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COMPARISON OF THICKNESS, GRADE, AND DEPTH OF RADIOACTIVE LAYERS AS DETERMINED BY GAMMA-RAY LOGGING AND BY CORE SAMPLING

By Carl M. Bunker

Trace Elements Investigations Report 612

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This report is preliminary and has not been edited for conformity with Geological Survey format and nomenclature.

*This report concerns work done on behalf of the Division of Raw Materials of the U. S. Atomic Energy Commission.

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COMPARISON OF THICKNESS, GRADE, AND DEPTH OF RADIOACTIVE LAYERS AS DETERMINED BY GAMMA-RAY LOGGING AND BY CORE SAMPLING

By Carl M. Bunker

ABSTRACT

Thickness, grade, and depth data were obtained by analyzing gamma-ray logs and core samples from 56 diamond drill holes penetrating uranium deposits in the Colorado Plateau. The data from the two methods were compared to determine variations found in gamma-ray log interpretation and chemical and radiometric analyses of the drill core. Correlations within each parameter varied among the drilling areas analyzed. Gamma-ray interpretations of grade compared to chemical analyses were within the range of -10 to +25 percent. Most depth measurements determined by gamma-ray log interpretation compared to drill core measurement were within 0.5 percent. Results of the study indicate a need for better thickness definition in both gamma-ray logging and core scanning equipment.

INTRODUCTION

In-hole gamma-ray logging is used primarily to obtain subsurface information that will be helpful in searching for uranium deposits. A particular application of gamma-ray logging is to determine semi-quantitatively the thickness, grade, and depth of a radioactive zone containing between 0.0X and X.00 percent equivalent uranium oxide. As a part of the gamma-ray logging program conducted on the Colorado Plateau, a study was made of discrepancies found in determinations of thickness, grade, and depth of uranium-bearing layers as determined by two radically different methods: (1) gamma-ray logging in drill holes and (2) examination and analysis of core samples from the drill holes. The purpose of this study was to compare and to determine the limitations of the two methods. The need for such comparative data is indicated by the frequent and occasionally large discrepancy between data obtained by the two methods. In addition, evaluation of such data should indicate possible modifications of gamma-ray logging equipment and operational techniques to eliminate the discrepancies.

Gamma-ray logging of drill holes does not give direct data on thickness and grade of the highly radioactive layers. Primary data are in the form of a continuous log showing the variation in radiation intensity with change in depth in the drill hole. The thickness in feet and grade in percentage equivalent uranium content of the radioactive layer are interpreted from a gamma-ray log. Depths to the top and bottom of the layer are indicated on the log.

Samples of the drill core were examined for uranium content by radiometric scanning and by chemical analysis. The depths from which samples were collected were determined from accurate measurements based on the length of drill rods referred to the collar elevation of the drill hole.

The data used for this comparative study were obtained from 56 drill holes in three areas in Colorado; the Long Park and Monogram areas in Montrose County, and the Disappointment Valley area in San Miguel County. The holes were drilled and logged shortly after July 1, 1954. The data from each of the three areas studied have been presented separately so that variations in operational methods by logging unit operators in each of the areas and variations in the characteristics of the logging equipment would be disclosed.

It was assumed that the data from the core sample, which include the radiometric and chemical analyses, the thickness of the radioactive layer, and the depth of the radioactive layer below the drill-hole collar are correct.

A condition on which zones were selected for study was that core recovery from these zones had to be 90 percent or greater.

All gamma-ray log data were obtained with U. S. Geological Survey gamma-ray logging equipment. The equipment utilizes a gamma-ray detector of the Geiger-Muller type, and was calibrated empirically for grade and thickness interpretation of anomalous radioactivity. This was done by logging simulated ore bodies in 4-foot diameter casing containing known grades and thicknesses of uraniferous material. From these data a calibration chart was prepared and used in interpretation of field data.

This investigation was conducted by the U. S. Geological Survey on behalf of the Division of Raw Materials, U. S. Atomic Energy Commission.

DETERMINATION OF THICKNESS, GRADE, AND DEPTH

Thickness

The thickness of the radioactive zones was determined by scanning the drill core for radioactivity and by interpreting features shown on the gamma-ray logs of the drill holes. The detector used to measure the radioactivity in drill core scanned successive lengths of 0.3 foot of core. Generally samples 0.3 foot in length are collected for chemical analysis even though the radioactivity is confined to a shorter interval of core. Therefore, the actual radioactive interval may be less than that indicated by the core scanner.

A limitation in the determination of thickness from the gamma-ray log is the effective length of the detector, which is approximately 7-1/4 inches. The thickness of a radioactive layer thinner than the length of the detector cannot be measured. Except for count rate, the logged anomalies for a 1-inch or a 7-inch layer of radioactive material have about the same configuration.

The thickness of a radioactive layer can be interpreted from a gamma-ray log by a direct measurement across the anomaly recorded on a strip-chart at a specified percentage of the peak value or magnitude of the anomaly.

This interpretation of thickness is based on logs of holes penetrating simulated ore bodies which were constructed with known grades and thickness of uranium ore. About 25 grade-thickness combinations were logged and the data were analyzed to determine the instrument response to various thicknesses. From this analysis a curve (fig. 1) was constructed showing the percentage of the peak value of the anomalies representing the respective thickness of the radioactive layer.

Examination of approximately 670 gamma-ray log thickness determinations of highly radioactive layers in the Morrison formation, the majority of which are in the Long Park area, Montrose County, Colorado, reveals that the average thickness of most of the layers is in the 0.8- to 1.4-foot range. This thickness range for radioactive layers in the Morrison formation may not be considered representative because the interpretations of thickness less than 0.8 foot may be in error owing to the equipment used and the Long Park area may not be representative of the Morrison formation. Discussions with several geologists in the Colorado Plateau indicate that the average thickness may be approximately 2 feet; however, the 2-foot-thick

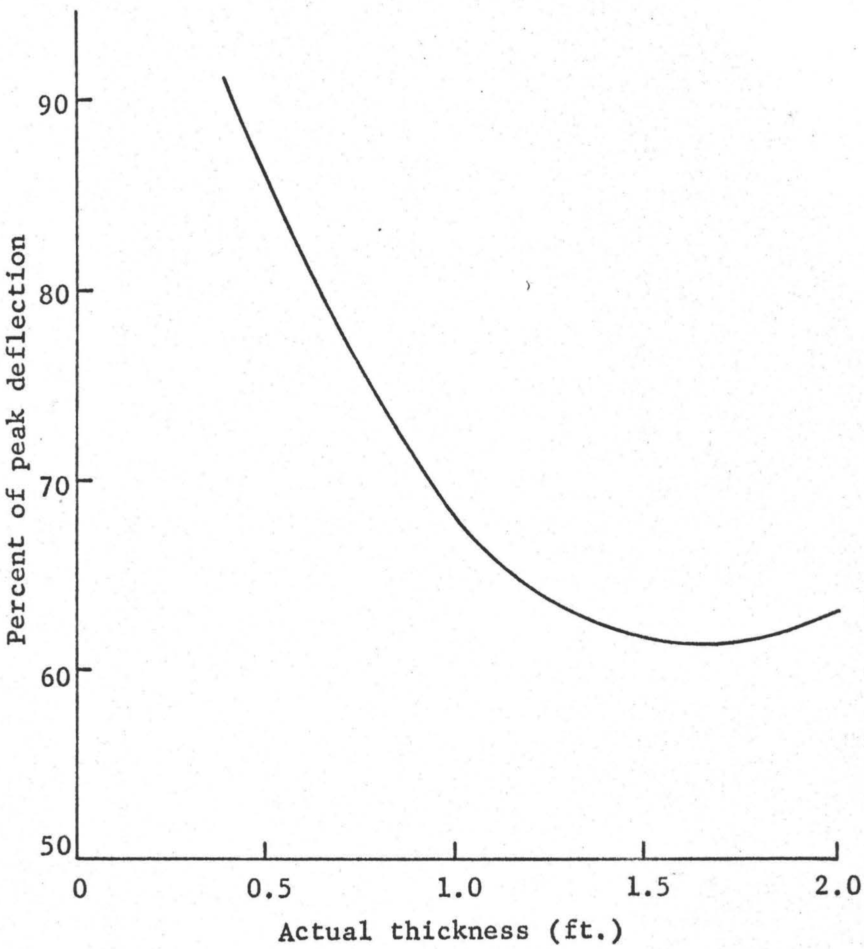


Figure 1. Percent of peak deflection at which strip-chart record shows actual thickness of layer in simulated ore body.

layers may be composed of 2 or more sub-layers of variable grade. The deflection-thickness curve (fig. 1) shows that thicknesses of 2 feet are estimated at 63 percent of maximum deflection on the strip-chart record; also, the thicknesses in the 1- to 2-foot range lie in the 61-68 percent of peak range. Therefore, an average value of 65 percent should give a fairly accurate thickness determination where the true thickness is between 1 and 2 feet.

