UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

SEMI-QUANTITATIVE DETERMINATION OF URANIUM AND STRATIGRAPHIC CORRELATION BY GAMMA-RAY LOGGING OF DRILL HOLES IN CARNOTITE DEPOSITS

by

Kenneth G. Bell

August 1949

Trace Elements Investigations Report 87

USGS - TEI Rept. 87
Consisting of 11 pages
Copy No. 12 of ___ copies
Series B
Issued to (see below)

The distribution (Series B) of this report is as follows:

Copies 1 and 2 .... AEC, Washington (J. C. Johnson)

Copies 3 through 7 .... AEC, New York (P. L. Merritt)

Copy 8 .... AEC, Denver, Colorado (C. C. Towle, Jr.)

Copy 9 .... AEC, Spokane, Washington (E. E. Thurlow)

Copy 10 .... AEC, Grand Junction, Colorado (W. G. Fetzer)

Copies 11 through 25 .... U. S. Geological Survey

1 Master copy (mat) for TEPCO Files

CONTENTS

ILLUSTRATIONS

SEMI-QUANTITATIVE DETERMINATION OF URANIUM AND STRATIGRAPHIC CORRELATION BY GAMMA-RAY LOGGING OF DRILL HOLES IN CARNOTITE DEPOSITS

by

Kenneth G. Bell

ABSTRACT

Results of experimental work show that all concentrations of carnotite containing in excess of 0.01 percent equivalent uranium can be detected by the gamma-ray logging of small-diameter drill holes. Semi-quantitative determinations of equivalent uranium can be made with an accuracy of 20 percent. The logging instrument, which is truck-mounted for mobility, is composed of a power plant, reel assembly and co-axial cable, and electronic circuits. The electronic circuits include a Geiger-Mueller tube and pulse amplifier enclosed in a 7/8-inch diameter probe, a receiver-integrator, a meter circuit, and a regulated power supply. The logging instrument functions as a counting-rate meter and produces a graphical representation of gamma-ray activity through the medium of a strip-chart recorder. An empirical calibration procedure has been devised, but final calibration of the logging instrument is not complete. Preliminary investigations indicate that gamma-ray logging of small-diameter drill holes can be used as a method of stratigraphic correlation when the equivalent uranium content of adjacent strata differ by an amount exceeding 20 percent.

GENERAL TEXT

The U. S. Geological Survey is conducting a project which has as a primary objective the development of a geophysical method of making semi-quantitative determinations of the equivalent uranium content of ore bodies and rock strata through the medium of gamma-ray logging of small-diameter drill holes. A secondary objective is the developme.. of a technique for stratigraphic correlation of ore-bearing beds. This project is being carried on in conjunction with the exploration of the carnotite ores of the Colorado Plateau. A complete realization of the objectives of the project would permit estimations of the thickness and grade of uranium ore encountered in drill holes with a small degree of error and without the necessity of taking core or sludge samples for chemical analysis.

The carnotite of the Colorado Plateau occurs in small irregularly shaped ore bodies of which the greatest horizontal dimension does not ordinarily exceed 100 feet, and the vertical dimension does not ordinarily exceed 10 feet. Most of these ore bodies lie within the Salt Wash member of the Morrison formation of Jurassic age. The ore-bearing strata consist predominantly of fine- to medium-grained sandstones. Thin lenticular strata of clay shale and mudstone are interbedded with the sandstone. A thickness of 100 feet of strata is believed to include at least ninety percent of the carnotite deposits.

Carnotite was first discovered in outcrops exposed along the walls of several of the canyons which dissect the Colorado Plateau. Most of the ore which has been mined has been taken from ore bodies found by visual examination of outcrops. A small amount of ore has been taken from bodies found by digging shallow prospect pits at localities where the ore-bearing strata lie only a few feet below the surface of the ground. The thorough examination of the exposures of the ore-bearing strata by prospectors has made the exploration of buried portions of the strata necessary in order to effect the discovery of additional ore bodies. This exploration is most advantageously accomplished by means of drill holes. At the present time exploration is being carried on entirely by this method.

The drilling done to date has been restricted to depths of 500 feet or less, and the diameters of the holes have been kept as small as is practical for efficient drilling operations so as to keep costs at a minimum. It has been the practise to attempt to take core samples through the entire thickness of the ore-bearing strata. If the ore-bearing strata lie some two to four hundred feet below the surface of the ground, the upper portions of the holes are plug-drilled and no samples are taken.

