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STATISTICAL INTERPRETATION OF SAMPLE ASSAY DATA FROM THE MI VIDA URANIUM MINE, BIG INDIAN DISTRICT, SAN JUAN COUNTY, UTAH

By George S. Koch, Jr., Richard F. Link,
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by

George S. Koch, Jr.,[1] Richard F. Link,[2] and Scott W. Hazen, Jr.[3]

ABSTRACT

The Mi Vida mine, Big Indian district, San Juan County, Utah, is in an ore deposit of uranium and vanadium minerals disseminated in certain sedimentary beds of the Triassic Chinle formation. Statistical analysis of assays of samples taken from the ore body affords an estimate of the grade of the ore body and provides a prediction about the direction of best mineralization beyond the sampled area

The basic data analyzed are assay results for uranium (U_3O_8), vanadium (V_2O_5), and lime (CaO) from 225 channel samples cut at 79 sample points.

Through the use of appropriate statistical methods, particularly regression analysis, the grade of ore may be estimated more precisely than by conventional means, and the most favorable direction to extend the mine may be predicted. Frequency distributions of assay residuals for uranium, vanadium, and lime are compared to frequency distributions of assays without regard to trend. Correlations among these variables are obtained and interpreted.

The statistical methods employed illustrate certain techniques that may be used to analyze assay data from ore deposits in general.

INTRODUCTION

In 1953, engineers of the Bureau of Mines examined the Mi Vida uranium mine of the Utex Exploration Co. in the Big Indian mining district, San Juan County, Utah (fig. 1). A description of the mine and operations was

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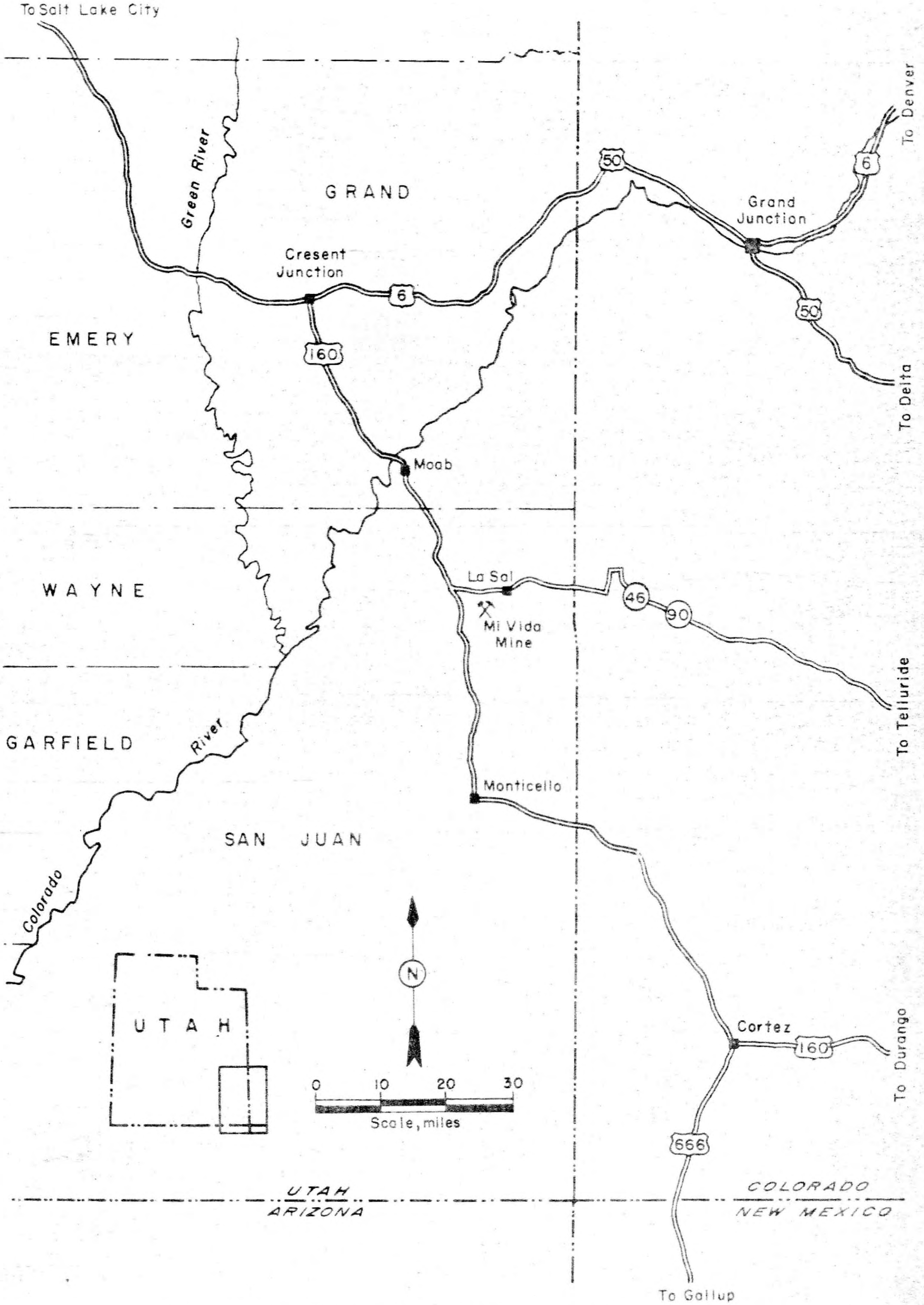