Prior to and during this study, the thickness of radioactive layers was estimated by measuring across the anomaly curve at 70 percent of the peak deflection. The 70 percent value, as compared to a lower percentage, favors thin layers for accuracy in estimating thickness. The relationship of the actual thickness of radioactive layers of various thicknesses in simulated ore bodies to the estimated thickness from the gamma-ray log using the 70 percent figure is shown in figure 2. The thicknesses of layers greater than 0.9 foot are underestimated by approximately 0.1 foot; at 0.9 foot are correct; and at 0.4 foot are overestimated by 0.34 foot, or a factor of 1.85. The effect on the grade interpretation when the thickness is underestimated by 0.1 foot is a grade increase of about 2 percent. The use of the 65 percent of peak value reduces the discrepancy between estimated and actual thickness in the 1- to 2-foot range but increases the error for the thinner layers.

Present mining economics require that the radioactive layers be greater than 1 foot thick to constitute ore. Considering this, the interpretation of ore thicknesses as determined from the gamma-ray log should be very accurate.

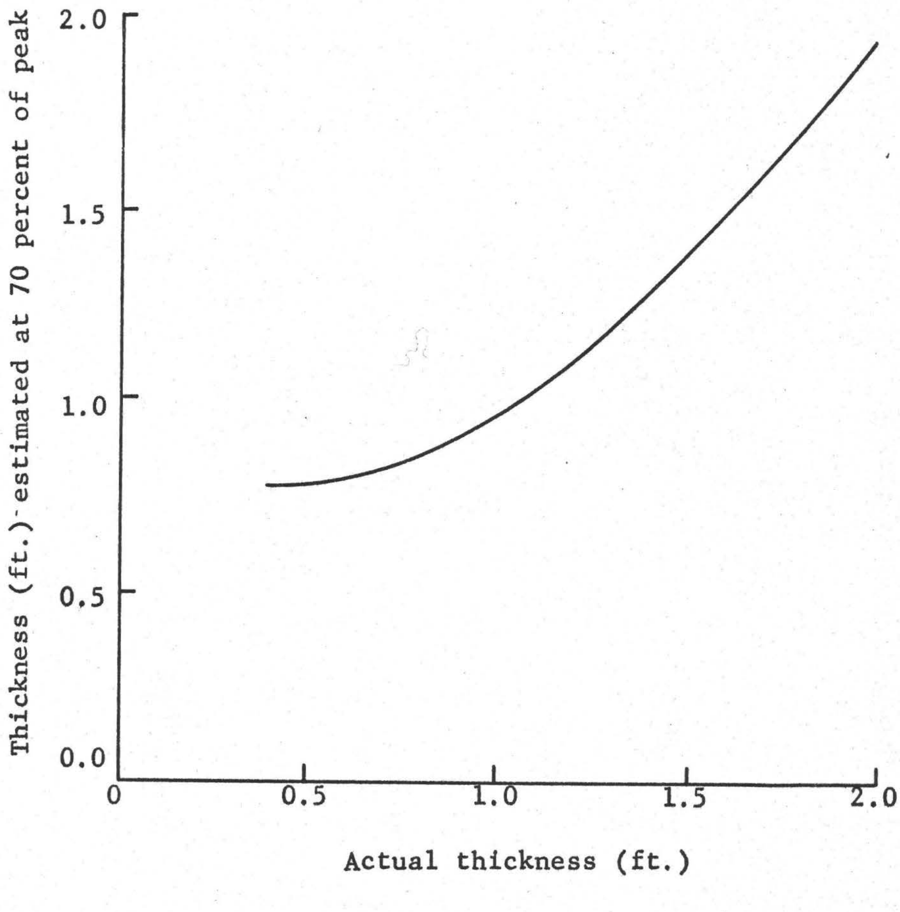


Figure 2. Comparison of actual thickness of radioactive layer in simulated ore body with thickness estimated at 70 percent of peak deflection.

Errors in the interpretation of the thickness of layers may be caused by the location of the drill holes. In an extreme case, a drill hole might conceivably be drilled adjacent to, but outside of, a radioactive layer thereby cutting no radioactive material. The gamma-ray log of such a hole might indicate an appreciable thickness of radioactive material.

Grade

This study involves grades of radioactive material determined by five methods: (1) chemical analysis of core, (2) radiometric analysis of core, (3) interpreted analysis from the gamma-ray log, (4) radiometric analysis corrected for disequilibrium to equivalent chemical analysis, and (5) the radioactivity analysis of drill core weighted for differences of thickness determinations as measured from core and gamma-ray log interpretation.

Chemical and radioactivity analyses of drill core

Samples selected by the core scanner are analyzed chemically for uranium oxide content and radiometrically for equivalent uranium content. The results of these analyses may not agree because of secular disequilibrium, statistical error, and error in chemical analysis.

Disequilibrium of the uranium and its daughter products may be caused by natural processes or by preparing samples for analysis. Disequilibrium may be caused by the grinding process preceding radioactivity analysis of core samples at which time radon may be driven off by friction heat and may also escape from pore spaces in the rock as a result of fracturing. Unless the samples are allowed to stand for several days after grinding to regain equilibrium the radioactivity analysis will be lower than the chemical analysis.

Statistical error is inherent in all radiometric analyses, and is a function of the total number of events or counts observed. For count-rate meters the magnitude of the fluctuation from an average counting rate depends on the total number of events recorded in the inherent interval, the time constant, of the instrument. Figure 3 shows the standard deviation of count rate observed with gamma-ray logging equipment. In ratemeter equipment standard deviation is affected by both count rate and time constant. A change in time constant between two count-rate ranges occurs at 1,000 counts per minute in the meter of the gamma-ray logging equipment used in this study.

Even though it has been assumed that in all cases the chemical analyses are correct, errors undoubtedly exist in the method of chemical assay and, as in the radiometric analysis, tend to occur where greater accuracy is required, in the low-grade material.

Interpreted analysis from the gamma-ray log

A radioactivity analysis in terms of grade and thickness is obtained by use of the thickness and count-rate measurements obtained from the gamma-ray log and interpretation of the information from a calibration chart.

Extensive laboratory investigation of the response of the gamma-ray logging equipment under controlled conditions indicates that the error among various components of the equipment plus the statistical error inherent in random counting does not exceed 11 percent standard deviation.

A core sample may not be representative of the layer from which it has been obtained. This may be a major source of error in the comparison