Drill holes represent a substantial capital investment; therefore, it is desirable that the greatest possible amount of information be obtained from them. An accurate estimation of the grade of ore existing in any kind of ore body, if obtained by chemical analysis of core samples, is dependent upon a high percentage of core recovery. Carnotite ore is soft and friable; therefore, there is often a considerable core loss, especially when drilling through the higher-grade ore bodies. Estimation of the grade of uranium ore existing in an ore body, if obtained by gamma-ray logging of a drill hole, is not dependent upon core recovery. A drill hole can be checked with a gamma-ray logging instrument as soon as the drilling is completed, and the information can be obtained without the delay of several days or a few weeks required in the case of chemical analysis of core samples.

The desirability of developing a rapid geophysical method for the detection of radioactive minerals was brought about by the intensified search for uranium ore which began about 1942. In the United States, the Colorado Plateau is the only area which has produced substantial quantities of the radioactive elements. Prior to 1942, several mineralized localities on the Plateau had been tested by large numbers of diamond-drill and jack-hammer holes. The objective of the exploration was to locate ore bodies which could be mined for their vanadium content. Little attention was paid to the uranium content of the ore. In 1943, it was realized that a considerable amount of data in regard to the uranium content of carnotite ore bodies could be obtained if a practical geophysical method of making gamma-ray logs of these drill holes could be devised. The method would be applicable, of course, to all holes that might be drilled in the future.

The project of designing and constructing an instrument for the gamma-ray logging of small-diameter drill holes was started late in 1943 by personnel of the Union Mines Development Corporation. Because of an urgent necessity for completing other projects, work was suspended during 1944, and then resumed in 1945. A preliminary design for the logging instrument was drawn up by C. H. Metzger and H. Faul. After some modifications had been made in the original design, an instrument was constructed and tested in the field. Dr. D. L. Collins and R. J. Smith participated in this work, and Smith has described the circuit._/ A large number of drill holes

_/ Smith, R. J., Barnaby, a transportable counting-rate meter for gamma measurements up to 200 feet distant by means of a small probe: U. S. Atomic Energy Commission, Tech. Inf. Div., AECD-1997, 1948.

was logged, and an empirical calibration procedure was devised. Use of the instrument has been briefly described by Faul._/ Work on the

_/ Faul, Henry, Radioactivity exploration with Geiger counters: Am. Inst. Min. Met. Eng., Tech. Pub. 2460, pp. 11-12, 1948.

project was discontinued by the Union Mines Development Corporation in 1946 and was resumed early in 1948 by personnel of the U. S. Geological Survey.

During the time that the project has been carried on by the U. S. Geological Survey, several modifications and improvements in the design of the logging instrument have been made. These changes have come about as a result of experience gained in the construction and testing of the original model. Some new logging instruments are in the process of construction. Preparations are being made to calibrate the logging instruments so that interpretations of the grade and thickness of ore bodies can be made with a small degree of error. Recent use of the logging instruments has shown that from 15,000 to 20,000 feet of drill hole can be logged in one month by one instrument.

The principal parts of the logging instrument are: a brass probe containing a Geiger-Mueller tube and a pulse amplifier, a co-axial cable which supports the probe in the drill hole and acts as an electrical conductor between the probe and the main electronic circuits, a reel assembly for holding and feeding the cable, the main electronic circuits which amplify and integrate the pulses received from the probe, an indicating device containing a milliammeter and a strip chart recorder, and a power unit. The entire assembly is mounted inside the body of a four-wheel drive truck. The truck body opens to the rear, and the co-axial cable is fed from the reel to the drill hole. Housing the instrument inside of a truck body provides protection against wind, dust, and direct sunshine. The use of a heavy four-wheel drive truck permits operation over rough terrain.

The logging instrument is operated by a two-man crew, one of whom is a technician and handles all of the controls. The second man serves as truck driver and performs any manual labor incident to the logging of a hole. The instrument truck is parked on any convenient spot in the immediate vicinity of the hole which is to be logged. The tail-gate is opened and the reel assembly is leveled by means of thumbscrews on the bottom of the chassis. The technician checks the electrical connections, assembles the probe, and then "warms up" the instrument. His helper lowers a dummy probe into the hole to make certain that it is free from obstructions and does not require reaming or casing. If the hole must be cleared of obstructions, both men assist in this work. If there are no obstructions, or after any obstructions have been removed, the helper sets up a tripod-mounted sheave so that the edge of the wheel is directly over the center of the hole. A second sheave is attached to a pipe which is clamped to the tail-gate of the truck. Manipulation of the two sheaves permits the cable to be guided in any direction from the reel to a hole. The helper places the cable over the two sheaves and then slowly lowers the probe into the hole while the technician unwinds cable from the drum. When the probe touches the bottom all slack cable is taken in, and a reading is taken from a scale calibrated in feet and tenths of feet which is a part of the cross-feed mechanism of the reel.

