Natural potassium includes 0.012 percent of the K^{40} isotope. This isotope is radioactive, has a half-life of 1.3×10^9 years, and emits beta particles and gamma-rays (Birch, 1951). Any potassium present in rock formations contributes to the total quantity of gamma-rays measured during gamma-ray logging of drill holes. The amount of potassium commonly present in terrestrial materials is often so small that the gamma-rays emitted by its radioactive isotope are not a significant factor in the interpretation of gamma-ray logs. However, rocks, such as some evaporites of marine origin, contain appreciable amounts of potassium, and show anomalous radioactivity on gamma-ray logs of drill holes.

Experimental gamma-ray logging of five core holes drilled through potash deposits and potassium-rich strata of the Salado formation in southeastern New Mexico was undertaken by the Geological Survey during the period of June 1950 to February 1952. Gamma-ray logs of the five drill holes were made by the Geological Survey. Under contract with the Geological Survey gamma-ray and neutron logs of three of the drill holes were made by one contractor, and gamma-ray and electrical resistivity logs were made of the same holes by another contractor. The long time interval between the start and the completion of this experimental work resulted from the requirements established for the selection of drill holes. It was essential that the drill holes penetrate several types of deposits. A depth limitation on the logging operations was imposed by the cable length available on the Geological Survey's logging equipment and by the additional cost of preparing the drill holes for the larger diameter instruments used by the commercial well surveying companies.

Therefore, many of the drill holes completed during this period could not be used for the experimental work.

The investigation was undertaken by the Geological Survey as part of a study of the potash resources of southeastern New Mexico. The objectives of the experimental logging were: (1) to determine the feasibility of identifying potash deposits from radioactivity and electrical resistivity logs of holes drilled in exploration for oil and gas; (2) to explore the possibilities of making thickness and grade determinations of potash deposits from gamma-ray logs; and (3) to determine whether or not deposits of anhydrous potassium minerals can be distinguished from deposits of hydrous potassium minerals by means of either neutron logs or electrical resistivity logs. The successful use of any of these logging techniques can aid the search for potash deposits, because oil companies drill many holes through evaporites from which the cores are not taken, but in which radioactivity and electrical resistivity logs are made.

The drill holes in which experimental logging was conducted are in the Carlsbad potash district. This district comprises about 1,050 square miles in central eastern Eddy County and western Lea County, New Mexico (index map of figure 1). The marine evaporites of the area were described by Kroenlein (1939), Lang (1942), and Adams (1944). An excellent discription of the minerals which occur in the evaporites of the area was presented by Schaller and Henderson (1932), and Dunlap (1951) describes a potash deposit exposed in underground workings on the 800' level of the International Minerals & Chemical Corp. mine.

The experimental logging of drill holes was carried out with the cooperation of the International Minerals & Chemical Corp., the Potash Company of America, and the Southwest Potash Corp., all of whom permitted access to their drill holes and provided analytical data on the chemical composition of the cores recovered from their holes. The Lane Wells Company, Schlumberger Well Surveying Corp., and Mr. Paul C. Teas of Fort Worth, Texas contributed general information and copies of typical radioactivity and electrical resistivity logs of holes drilled for oil and gas.

GEOLOGY

The sedimentary rocks penetrated by holes drilled for potash deposits in the Carlsbad district are, in an ascending order, late Permian, Triassic, and Quaternary in age.

The rocks of late Permian age are composed dominantly of marine evaporites with minor amounts of dolomite and red beds. They are divided, in an ascending order, into the Castile, Salado, and Rustler formations. The Castile formation consists of about two-thirds laminated anhydrite and one-third salt; the Salado formation is dominantly salt; and the Rustler formation comprises interbedded anhydrite, dolomite, red beds, and salt. These late Permian rocks attain a maximum thickness of almost 5,000 feet in the Delaware basin--a large structural depression in which the southern half of the Carlsbad district is located (index map of figure 1). The evaporites extend beyond the margin of the basin into the adjoining structurally higher Northwestern Shelf to the north and Central Basin Platform to the east (index map of figure 1). Here the evaporites rest on dolomite and anhydrite of the Tansill formation of late Permian age. The upper surface of the Permian rocks in the area is marked by a structural break along which the strata are truncated and reduced in thickness.

Resting unconformably on the upper Permian evaporites of the area are 1,200 feet of red beds. The red beds are composed of reddish-brown claystone, siltstone, and fine- to coarse-grained sandstone, and are divided, in an ascending order, into the Pierce Canyon redbeds and the Santa Rosa sandstone (Lang, 1942). The red beds of the two formations may range from late Permian(?) to Late Triassic in age.