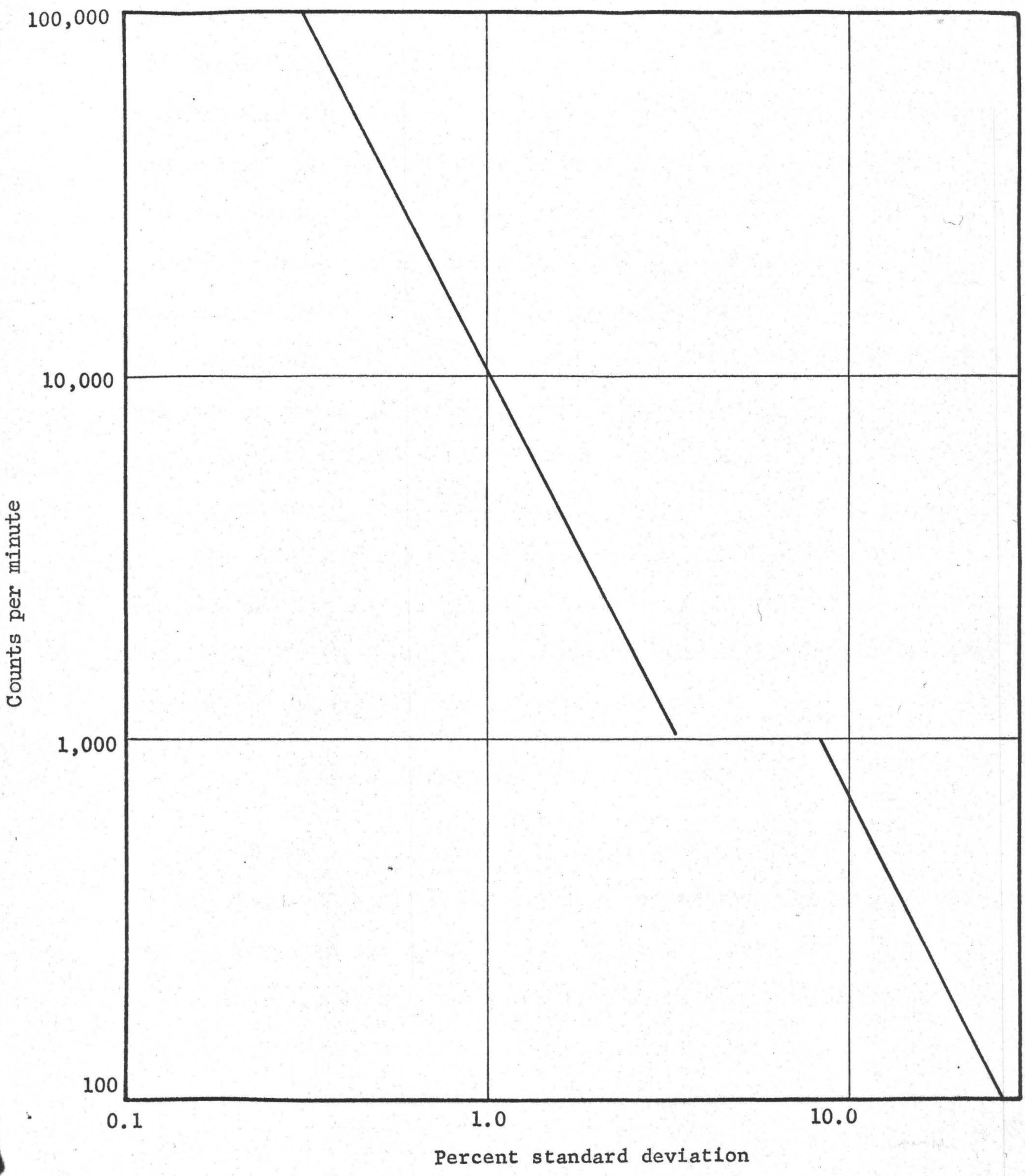


Figure 3. Standard deviation of count-rate measurement obtained with gamma-ray logging equipment.

of grade data obtained from drill core and from gamma-ray logging equipment. The largest core taken in most uranium exploration is 2-3/4 inches in diameter whereas the effective diameter for a gamma-ray log measurement may be as large as 5 feet depending on the rock density and the efficiency of the gamma-ray detector.

Equivalent chemical analysis

Chemical analyses were not available for all of the core samples analyzed for radioactivity. Because the comparisons in this study are based on the chemical analyses it was necessary to determine the relationship between the chemical and radiometric analyses of the drill core. To determine this relationship, the results of analyses of the drill cores which had been analyzed both chemically and radiometrically for uranium content were plotted on graphs. Determination of this relationship permits all radiometric analyses to be converted to equivalent chemical analyses. The relationships between the chemical and radiometric analyses of drill core from the Long Park (fig. 4), Monogram Mesa (fig. 5), and Disappointment Valley (fig. 6) areas show that on the average the radiometric analyses are 20 to 30 percent lower than the chemical analyses.

Weighted radioactivity and gamma-ray log interpretation analyses

Although it has been assumed that the thickness as determined from the drill core samples is absolutely correct and that thicknesses over 0.8 foot as determined from the gamma-ray log interpretation are very accurate, the results differ and therefore the following adjustment in grade has been made:

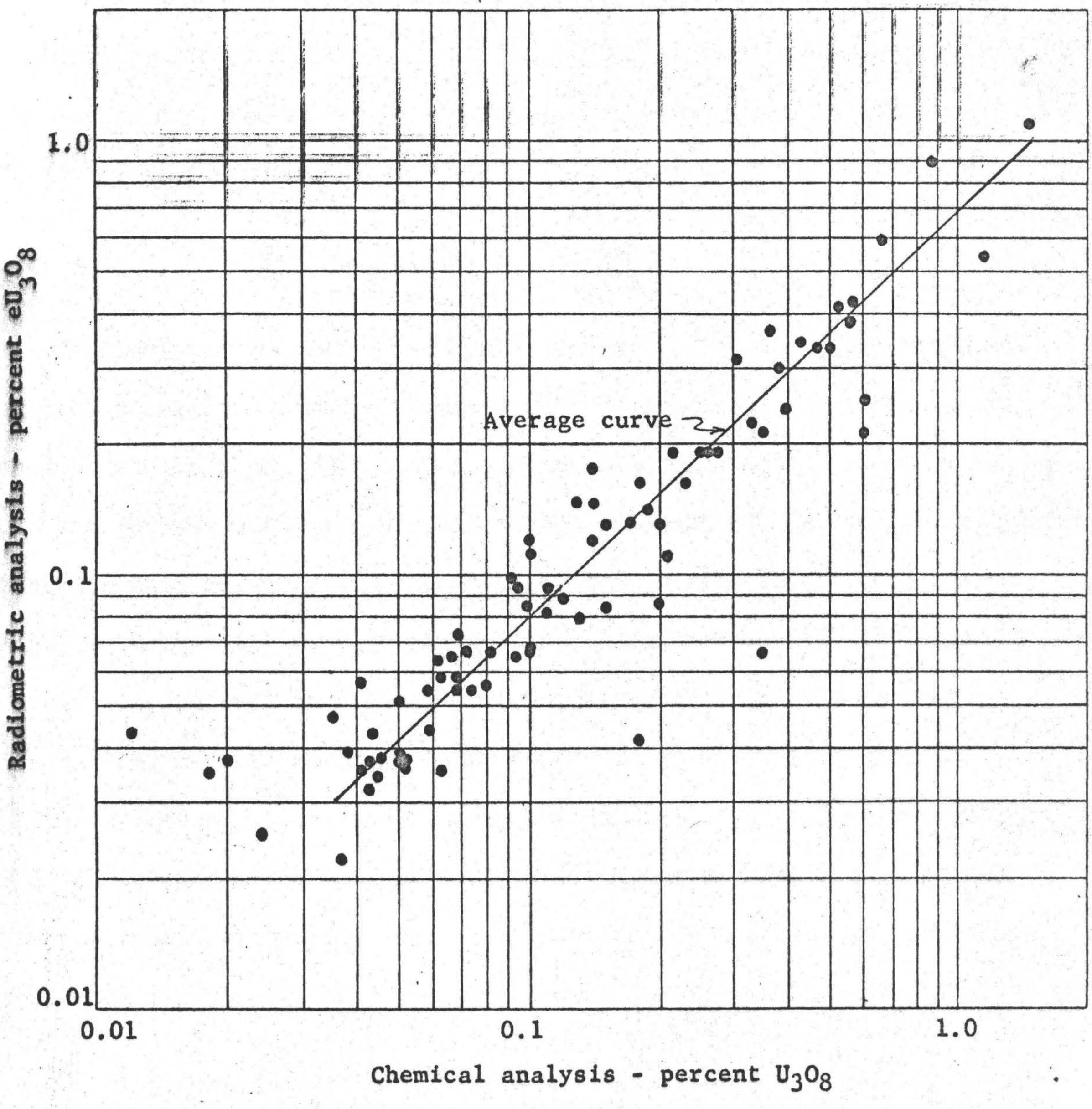


Figure 4. Relationship between chemical and radiometric analyses of drill core from the Long Park area, Montrose County, Colo.