The logging of the hole is commenced by starting the reel driving motor. As the probe is being withdrawn from the hole, the technician constantly watches the output rate meters. If an ore zone is encountered and the rate meters are driven off scale, the next higher range setting must be immediately set into the instrument.

When the lower end of the probe reaches ground level the reel motor is stopped. A second reading is taken from the calibrated scale of the cross-feed mechanism, this reading being the upper datum for the hole. If, during the course of logging the hole it has been necessary to change the range setting, then the hole is relogged at the highest range setting used.

Figure 1.--The operation of the logging instrument furnishes a permanent record of the intensity of gamma-ray radiation at all points along the depth of a drill hole. An essentially constant degree of gamma-ray activity, such as exists along the length of a drill hole passing through rock containing uniformly distributed radioactive constituents, will produce a straight line on the strip-chart recorder. If the probe passes a concentration of radioactive ore during its progress through a drill hole, a deflection of the recording device occurs and a curve is produced on the chart. The area under the curve is indicative of the thickness and grade of the ore body as it exists within a radius of approximately two feet from the drill hole.

Figure 2.--The logging instrument has not been completely calibrated. Experimental work on simulated drill holes has provided some empirical calibration data which allow a reasonably accurate estimate to be made of the thickness and grade of an ore zone from the size and shape of the curve produced by the recorder. The interpretation is based on the equation:

$$\frac{T \times G}{D \times B} = \text{Constant}$$

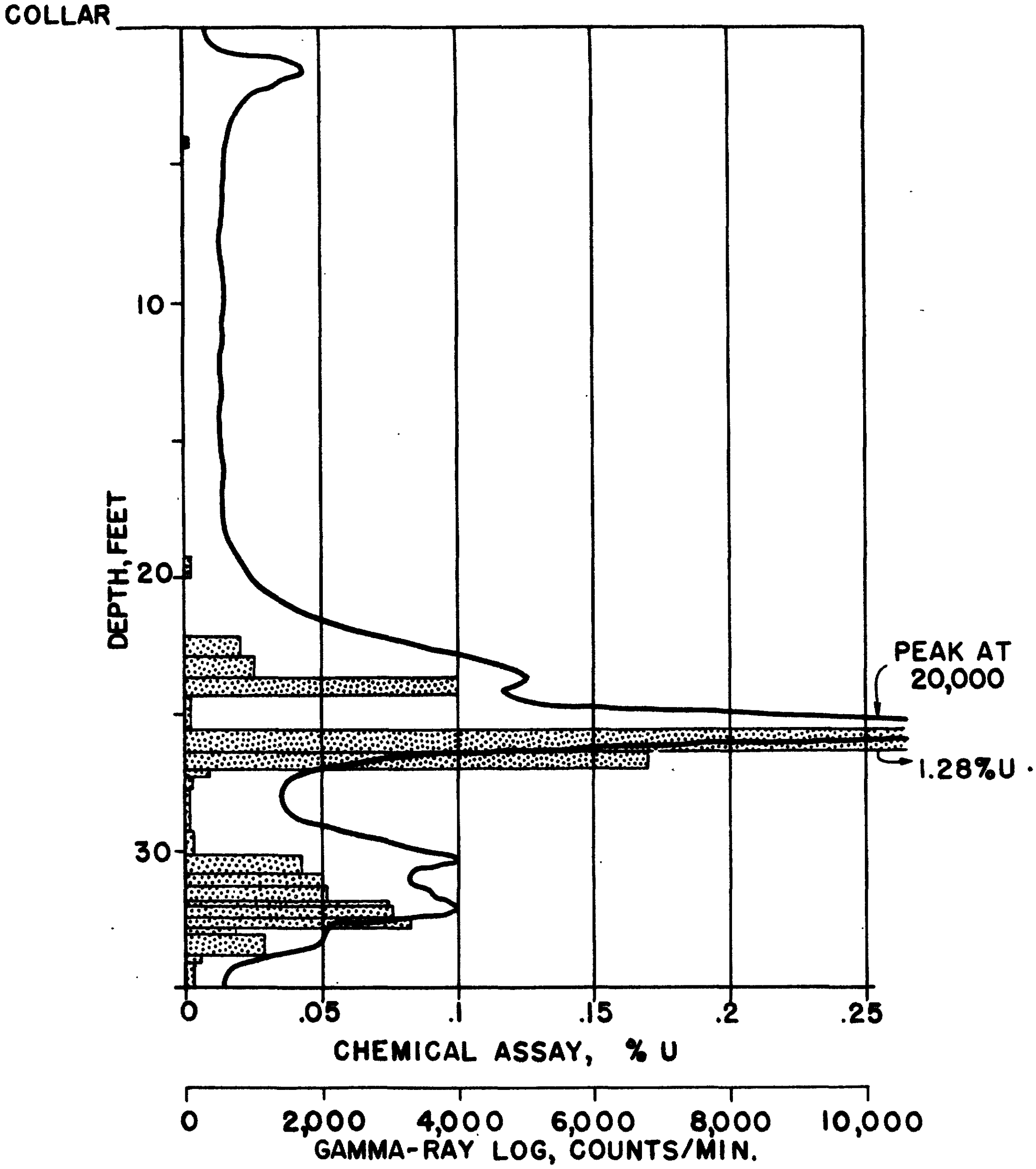

Figure 1. Gamma-ray log of hole CT-50, and chemical assays of core. A tube of the TGC type was used.

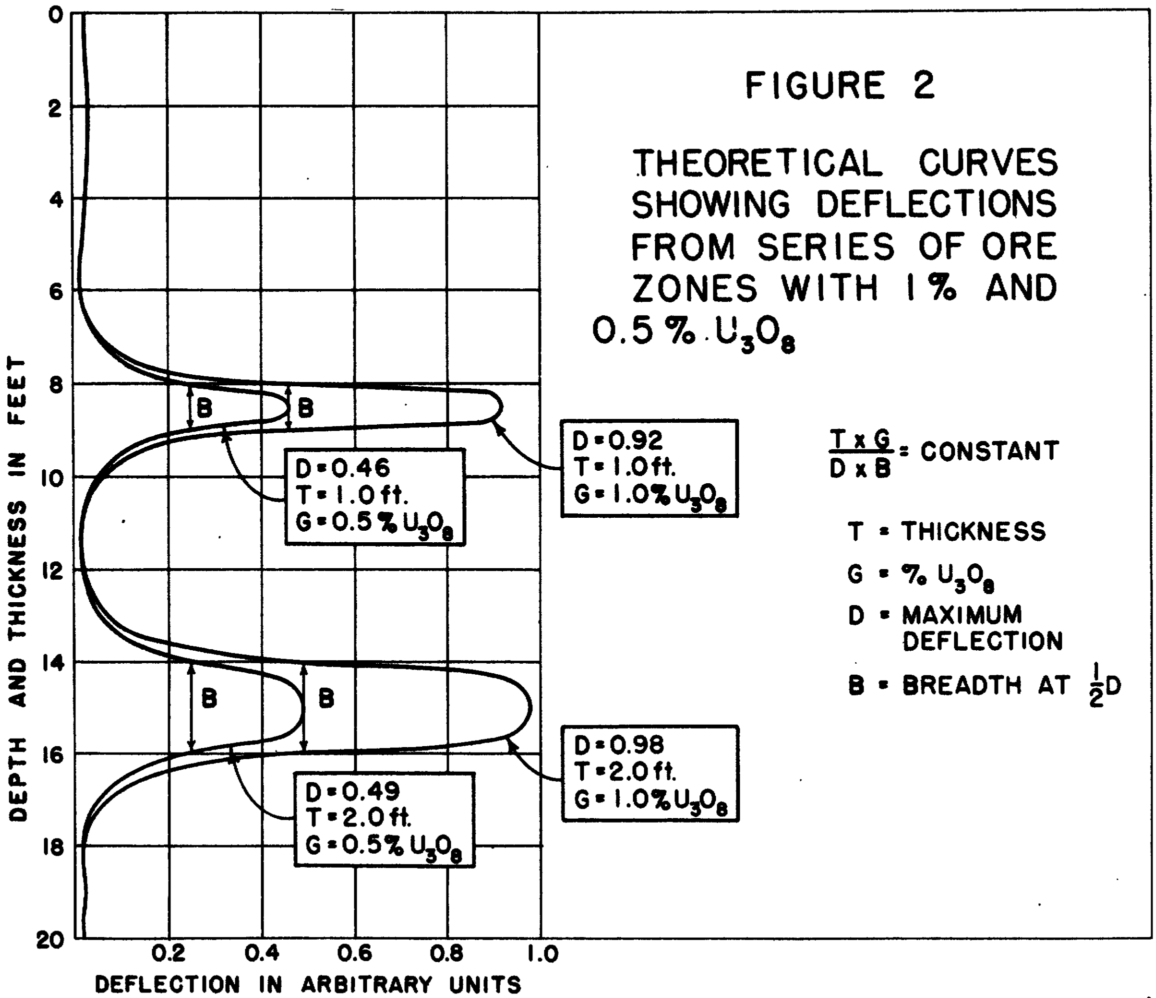
FIGURE 2
THEORETICAL CURVES SHOWING DEFLECTIONS FROM SERIES OF ORE ZONES WITH 1% AND 0.5% U_3O_8
$\frac{T \times G}{D \times B}$ = CONSTANT
T = THICKNESS
G = % U_3O_8
D = MAXIMUM DEFLECTION
B = BREADTH AT $\frac{1}{2}$D
D = 0.92
T = 1.0 ft.
G = 1.0% U_3O_8
D = 0.46
T = 1.0 ft.
G = 0.5% U_3O_8
D = 0.98
T = 2.0 ft.
G = 1.0% U_3O_8
D = 0.49
T = 2.0 ft.
G = 0.5% U_3O_8
B
DEPTH AND THICKNESS IN FEET
0
2
4
6
8
10
12
14
16
18
20
0.2
0.4
0.6
0.8
1.0
DEFLECTION IN ARBITRARY UNITS