The Triassic red beds are unconformably overlain by the Gatuna formation and surficial deposits of Quaternary age. The Gatuna formation is a poorly bedded, semiconsolidated body of reddish-brown claystone, siltstone, and conglomeratic sandstone, and many of its constituents are derived from the redbeds of the Pierce Canyon and Santa Rosa formations. The surficial deposits of the area include widespread caliche, alluvium composed of clay, silt, sand, and gravel, playa deposits consisting of salt, gypsum, and calcareous and gypsiferous clay and silt, and loose, wind-blown sand. The Quaternary rocks and deposits generally are thin, although locally they thicken to about 400 feet.

The potash deposits of the Carlsbad district occur in the Salado formation. This formation is largely a monotonous sequence of thin-bedded halite interrupted at irregular and widely spaced intervals by layers composed of anhydrite, polyhalite, and mixtures of the two minerals (fig. 1). A few fine-grained sandstones and siltstones are interbedded with the halite, and thin gray claystone seams typically are present at the base of anhydrite and polyhalite beds. Detrital materials consisting of clay, mica, and quartz are present in many of the halite beds, and account for as much as 25 percent of the constituents in some salt beds. Most of the halite strata contain minor amounts of potassium minerals which seldom exceed 5 percent. The most abundant and widespread potassium minerals in the formation are polyhalite, sylvite, langbeinite, carnallite, kainite, and leonite. Their composition is as follows:

Mineral	Composition	Percent K_2O	Percent H_2O
Sylvite	KCl	63.2	----
Leonite	$K_2SO_4.MgSO_4.4H_2O$	25.7	19.7
Langbeinite	$K_2SO_4.2MgSO_4$	22.7	----
Kainite	$KCl.MgSO_4.3H_2O$	18.9	21.8
Carnallite	$KCl.MgCl_2.6H_2O$	17.0	38.9
Polyhalite	$K_2SO_4.MgSO_4.2CaSO_4.2H_2O$	15.6	6.0

Sylvite and langbeinite are the only anhydrous potassium minerals in the Salado formation, and they are at present the only potassium minerals of economic importance.

Polyhalite, which is one of the hydrous minerals, is the most abundant and widespread potassium mineral. It is not economically valuable, but is important in the stratigraphy of the Salado formation. The mineral forms discrete beds, and occurs with anhydrite in other beds. These polyhalite-anhydrite beds are widespread, laterally persistant layers that serve as stratigraphic marker beds. Some of them are recognized by names, such as the Union anhydrite of local usage, and others are recognized by number. Numbering of potassium-bearing beds was introduced by Smith (1938). A modification of his system currently is used by most of the potash companies in the Carlsbad district. The polyhalite-anhydrite marker beds are numbered, and salt beds containing potash deposits are given names, such as the First Ore Zone. The lithologic character and thickness of the polyhalite-anhydrite marker beds, the potassium-bearing ore zones, and the name or number by which each bed or group of beds is recognized are shown on the composite columnar section (fig. 1).

The ore zone containing the potash deposits of economic interest are in the middle part of the Salado formation. The deposits are compact mineral bodies that have a sharp outline against the salt beds. They consist of a mixture of halite with minor clay and quartz and one or more of the highly soluble potassium minerals--sylvite, langbeinite, carnallite, kainite, and leonite--and associated magnesium minerals, such as kieserite, bloedite, and vanthoffite. Polyhalite may occur in the deposits, but it is always a minor constituent, averaging less than 3 percent. The potassium and associated magnesium salts generally account for 25 to 45 percent of mineral constituents of the deposits, although locally the salts occur in concentrations as great as 90 percent. The clay and quartz content of the deposits ranges from 2 to 6 percent. The deposits attain a maximum thickness of about 21 feet, but their average thickness is about 4 to 5 feet.

EQUIPMENT

The equipment used by the Geological Survey is like that commonly used in routine gamma-ray logging of uranium deposits except for the size of counter tubes. Inasmuch as the potash deposits are considerably less radioactive than uranium deposits, relatively large counter tubes were used to obtain a high counting rate. The counter tubes were of two sizes--1 inch in diameter by 12 inches in length and 2 inches in diameter by 20 inches in length. The commercial logging companies used equipment identical to that used in routine logging operations of oil and gas holes: one with an ionization chamber and the other with a Geiger-Mueller counter tube as detecting element. Technical details of the equipment were not furnished with the logs.