FIGURE 1. - Location Map, Mi Vida Mine, San Juan County, Utah.

published by the Bureau in 1953 (4).[4] During the examination, 225 samples cut in the underground workings were assayed for uranium, vanadium, and lime (calcium oxide). Because of restrictions at that time on publishing uranium data, the assay results of the samples were not given in the 1953 report. Recently, however, these data became available for publication.

In this report, one of a series describing work done at the Denver Mining Research Center of the Bureau of Mines on methods to improve mine sampling and evaluation, various statistical techniques, particularly that of regression analysis, are applied to the Mi Vida assay data, and the results are interpreted.

The Mi Vida ore deposit was discovered in July 1952 by Charles A. Steen, a geologist and prospector, while boring the first diamond-drill hole in the Big Indian district. High-grade ore, 14 feet thick, was penetrated by the borehole. Sinking of a shaft, 30 feet southeast from the discovery borehole, was begun in October, and the first shipment of ore was made on December 6, 1952. The discovery shaft, the extent of the workings when sampled by the Bureau in 1953, and the extent of the workings in 1961 are shown in figure 2.

ACKNOWLEDGMENTS

The authors thank the Utex Exploration Co. for cooperating in the 1953 sampling program. Particular thanks for his interest and advice are due to Charles A. Steen, who in 1953, was chief geologist of the Utex Exploration Co. R. R. McLellan, of the Bureau of Mines, cooperated in the original work. W. L. Dare, R. D. Berkenkotter, and B. G. Horton, all of the Bureau of Mines, assisted in sampling the Mi Vida mine.

LOCATION, PHYSICAL FEATURES, AND GENERAL GEOLOGY

The Mi Vida mine is 38.1 miles, by road, southeast of Moab, Utah, on the Mi Vida and adjacent claims, in the Big Indian mining district, and in sec. 11, T. 30 S., R. 24 E., Salt Lake Meridian, San Juan County, Utah. The mine can be reached by traveling 30.3 miles southeast from Moab on U. S. Highway 160, then 7.8 miles, generally northeast, on a paved road up Steen Canyon; this road is used by trucks transporting ore from the mine (fig. 1).

Topography of the area is typical of the semidesert Colorado Plateau region, comprising a series of anticlines and synclines with the drainage forming steep-walled canyons and mesas capped locally by massive cliff-forming sandstone. Vegetation is sparse, consisting of scrub pine, pinon, and sagebrush. The climate is arid, with temperatures rising above 100° F in the summer and falling below freezing in the winter. Snows, usually less than six inches deep, occasionally reach a depth of two feet. Except after severe storms and during spring thaws, dirt roads to the mines in the area are passable.

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[4] Underlined numbers in parenthesis refer to reports given in the list of references at the end of this report.