where T = thickness of the ore zone in feet, G = grade of the ore expressed as percent equivalent U_3O_8, D = maximum deflection or height of the curve in scale units, and B = width of the curve at one-half the maximum deflection. A full scale deflection represents one milliampere of current, therefore D is always represented by a decimal value. The value of B is expressed as feet. T and G are fixed values of a particular ore body. D and B can be varied by using Geiger-Mueller tubes of different characteristics and by changing the range and time-constant settings of the logging instrument.

The graphical records produced by the logging instrument are subject to the statistical fluctuations characteristic of all measurements of radioactivity. The instrument functions as a counting-rate meter, and therefore, all measurements made with it have a relative deviation inherent to this type of measuring device. The relative deviation can be decreased by obtaining more pulses per unit of time, that is, by decreasing the logging speed; or by increasing the capacitance in the meter circuit, that is, the time constant; or by a combination of these two variable factors. Increasing the time constant has the disadvantage of producing a broader curve on the recorder chart and thereby making the estimation of the thickness of an ore zone less accurate. The most satisfactory procedure for obtaining the greatest degree of accuracy is to use a slow logging speed and a time-constant setting which does not give a distorted indication of the thickness of an ore zone.

The experimental logging of more than three hundred holes has indicated that it is possible to detect consistently concentrations of equivalent uranium down to a minimum value of 0.01 percent. When a logging speed of 5 feet per minute is used, estimations of grade can be made with an accuracy of about 20 percent. A slower logging speed makes possible a more accurate estimation of grade because of the greater number of pulses received from a given thickness of ore. With suitable range and time-constant settings, it has been found possible to detect concentrations of equivalent uranium between the values of 0.01 percent and 0.006 percent, and to obtain deflections showing the proper order of magnitude. Detection of the extreme low concentrations of equivalent uranium requires a slow logging speed, a low range setting, and a long time-constant setting. The shorter time-constant settings do not smooth out statistical fluctuations sufficiently to separate the deflections produced by thin ore zones having low concentrations of equivalent uranium from those of normal background variations.

Most of the experimental logging has been done upon drill holes from which core samples have been taken. The equivalent uranium content of the core samples has been determined by radiometric measurements made with laboratory scalers. The actual uranium content has been determined by chemical analysis. A direct comparison of the results of drill-hole logging and laboratory determinations of uranium and equivalent uranium can be made. These data will be used in the process of making the final calibration of the logging instrument.

The usefulness of the gamma-ray logging instrument as a tool for stratigraphic correlation of ore-bearing horizons has not been completely determined. Experimental work has been devoted mainly to the detection and the estimation of grade of concentrations of radioactive minerals which have a possible economic value. The intensity of gamma-ray activity which must be measured for stratigraphic correlation, falls near the lower sensitivity limit of the logging instrument. This intensity is considerably lower than that existing in radioactive ore bodies. Preliminary investigations indicate that the logging instrument can be used successfully as a tool for stratigraphic correlation when the equivalent uranium content of adjacent strata differ by an amount exceeding 20 percent.