DRILL HOLE DATA

Experimental logging was carried out in five drill holes by the Geological Survey and in three of the five holes by the commercial companies (table 1). The drill holes contained 5-inch inside diameter casing from the surface to the "top of salt," and were uncased from the "top of salt" to total depth. Drilling fluid filled the holes to within a few feet of the surface. The drilling fluid was a saturated solution of potassium and sodium chloride in which all of the potassium minerals except carnallite were stable. The cores recovered from the drill holes showed evidence of the solution of carnallite, and other evidence of solution of carnallite was found on the electrical resistivity logs of the holes.

The salt beds of the Salado formation were drilled with a bottom-discharge type of diamond core bit, having an external diameter of 3-5/8 inches, and yielding a 2-1/2-inch diameter core. The core was recovered in 20-foot sections with a double-tube core barrel. Core recovery exceeded 98 percent for each of the drill holes, and was 100 percent through all of the potash deposits.

The three drill holes in which the private companies conducted logging operations were reamed to 4-3/4 inches diameter after coring. Reaming to a larger diameter was required in order to accommodate the relatively large-diameter well-logging instruments used by the two companies.

TABLE 1.--SUMMARY OF DRILL HOLE DATA

Company	Hole no.	Location	Logged by	Type of log
Southwest Potash Corporation	55	SE 1/4 NE 1/4, sec. 15, T. 19 S., R. 30 E.	Commercial company (1)	Gamma-ray, neutron
			Commercial company (2)	Gamma-ray, electrical resistivity
			U. S. Geological Survey	Gamma-ray, lithologic
International Minerals & Chemical Corporation	103	Center of SW 1/4, sec. 7, T. 22 S., R. 30 E.	Commercial company (1)	Gamma-ray, neutron
			Commercial company (2)	Gamma-ray, electrical resistivity
			U. S. Geological Survey	Gamma-ray, lithologic
Potash Company of America	131	NE 1/4 NW 1/4, sec. 35, T. 19 S., R. 30 E.	Commercial company (1)	Gamma-ray, neutron
			Commercial company (2)	Gamma-ray, electrical resistivity
			U. S. Geological Survey	Gamma-ray, lithologic
International Minerals & Chemical Corporaation	147	Center of SE 1/4, sec. 20, T. 22 S., R. 30 E.	U. S. Geological Survey	Gamma-ray, lithologic
International Minerals & Chemical Corporation	150	NW 1/4 NW 1/4, sec. 1, T. 22 S., R. 29 E.	U. S. Geological Survey	Gamma-ray, lithologic

SUPPLEMENTARY TESTS

Samples of potash ore and rocks from the evaporite deposits in the district were analyzed for uranium and thorium by the Geological Survey. The results show that potassium is the major source of gamma radiation in the rocks and mineral deposits of the area. Thorium is not present in detectable concentrations; and most of the rocks contain less than 0.001 percent of uranium. However, sandstone beds near the top of the Salado formation (fig. 1) contain as much as 0.001 percent of uranium, and much of their radioactivity is derived from uranium and its decay products.

The cores obtained from the drill holes logged by the three organizations were passed through a radiometric core scanner in which the radioactivity of drill cores was measured. This work was done to determine the practicability of analyzing cores by radiometric methods. Initial calibration of the instrument in terms of potash (K_2O) concentration was established by tests on simulated cores containing known amounts of potash and was maintained thereafter by periodic checks. The cores were scanned in 1-foot segments. This short length was adopted because 1-inch by 12-inch counter tubes of the same type used for drill hole logging were used in the core scanner. Initial tests were conducted with a 1 minute counting period; but this proved too short to obtain accurate results. Increasing the length of the counting period showed that counting periods too long for practical use were required to obtain reasonably accurate results. This circumstance is characteristic of the counter tubes used in the experimental work and is not a condemnation of the technique. Other detectors having higher counting rates probably will give accurate results in a short counting period.

Written descriptions of the cores were prepared in considerable detail, and were used in plotting lithologic logs of the individual drill holes. The lithologic logs were used in conjunction with the gamma-ray, neutron, and electrical resistivity logs to locate and identify the mineralogic, textural, or structural feature from which individual deflections are derived. The cores were re-examined, as necessary, to confirm the correlation of geology and geophysical response.

The cores selected for chemical analysis included rocks and deposits consisting of individual potassium minerals and mixtures of several potassium minerals. The cores were broken into samples ranging from 3 to 18 inches in length; uniformity of potash (K_2O) content and mineral composition determined the length of individual samples. The samples were halved. One part was analyzed by the company drilling the hole from which the core was obtained and the other part was retained by the company as reference material.