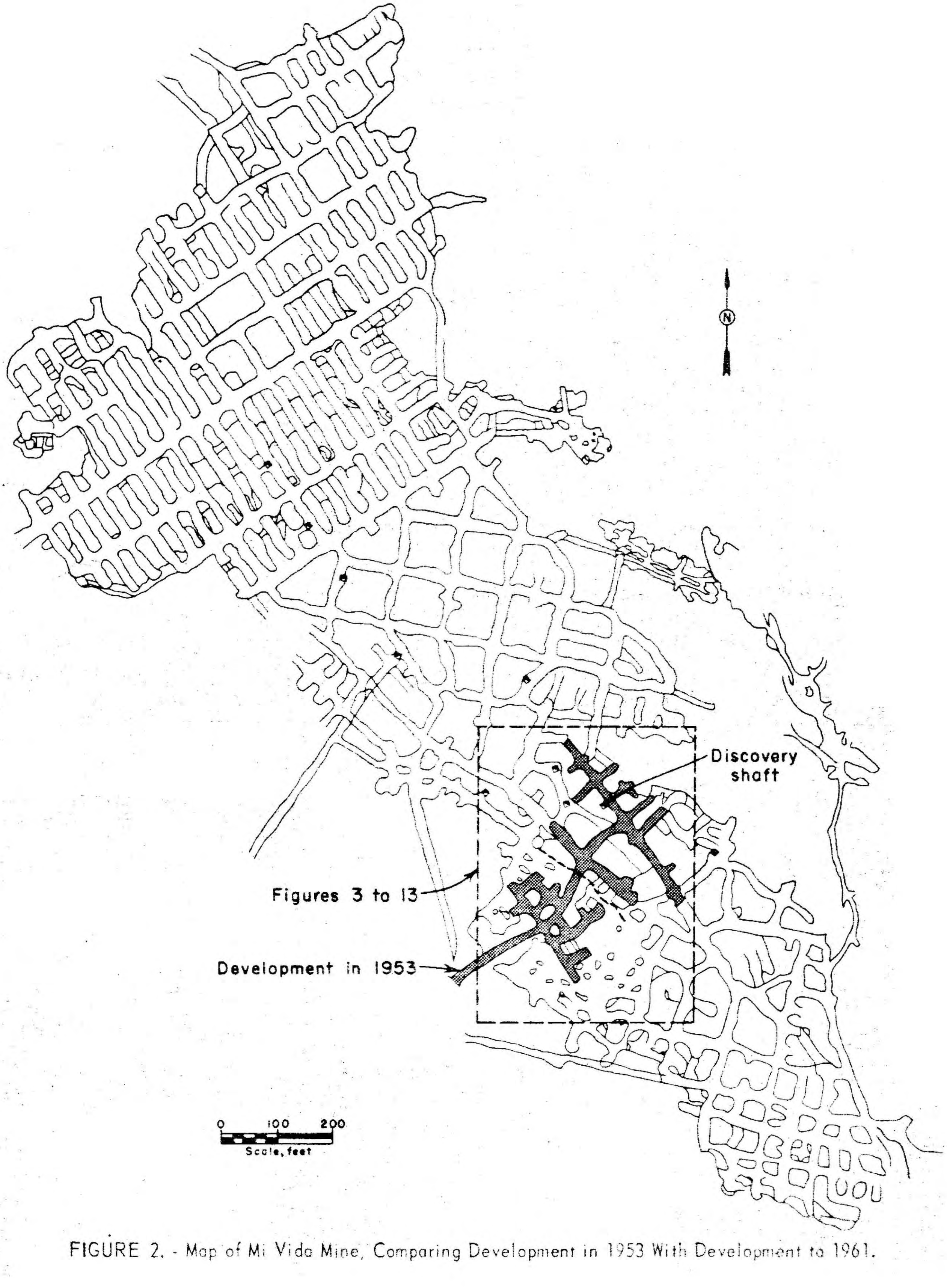

FIGURE 2. - Map of Mi Vida Mine, Comparing Development in 1953 With Development to 1961.

The Big Indian mining district is on the southwest flank of the Lisbon Valley anticline, which plunges to the northwest; the ore-bearing horizon is overlain by a considerable thickness of Jurassic and Cretaceous sedimentary rocks. In the mine area the Triassic Chinle formation consists of variegated mudstones and siltstones, intraformational conglomerates, and fine- to medium-grained crossbedded sandstones. The ore-bearing unit, in the Chinle formation, contains fossil plant remains replaced by pyrite or uraninite or pre-

SAMPLING OF THE MINE

The sampling of the Mi Vida mine in 1953 was done with standard methods The work, completed in 4 days, required 15 man-shifts to cut 225 samples, which were shipped to the Bureau of Mines Metallurgical Division, Salt Lake Experiment Station, Salt Lake City, Utah, to be assayed for uranium, vanadium, and lime. Sample locations are shown on the assay map (fig. 3).

Inasmuch as the water supply at the mine had to be transported from Moab by truck, it was inexpedient to wash the mine faces before sampling. Instead, a long-handled, stiff-bristled brush was used to remove the heavy coating of fines that had accumulated on the faces from blasting. Cleaning of each face was completed with a whiskbroom immediately before the samples were cut. This procedure removed the high-grade uranium dust and fines that would have tended to "salt" the samples.

With few exceptions, the vertical width of samples was maintained at less than five feet. Widths were selected on the basis of rock character (massive or fractured), rock type (sandstones and mudstones), and color gradations. Sample widths were marked on the face by a horizontal white paint line; the sample number and width measurement for each sample were painted on the face. At virtually every sample location a pile of broken muck had accumulated on the floor at the bottom of the face. Because removal of the much was impracticable, these inaccessible portions of the faces were disregarded in cutting the samples and in the calculations.