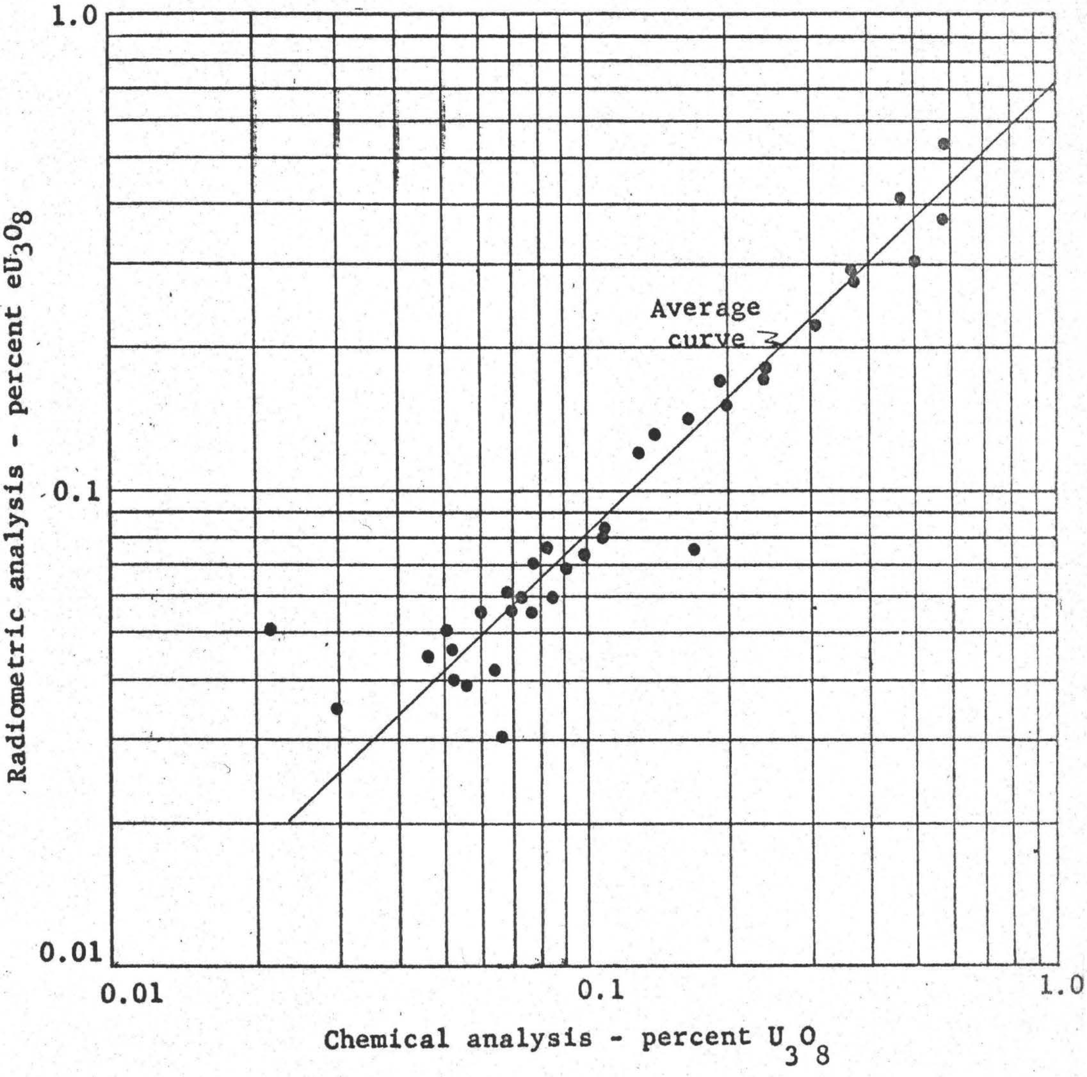


Figure 5. Relationship between chemical and radiometric analyses of drill core from Monogram Mesa, Montrose County, Colo.

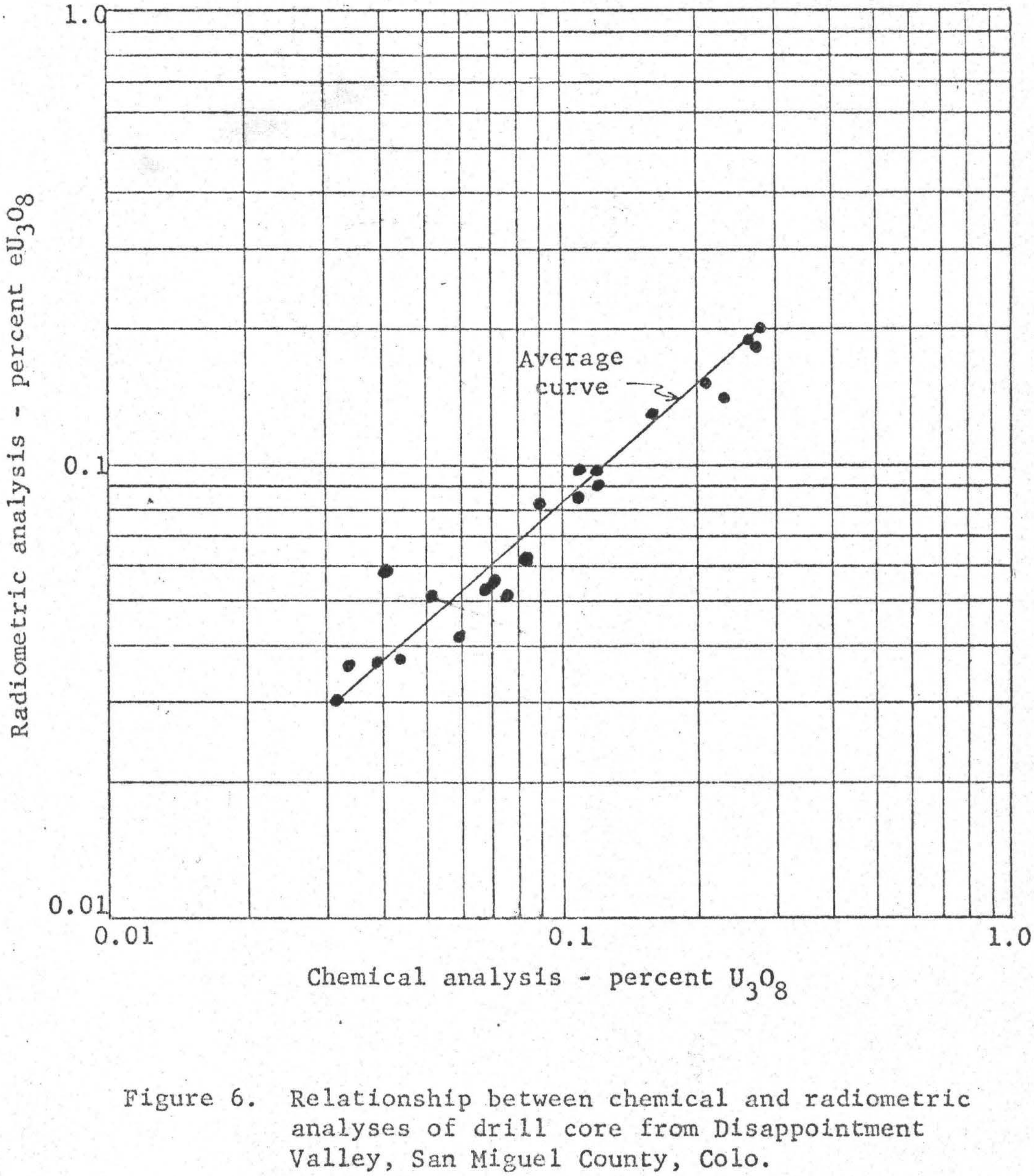


Figure 6. Relationship between chemical and radiometric analyses of drill core from Disappointment Valley, San Miguel County, Colo.

1. The radioactive zones chosen for comparing grade analyses were approximately 1 foot thick to reduce the error caused by the thickness resolution of the equipment.

2. The average grade of the core sample interval was obtained.

3. The grade of the gamma-ray log interpretation was adjusted to correct for the differences in thickness.

Analyses and interpretations were weighted as illustrated in the following example:

Core analysis			Gamma-ray log		
Sample depth	Thickness	Percent eU_3O_8	Anomaly	Thickness	Percent eU_3O_8
481.6-482.2	0.6	0.038	481.5-482.5	1.0	0.028
482.2-482.5	0.3	0.006			

The average percent eU_3O_8 value for the two core samples was determined as follows:

$$0.6 \times 0.038 = 0.0228$$

$$\underline{0.3} \times 0.006 = \underline{0.0018}$$

$$0.9 \qquad 0.0246 \div 9 = 0.027$$

The grade determined from the gamma-ray log interpretation was adjusted for the differences in thicknesses as determined from measurement of the core and by gamma-ray log interpretation. By reducing the gamma-ray log thickness to agree with the core thickness the weighted grade is increased. The calculation was made as follows:

$$\frac{\text{Gamma-ray grade}}{\text{Weighted gamma-ray log grade}} = \frac{\text{Core thickness}}{\text{Anomaly thickness}}$$

$$\frac{0.028}{x} = \frac{0.9}{1.0} \qquad x \qquad \frac{0.028}{0.9} = 0.031 \text{ weighted percent } eU_3O_8$$

The foregoing method of adjusting data provides a means of comparing the two sets of data on the basis of equal thickness.