GAMMA-RAY LOGS

Gamma-ray logs are graphs showing the distribution and relative concentration of radioactive elements in rocks penetrated by a drill hole. The depth below surface, derrick floor, or collar of the hole is recorded on the ordinate (vertical axis) of the graph and variations of intensity in gamma radiation is plotted on the abscissa (horizontal axis). The relative intensity of radiation, which increases from left to right on the graph, is expressed in terms of some arbitrary unit, such as counts per second.

The gamma-ray logs of the three drill holes logged by the Geological Survey and the commercial companies are dissimilar in some respects (fig. 2). These dissimilarities are caused by use of different types of gamma-ray detecting devices, instrument settings (time constant and range factor), cable speeds (velocity at which detecting device is withdrawn from drill hole), and recorders were used to detect, measure, and plot the radioactivity of the salt and potash deposits.

The least sensitive counter device is the 1-inch by 12-inch Geiger-Mueller tube used in the Geological Survey logging instrument. This instrument has the shortest effective length for detecting and measuring gamma-radiation and the lowest counting rate. However, as used with a slow cable speed (5 feet per minute) and a large vertical scale (1 inch equals 2.66 feet), it gives considerably more detailed information concerning minor variations of radioactivity within the salt beds and potash deposits than the other instruments used (figs. 2 and 4). The radiation detecting devices used by the well logging service companies have an effective length of 3.0 feet. Their gamma-ray logs have the same vertical scale (1 inch equals 20 feet), but have quite different deflection (horizontal) scales for showing the relative intensity of radiation (fig. 2). The radioactivity of the rocks and mineral deposits is expressed by one company in terms of "counts per second" whereas the second company uses "inches of deflection." The two logs show about the same amount of stratigraphic detail for individual beds and potash deposits, although the radioactivity anomalies on the first company's log extend farther from background (average intensity of radiation in unmineralized salt beds) than those on the second company's log (fig. 2). This feature probably is due to differences in instrumentation and logging method. Company (1)'s logs were made at cable speeds of 8, 14, and 24 feet per minute, and the ratemeter time constant, recorded only by the code symbol "H", is unknown. Company (2)'s logs were made at a cable speed of 15 feet per minute with a ratemeter time constant setting of 1 and 2 seconds.

Comparison of the gamma-ray logs of the drill holes with the lithologic logs of the cores obtained from the drill holes reveals that fairly large radioactivity anomalies were recorded at the depths of which potash deposits and polyhalite beds were encountered (fig. 3). Claystone seams and beds of clay-bearing halite are not particularly radioactive, and therefore, are not likely to be confused with potash deposits. Beds of sandstone and siltstone, which are present near the top of the Salado formation, are radioactive (fig. 1). Inasmuch as the beds of sandstone and siltstone are separated from the mineralized part of the formation by a considerable section of rock, they are not likely to be identified as one of the deposits.

The favorable results obtained demonstrate that gamma-ray logging of holes drilled for oil and gas is a convenient and practical method of searching for potash deposits in marine evaporites. Although few core samples containing less than 5 percent of potash (K_2O) were analyzed in the course of this investigation, it is estimated that halite beds containing about 1 percent of potash (K_2O) show anomalous radioactivity on gamma-ray logs. Deposits containing less than 8 percent of potash (K_2O) are classed as potential resources, and do not constitute ore at the present time. As shown on figure 2, the gamma-ray logs made by all three organizations are equally efficient for identification of mineable potash deposits.

Grade and thickness estimates from gamma-ray logs

A considerable effort was made to develop empirical methods for estimating grade and thickness of potash ore from the anomaly recorded on a gamma-ray log, but satisfactory results were not obtained. The unfavorable results were due to a combination of factors involving both geology and instrumentation. The deposits in the Carlsbad district are not homogeneous; the potash (K_2O) concentrations in a deposit show a considerable range of values in vertical section (fig. 4). Moreover, the deposits average 4 to 5 feet thick, and therefore, are thin in comparison with the fairly long (3.0 feet) detecting devices used by the well logging service companies. Instruments of such a length are not suitable for purposes of estimating grade and thickness of radioactive ore in thin or thin-layered deposits, such as those found in the Carlsbad district.