Depth

The major uses of the gamma-ray logging method are the grade calculation and location of radioactive material in a drill hole. These uses require that an accurate depth estimate be made from the gamma-ray log. The accuracy of the depth interpretation is limited by the equipment and by the experience of the operator and the interpreter.

The measuring component of the gamma-ray logging equipment consists of a sheave wheel and a mechanical or electro-mechanical system which connects the wheel to a strip-chart recorder. The recorder plots the relative amounts of radioactivity in the drill hole versus the depth indicated by the measuring system. The logging equipment is designed to limit the error in depth measurement to less than 0.5 percent. A factor which may cause the error to exceed that amount is stretching of the cable during logging.

If the equipment error in depth measurement is known, the log interpreter can compensate for it throughout the gamma-ray log when the interpretation is made, thereby minimizing the error in any particular depth determination.

Depths to the radioactive layers were referred to the drill hole collar and measured to the base of the radioactive layer--the base of the lower sample in a radioactive layer chosen by the core scanner, and the base of the layer as interpreted from the gamma-ray log. Errors occur in making both types of depth measurements.

The accuracy of the depth indicated by the core scanner depends on the measurement of the drill core as it comes from the drill hole, and on the resolution of the core scanner as discussed previously. When no core loss or human error in measurement occurs, the accuracy of the depths indicated by the core scanner should be within the limits of the resolution of the scanner. However, because there was a 10 percent core loss in some of the sampled zones used in this study and because core was obtained in 10-foot sections, the depths may be in error by as much as 1 foot plus the error caused by the core scanner.

COMPARISON OF DATA FROM GAMMA-RAY LOGGING AND FROM CORE SAMPLING

The data obtained from interpretation of the gamma-ray logs show a continuous measurement of the gamma-ray intensity throughout a drill hole. Except where 100 percent core recovery has been obtained the data derived from analyses of recovered drill core will give only partial information.

With but a few exceptions, the data based on core-sample analyses cannot be compared to the data obtained from interpretation of the gamma-ray log. Transposition and adjustment of data are necessary to permit comparison. The method of comparing data used in this study assumes that within the set of data based on core-sample analyses the chemical analyses of the core samples are uniquely correct and that all adjustments of data must be fundamentally although indirectly based on chemical analyses.

Thickness

Because of the difference in resolution of the equipment used to measure thickness, no direct comparison was attempted between gamma-ray logs and core-sample analyses. The grade data were weighted on the basis of equal thicknesses as explained in the section on determinations of thickness, grade, and depth.

Grade

Grades that are determined by drill-core analyses may differ from grades interpreted from gamma-ray logs owing to: (1) uranium loss from core samples, (2) heterogeneous layers, (3) cylinders of radioactive rock having a diameter less than that measured by the gamma-ray log, and (4) non-tabular layers. Other factors that may affect the validity of direct comparison of grades, such as disequilibrium and counting and analytical errors, have been discussed previously.

Although samples were chosen where the core recovery was 90 percent or greater, the amount of uranium loss from the core sample was indeterminable. Uranium associated with clay may be pulverized and floated away by drilling fluids. In the same category is unrecognized loss of uranium due to breakage and handling of the core.

Heterogeneity of the radioactive layer is a source of error in comparing radioactivity determined from core samples and gamma-ray logs. The sample from the drill core may contain either more or less radioactive material than the average content of the surrounding rock cylinder which, in effect, is the sample for the gamma-ray log.

It may be possible for a drill hole to penetrate a radioactive layer that is smaller than the cylinder of rock from which gamma-ray logs are obtained. Similarly, the drill hole may penetrate a radioactive layer near its horizontal limit, the distance between the drill hole and the edge being less than the distance from which the gamma-ray data are obtained. In either case, uranium grade determined from the gamma-ray log would be less than the actual grade of the radioactive layer.

Occasionally, drill holes penetrate wedge-shaped radioactive layers of rock. Drill core from layers of this type show a thinner layer than is indicated by the gamma-ray log. The gamma-ray log interpretation would probably overestimate both grade and thickness.

The grade interpretations of the gamma-ray logs were compared with radiometric analyses of drill core and with radiometric analyses corrected for disequilibrium of core samples (figs. 7, 8, 9). The graphs were constructed by plotting the grade interpretations from the gamma-ray logs against the radiometric analyses of the drill core. Because the comparisons in figures 4, 5, and 6 showed that the radiometric analyses of drill core were lower than the chemical analyses by a disequilibrium factor of approximately 0.8, the radiometric data were corrected by this factor. Data obtained from the Long Park area (fig. 7) indicate a 20 to 25 percent overestimation in grade determined from gamma-ray log interpretation as compared to radiometric core data. It should be noted, however, that geologists working in the Long Park area have examined many more radiometric and chemical analyses than were used for this report. Their examinations indicate that overestimation is only about 10 to 12 percent.

Information obtained from Disappointment Valley (fig. 8) and Monogram Mesa (fig. 9) indicates less than 10 percent variation between the two types of data.

Depth

The depths to radioactive layers as interpreted from the gamma-ray logs were compared with those measured from drill cores obtained in Long Park (fig. 10), Disappointment Valley (fig. 11), and Monogram Mesa (fig. 12).

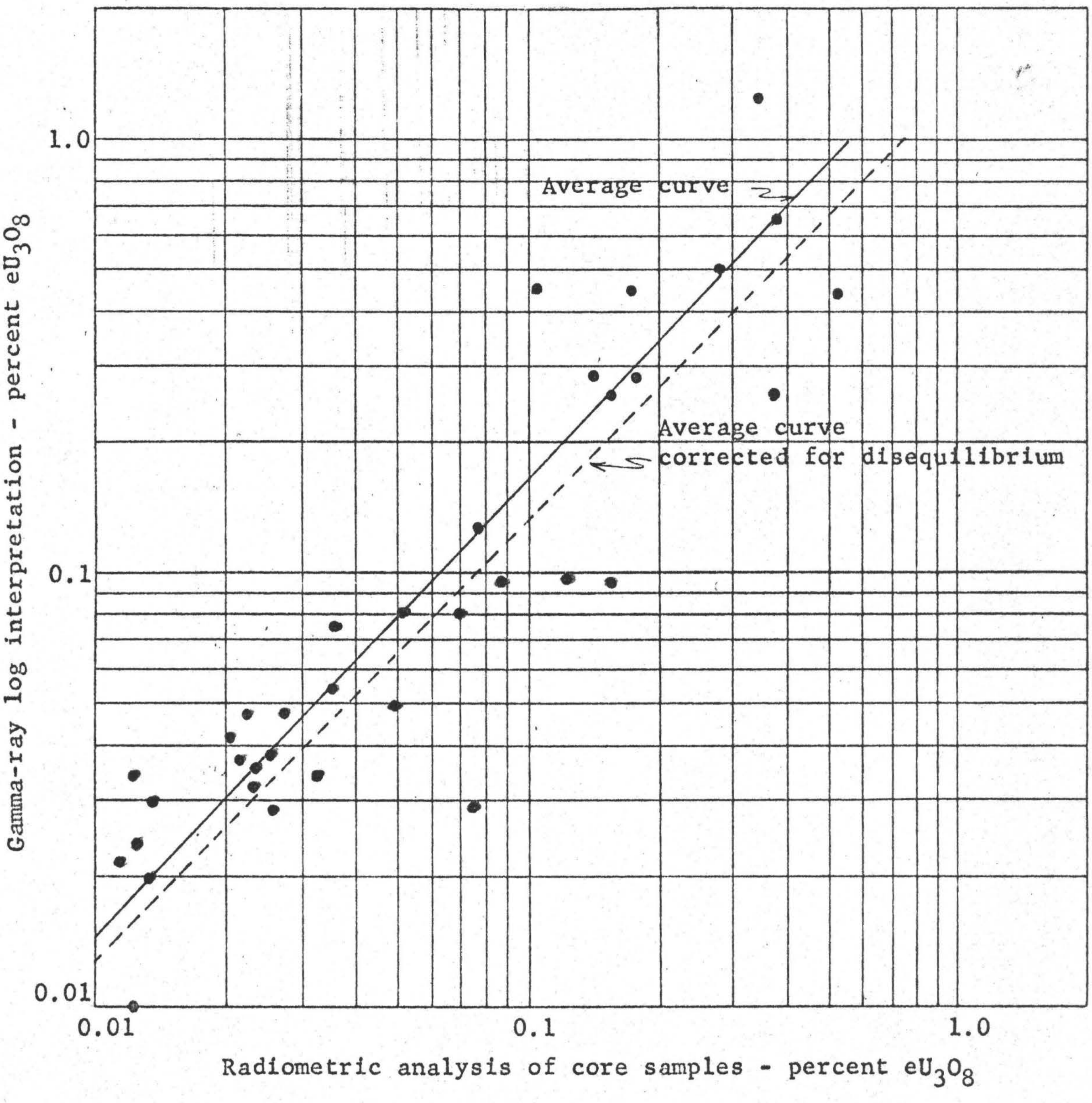


Figure 7. Comparison of grade from gamma-ray log interpretation with radiometric analyses of drill core samples and with radiometric analyses corrected for disequilibrium, Long Park area, Montrose County, Colo.

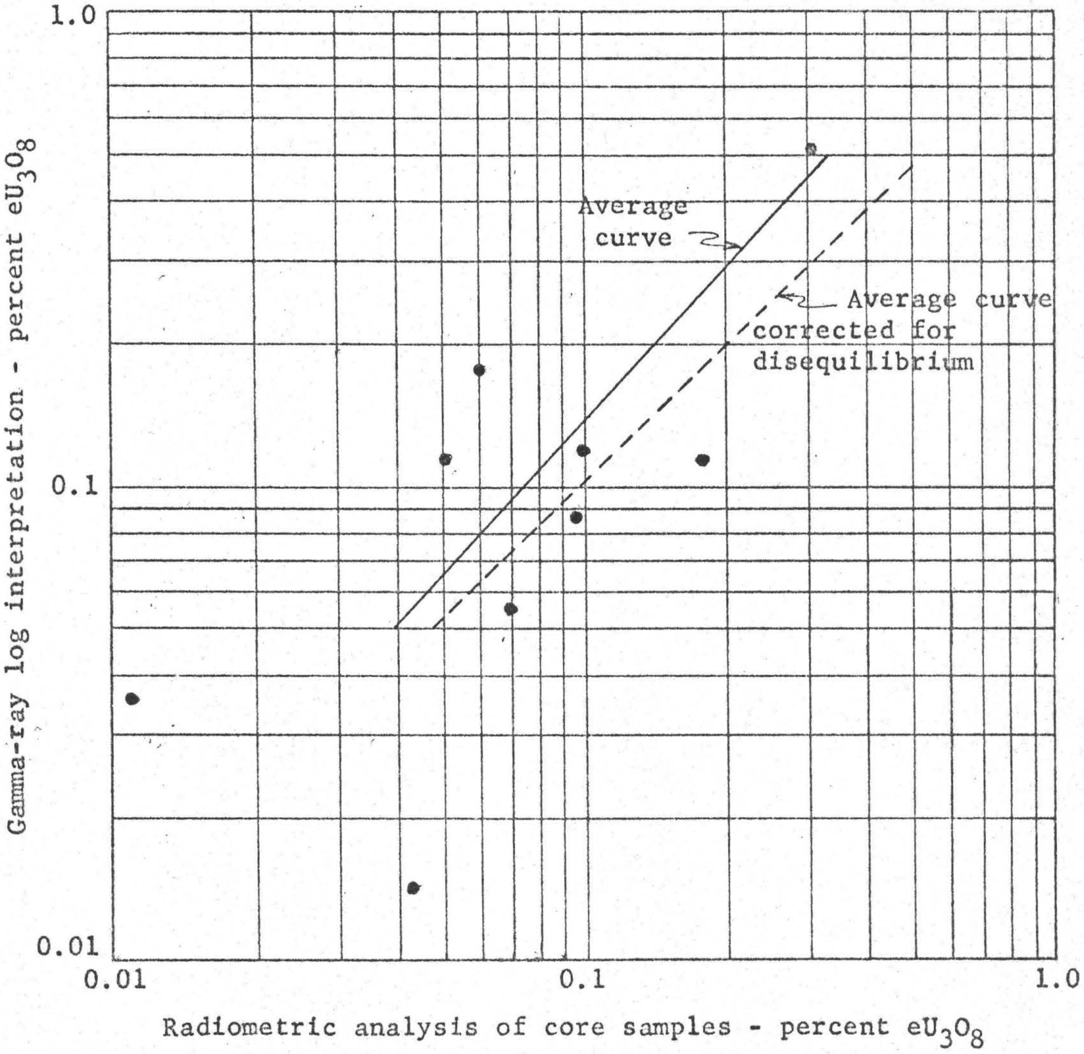


Figure 8. Comparison of grade from gamma-ray log interpretation with radiometric analyses of drill core samples and with radiometric analyses corrected for disequilibrium, Disappointment Valley, San Miguel County, Colo.

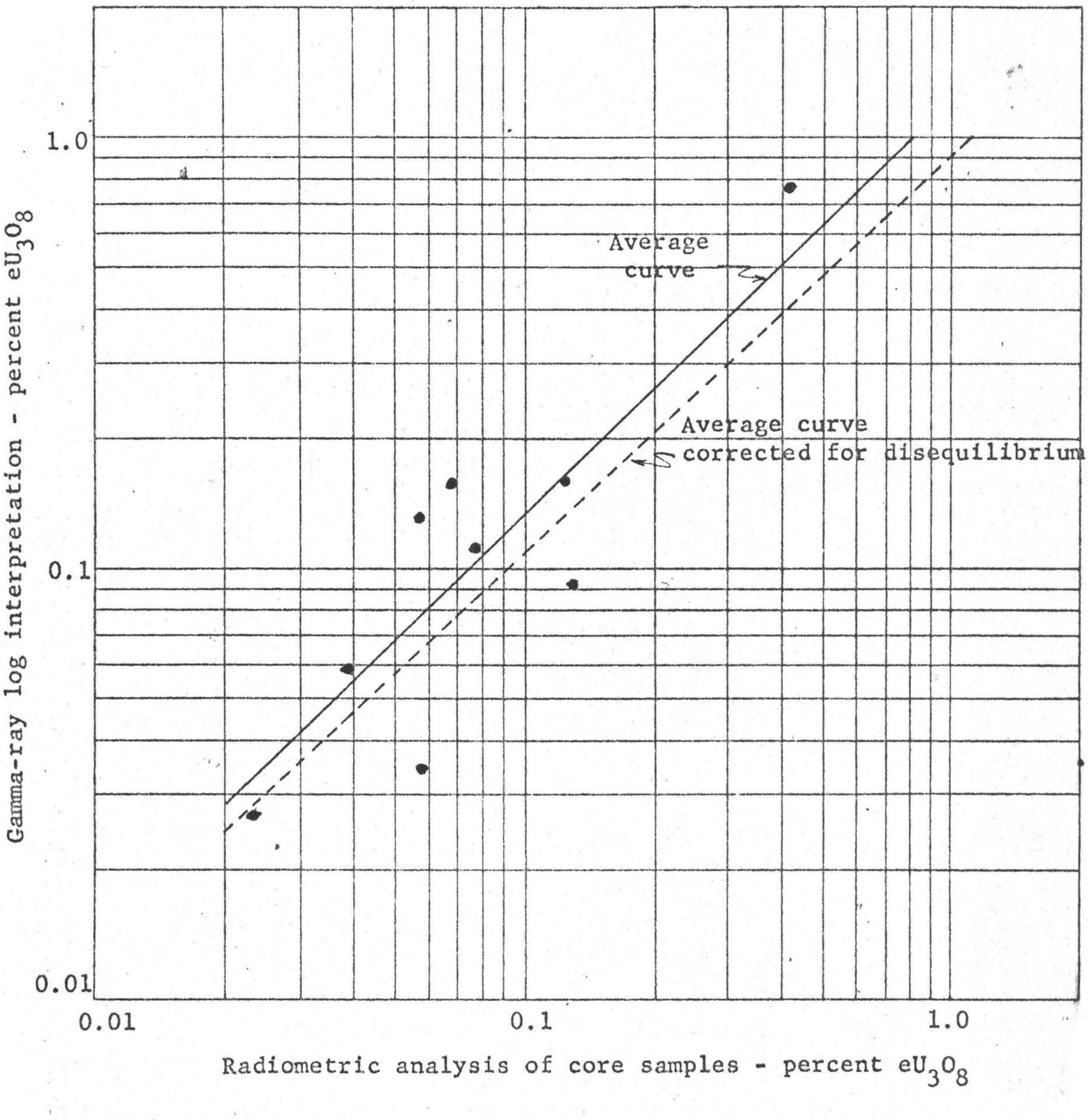


Figure 9. Comparison of grade from gamma-ray log interpretation with radiometric analyses of drill core samples and with radiometric analyses corrected for disequilibrium, Monogram Mesa, Montrose County, Colo.