Although the gamma-ray logs prepared by well logging service companies were found to be unsatisfactory in some respects, they are nevertheless valuable records. They are an excellent source of information concerning stratigraphic details of the evaporites. Moreover, with proper instrumentation and appropriate geologic conditions, the logs made in small diameter (4 to 6 inches), uncased drill holes can yield data of a semiquantitative nature. If a fairly short time constant (2 seconds or less) and a fairly slow cable speed (15 feet per minute or less) are used in logging such a drill hole, then the logs may be used to obtain an approximation of the minimum grade of ore in potash deposits that are more than 5 feet thick. With such conditions, potash deposits having an average grade of 10 percent of potash (K_2O) will yield a minimum deflection of 1-inch in "standard units" on company (1)'s intensity scale and a minimum counting rate of 140 counts per second on company (2)'s intensity scale.

The conditions under which the grade of ore can be estimated are seldom fulfilled in gamma-ray logging of holes drilled for oil and gas. Most of the holes are larger than 6 inches in diameter, and they are logged after casing and cement have been placed in the hole. Moreover, logging operations are carried out with fast cable speeds and long time constants, and a small depth scale (1 inch equal 20 feet) commonly is used in recording the radioactivity of marine evaporites. All these factors must be considered in estimating the grade of potash ore. Most of them effectively reduce the intensity of radiation recorded on the log, and the others limit the accuracy with which the top and base of the deposit can be picked. As a result, the intensity and thickness of the gamma-ray anomaly of a potash deposit is deceiving; the deposit is thinner and has a higher grade of ore than that which is indicated by the anomaly.

NEUTRON LOGS

The neutron log is a graph showing depth below the top of a drill hole and variations in the relative intensity of secondary gamma-rays. This radiation is artificially generated in the course of neutron well logging by bombarding strata and mineral deposits with high energy neutrons. Inasmuch as the neutrons are slowed down or stopped by hydrogen, the intensity of radiation recorded in neutron logging increases as the hydrogen concentration decreases, and conversely, decreases as the hydrogen concentration increases. Thus, the neutron log is a geophysical well log showing variations in concentration of hydrogen. The hydrogen may be present in hydrocarbon (gas or liquid), drilling fluid, brine, water, cement, or mineral; its chemical form or physical state is immaterial in neutron well logging.

Neutron well logging was carried out in conjunction with gamma-ray logging of three drill holes (table 1). The work was undertaken to determine whether neutron logs could be used to identify the type of potassium mineral that might be present in a potash deposit. Some deposits contain anhydrous potassium minerals, sylvite and langbeinite, as their major constituent; other deposits consist largely of hydrous potassium minerals such as leonite, kainite, and carnallite. Inasmuch as the anhydrous minerals are the only potassium minerals of economic importance, a method by which anhydrous potash deposits can be distinguished from hydrous deposits is of considerable value.

The mineralogic character of a deposit found by gamma-ray logging can be determined by neutron well logging. The results obtained in this investigation show that salt beds and anhydrous potash deposits yield intense secondary gamma radiation in neutron logging. The radiation is recorded as a strong right deflection on a neutron log (fig. 3). Deposits of hydrous potassium minerals and beds of polyhalite, claystone, siltstone, sandstone, and clay-bearing salt yield little or no secondary gamma-rays on bombardment with neutrons. As a consequence, they form moderate to strong left deflections on a neutron log (fig. 3). Such favorable results as those shown on figure 3 clearly demonstrate the usefulness of neutron well logging in the search for and the identification of potash deposits. Moreover, a radioactivity log (combination of gamma-ray and neutron log), yields considerable information concerning stratigraphic details of marine evaporites (figs. 1 and 3). Salt beds show no radioactivity on the gamma-ray log and strong radioactivity on the neutron log. Anhydrite beds are moderately radioactive in neutron logging, but yield no radiation in gamma-ray logging. Polyhalite, claystone, siltstone, sandstone, and clay-bearing salt beds are radioactive in gamma-ray logging, and weakly or non-radioactive in neutron logging. None of the rocks, however, are as radioactive as mineable deposits of sylvite and langbeinite (figs. 1 and 3).

An undesirable feature of neutron well logging is extreme sensitivity over a very small range in the hydrogen content of hydrous materials. Comparison of the neutron logs and the results of chemical analyses reveal that a small amount (at least 2 percent and possibly as much as 4 percent) of hydrous clay minerals is sufficient to reduce appreciably the intensity of secondary gamma radiation so that a moderate left deflection is recorded in neutron logging. As a result, some potash deposits, which contain 4 to 6 percent of hydrous clay minerals, mica, and quartz, have a moderate left deflection that is unrelated to the type of potassium mineral (fig. 3). Under such conditions, it is extremely difficult to determine whether anhydrous or hydrous potassium minerals are present in the deposits. Moreover, a small amount of carnallite (38.9 percent of water) in a sylvite deposit yields a left deflection; the carnallite content of the deposit need not exceed 5 percent to yield a distinct anomaly.