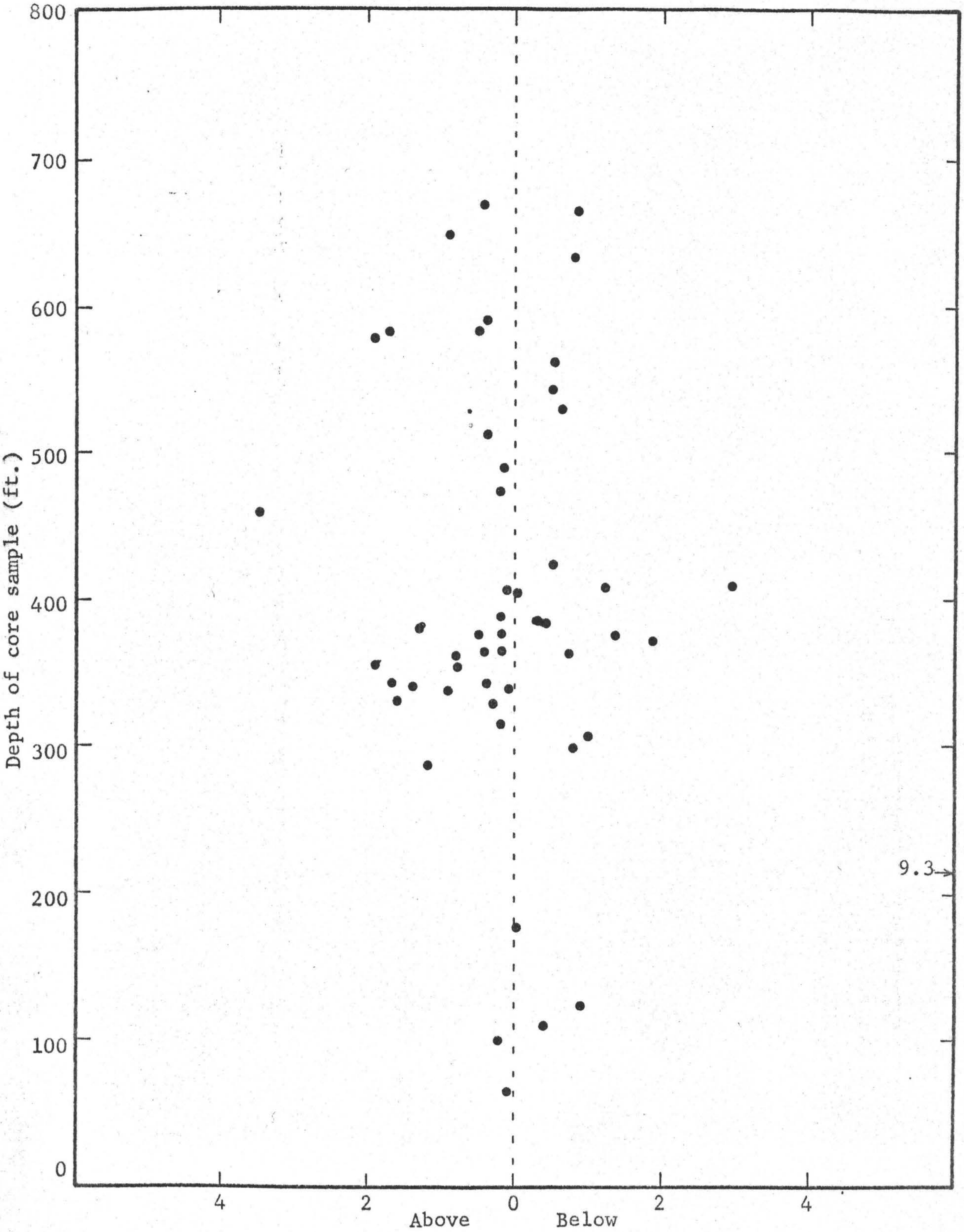


Figure 10. Variation in depth of gamma-ray anomaly with depth of core sample, Long Park area, Montrose County, Colo.

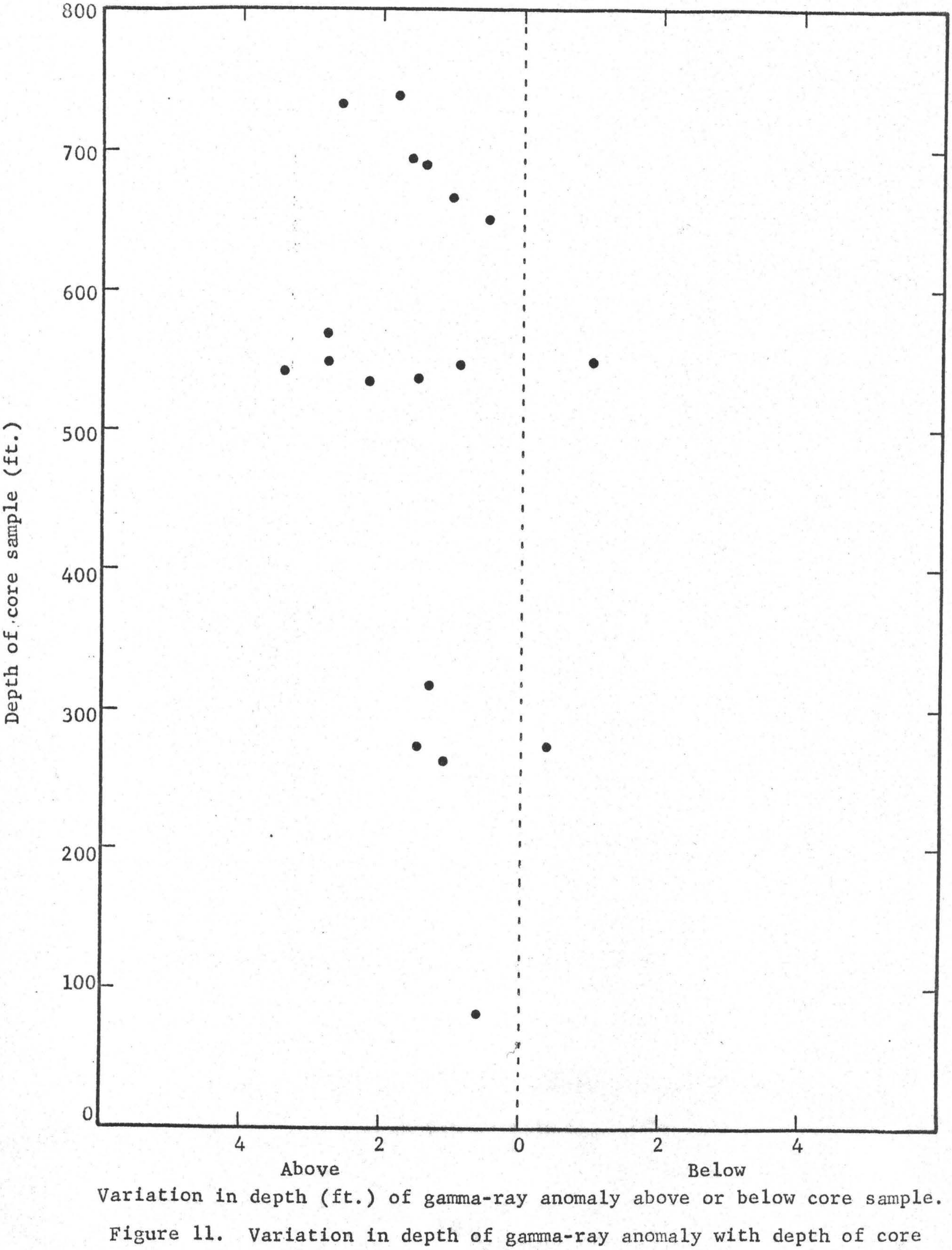
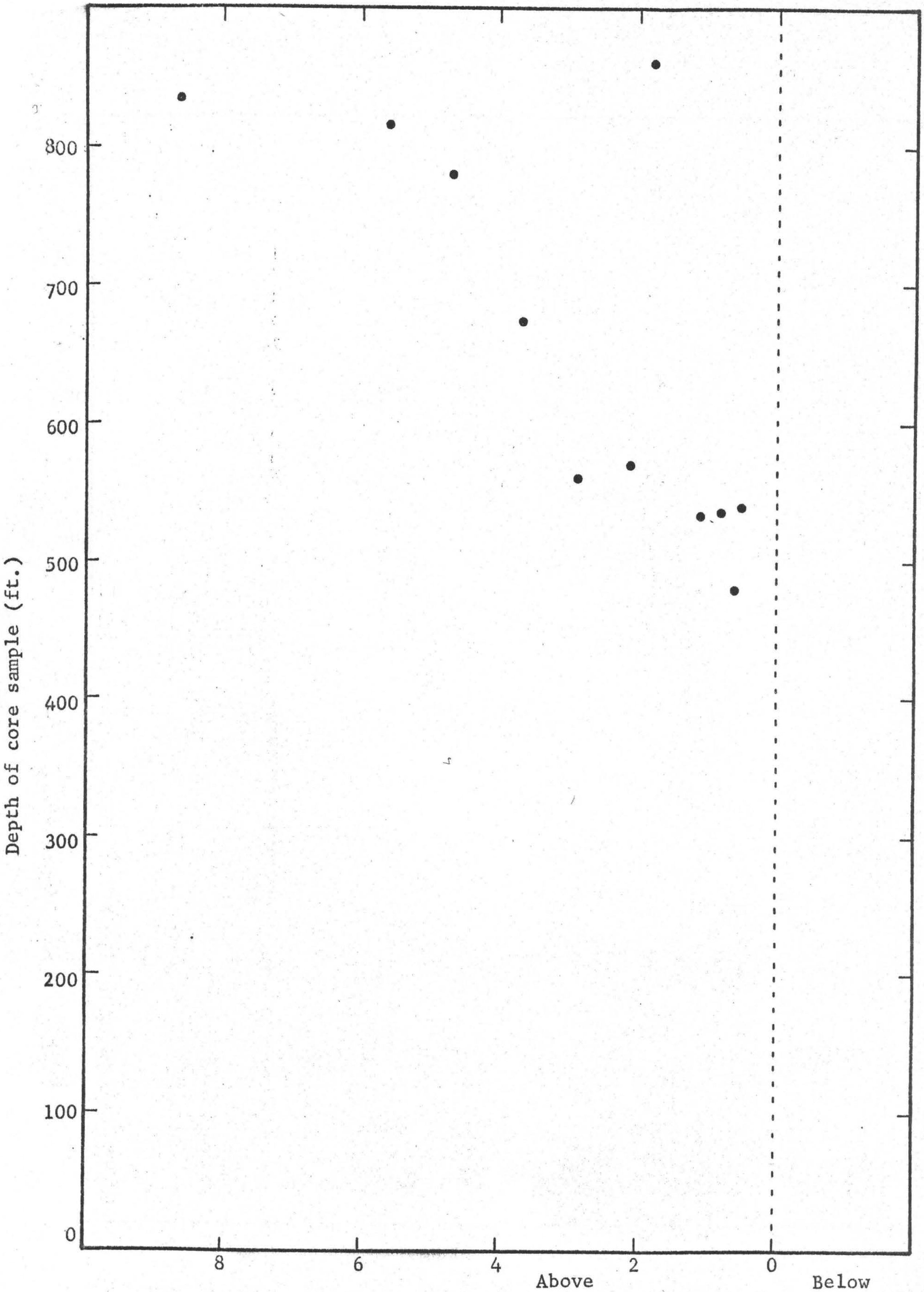