Further complications in the interpretation of neutron logs are introduced by some conditions commonly encountered in holes drilled for oil and gas. Minor variations in the diameter of a drill hole and in the thickness of cement are detectable in neutron logging. A fairly small increase in the thickness of cement or in bore hole diameter where fluid is present in the hole shows on the neutron log as a left deflection or as a reduction in the amplitude of a deflection. A reduction of amplitude also accompanies the change from open to cased hole and from a small to a large diameter hole.

ELECTRICAL RESISTIVITY LOGS

Although electrical resistivity well logging and neutron well logging are concerned with the measurement of different physical and chemical properties of strata, the two logging methods yield logs that commonly show considerable similarity in response to the geology of individual beds. Because of this apparent relationship between resistivity and hydrogen concentration, electrical well logging was carried out in the same drill holes that were logged by the neutron method (table 1). The purpose of the logging was to determine whether an empirical relationship between resistivity and hydrogen concentration or between resistivity and mineralogy of individual strata and potash deposits could be recognized. The recognition of some correlation of resistivity and geology would have considerable value inasmuch as electrical well logging has been the logging method that is most commonly used by the oil industry in southeastern New Mexico.

The primary function of electrical well logging is to locate permeable and resistive strata. Variations of apparent resistivity are expressed on electric logs in terms of ohm meter squared per meter (ohms m^2/m), and commonly is recorded in the form of a normal curve and a lateral curve. An electrode spacing of 10 inches was used in the experimental logging to obtain the normal curve shown in figure 3, and an electrode spacing of 32 inches to obtain the lateral curve. Spontaneous-potential well logging was not attempted because the drilling fluid was a concentrated solution of sodium and potassium chloride and the salt beds have exceptionally small permeability.

The experimental logging found variations of apparent resistivity that have limited application in the identification of potash deposits. Carnallite-bearing deposits, sandstone beds, claystone seams, and salt beds containing 15 to 20 percent of clay (clay minerals, mica, and quartz) have low resistivity (high conductivity); they yield anomalies that stand out as distinct left deflections on the lateral curve and are poorly defined on the normal curve (fig. 3). Examination of the cores reveals that the conductive strata and carnallite deposits have only one physical property in common; they are the most porous layers in the cores. The porosity of the carnallite deposits, however, unlike that of the sandstone, claystone, and clay-bearing salt beds, is secondary; it develops as a consequence of drilling the deposits with a fluid that dissolves carnallite. Removal of carnallite gives the deposits considerable vuggy porosity, and enlarges the drill hole. The solution cavities and the increase of hole diameter are detectable in electric logging as a decrease of apparence resistivity. Therefore the apparently low resistivity of carnallite-bearing deposits is derived from the secondary porosity and the enlargement of the hole, and is not related to specific electrical properties of carnallite. The water soluble potassium minerals yield anomalies in electric logging only when they are leached by the drilling fluid. Inasmuch as the drilling fluid used by the oil industry is almost invariably unsaturated with respect to potassium and magnesium chloride, deposits of water soluble potassium salt will dissolve, and will be detectable in electric logging. The low resistivity anomalies of the deposits should serve as a means of differentiating between potash deposits of economic interest and polyhalite beds.

The relation between solution cavities and low resistivity should be used with extreme caution for proper interpretation of resistivity logs. The formation of solution cavities is controlled by the solubility of individual minerals in the fluid used in rotary drilling of potassium-bearing evaporites. Some drilling fluids, such as the saturated sodium-potassium chloride brine used in this study, dissolve only carnallite; such drilling fluids, however, are rarely used by oil companies in drilling marine evaporites. Some companies use a salt-base mud in which halite, anhydrite, and polyhalite are stable, but in which the highly soluble potassium minerals are unstable and dissolve. Other companies use a fresh-water mud that has little or no detectable effect on anhydrite and polyhalite but dissolves halite and the potassium minerals.

A salt-base mud will form solution cavities in deposits of highly soluble potassium minerals. Such solution cavities yield in electric logging a low resistivity anomaly that has much the same general appearance as that formed by porous strata, such as sandstone and clay-bearing salt beds. However, the porous strata are considerably less radioactive than mineable deposits of potassium minerals, and therefore, can be identified by gamma-ray logging. Although polyhalite beds yield fairly strong anomalies, they are more resistive than the potash deposits and are not likely to be confused with them.

The use of fresh-water mud in drilling marine evaporites forms solution cavities in potash deposits and salt beds, and the layers of relatively insoluble anhydrite and polyhalite stand out as ledges along the bore hole wall. Such ledges are recorded in electric logging as resistive beds, and yield conspicuous right deflections on a resistivity log (fig. 5). Potash deposits and salt beds have low resistivity, and distinguishing one from the other can be quite difficult (fig. 5). However, with a combination gamma-ray and electrical resistivity log, such as is shown in figure 5, much information concerning the distribution of potash deposits and stratigraphic details of the evaporites can be obtained. The composition of individual resistive layers is readily determinable by visual inspection of the gamma-ray logs. Polyhalite beds are both radioactive and highly resistive; anhydrite beds lack the radioactivity of polyhalite, although they are as highly resistive. The potash deposits are radioactive but lack the high resistivity of the polyhalite beds, and therefore are readily identified inasmuch as the salt beds are not particularly radioactive. From the foregoing discussion, it is evident that an electrical resistivity log of a hole drilled with fresh-water mud gives about the same amount of information that is obtainable from a caliper log of the drill hole.

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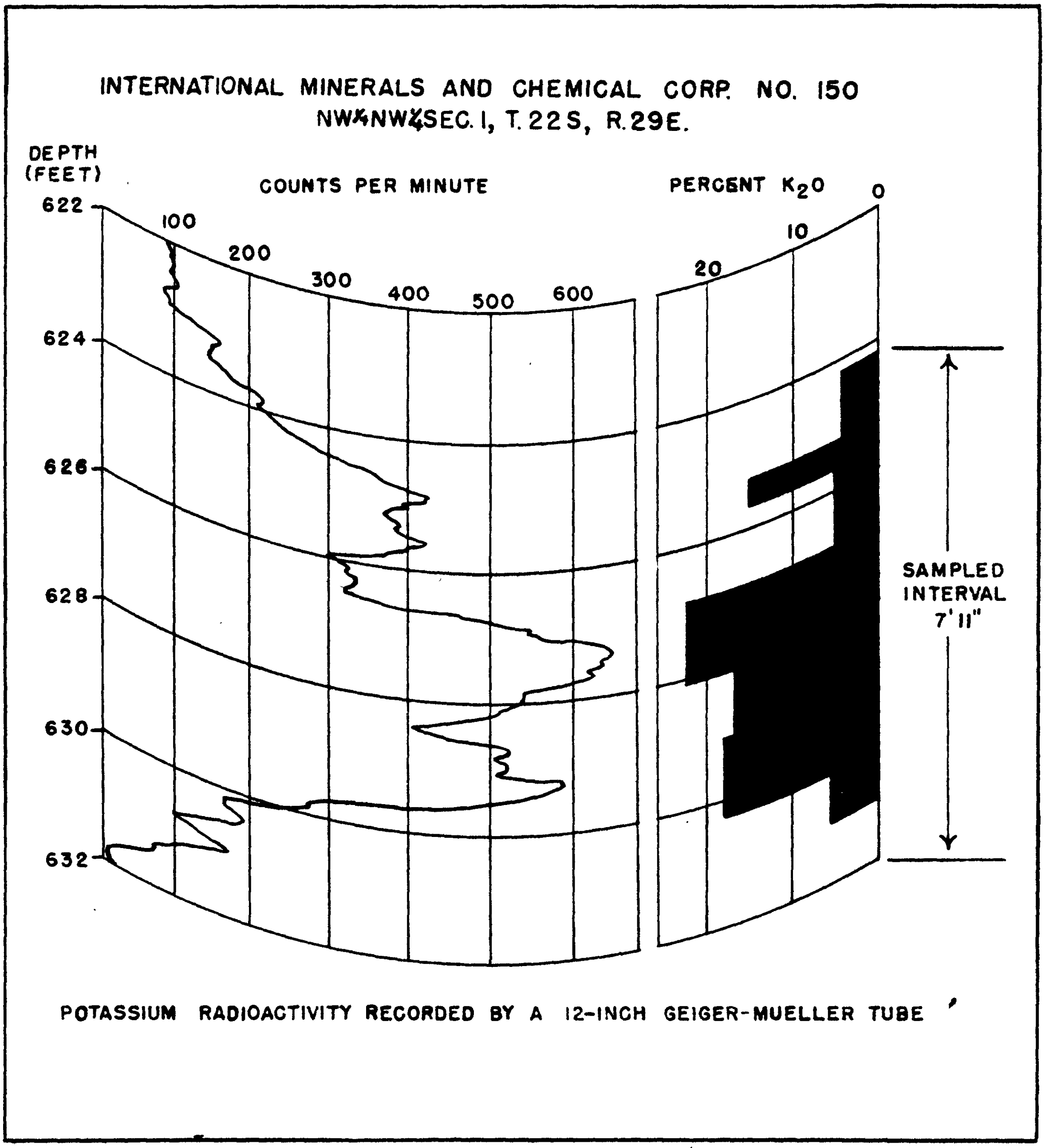

Figure 4. Abridged gamma-ray and graphic logs of a potash deposit, showing typical variations of potash concentrations in vertical section.