Figure 11. Variation in depth of gamma-ray anomaly with depth of core sample, Disappointment Valley, San Miguel County, Colo.



Variation in depth (ft.) of gamma-ray anomaly with depth of core.

Figure 12. Variation in depth of gamma-ray anomaly with depth of core sample, Monogram Mesa area, Montrose County, Colo.

On these figures zero is the base of the drill core samples. Where the base of the interpreted radioactive layer was higher in the drill hole than the radioactive sample the discrepancy in depth was plotted on the upper or plus side of the zero line, and vice versa. Only one example was obtained from each gamma-ray log so that the data would not be shifted erroneously by an excessive number of good or bad samples from a drill hole.

Comparison of data from the Long Park area (fig. 10) shows that 70 percent of the depth interpretations are within 1 foot of the depth measurement of the drill core samples and that 94 percent are within 2 feet. One interpretation was 9.3 feet too low, an error that could have been made by miscounting the number of 10-foot drill rods in the hole, by inverting a 10-foot section of drill core, or by mismeasuring by 10 feet on the gamma-ray log. The greatest number of discrepancies over 2 feet are in the 300-400 foot range. These anomalies probably occur near the center of the gamma-ray log where there is no depth reference point, except for the ends of the log, from which depth corrections can be made.

The error in the Disappointment Valley data (fig. 11) is within the anticipated 0.5 percent but it probably could have been reduced by correction during interpretation.

The error in the Monogram Mesa data (fig. 12) is slightly greater than the anticipated error and was probably caused both by malfunctioning equipment and insufficient correction during interpretation.

CONCLUSIONS

Errors in measuring the thickness of a radioactive layer in the drill core and in interpreting the thickness from the gamma-ray log, which make direct comparisons difficult, are related directly to the thickness resolution of the scanning and logging equipment. A solution to this problem is the use of gamma-ray detectors of minimum length and maximum sensitivity. Minimum length is required for maximum thickness resolution; however, the detector sensitivity should not be sacrificed, for a loss in count-rate increases statistical error which, in turn, increases the error in grade interpretations. A sodium iodide scintillation crystal is the best detector available at present, but associated equipment has not been proved sufficiently stable to make accurate radiation measurements in the field.

Thickness determination from gamma-ray log data obtained from radioactive layers that are thinner than the effective length of the detector, in this case about 0.6 foot, are of dubious validity. The results of this investigation show that the determination of the thickness of most radioactive layers may be improved slightly by measuring the thickness at 65 percent of the peak deflection of the recorded radioactivity. This conclusion pertains only to data obtained with the gamma-ray logging equipment used in this study.

It is not surprising that grades interpreted from gamma-ray logs are sometimes higher than the chemical analyses of the drill core samples because of the various factors that favor a high estimate. These include poor recovery of core, loss of uranium from the core samples, logs obtained from radioactive layers having a diameter less than the cylinder from which gamma-ray measurements are obtained, and logging of non-tabular radioactive layers. Although circumstances favor a high estimate, a low estimate is not unusual and may occur when a drill hole penetrates an ore deposit that tapers sharply from the center of the drill hole or when secular disequilibrium favors a high radium to low uranium ratio.

A graphic example of a comparison of drill core sample analysis and gamma-ray log interpretation (fig. 13) shows that, in general, the parameters compare favorably. The depths agree within about 1 foot which is acceptable. The grade determined from the gamma-ray log is slightly higher than that from core sample analysis.

Most of the depth estimates determined from gamma-ray logs agree with drill core measurements to an accuracy greater than 0.5 percent. Some depth-measuring instrumental components, shown by this study to be malfunctioning, have been modified to increase the measurement accuracy. Cable stretch, a source of error in depth determination, was reduced by pre-stretching new cable before sending it to the field. Operator-interpreter personnel have been instructed to compare actual cable lengths with indicated lengths to make proper compensations during interpretation.

An error in depth estimation caused by cable sag between drill hole collar and cable reel can be reduced by keeping the reel as close to the collar as possible during logging.

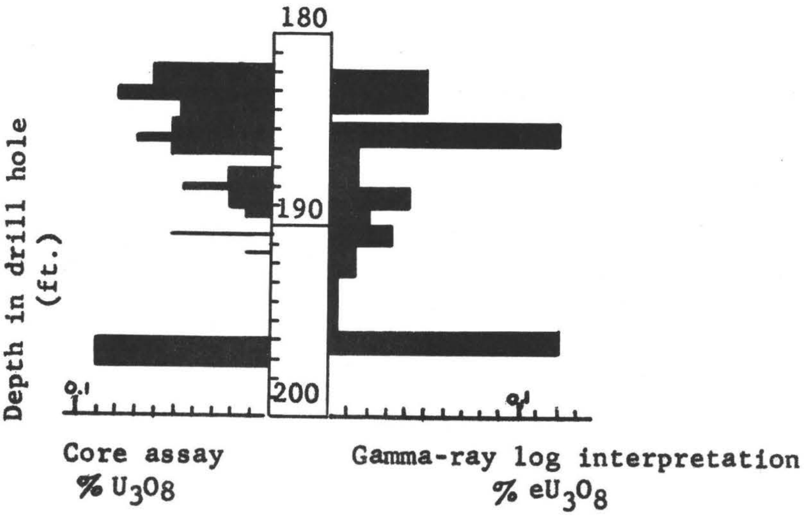


Figure 13. Graphic correlation of core assay with gamma-ray log interpretation.