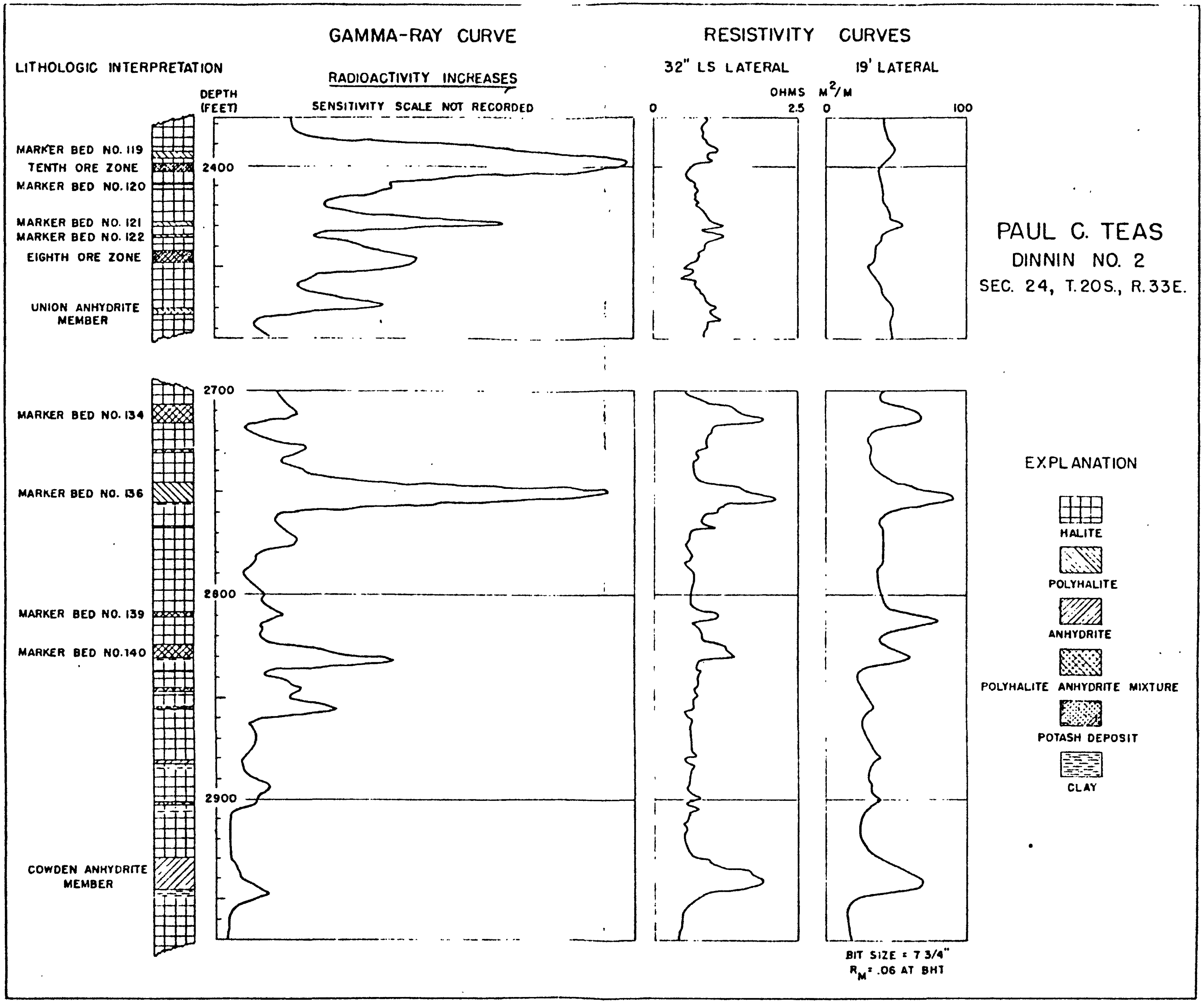

Figure 5. Lithologic interpretations derived from gamma-ray and electrical resistivity logs of a well drilled with fresh-water mud.