Channel samples were cut vertically across each sample interval. Because of the high lime content of the rock, most of the samples had to be cut with a moil. Canvas sheets were used to catch the chippings, except when work was conducted from ladders along the faces of high drifts, in which instances boxes were used. Uniform size sample sacks were used, and each sample weighed about eight pounds.

STATISTICAL INTERPRETATION OF THE SAMPLE ASSAY DATA

The 225 samples were cut at the 79 points indicated in figure 3. At each point, from two to six samples were taken, depending on the thickness and character of the ore body. The original sample and assay data are listed in Appendix A.

The principal data considered in this report are weighted-average assays at each of the 79 sample points, as listed in Appendix B. These data were

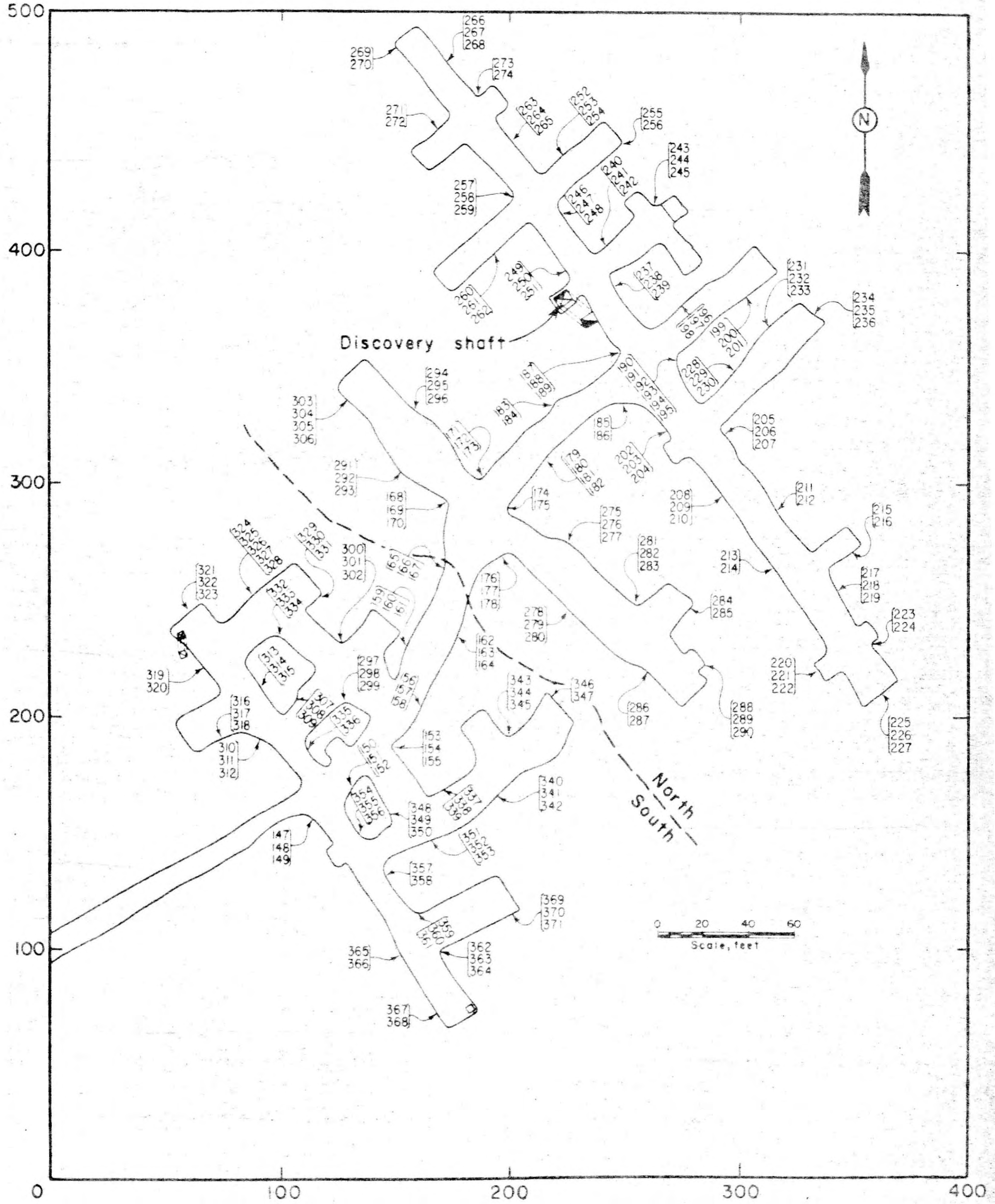

FIGURE 3. - Assay Map Showing Sampling of Underground Workings.

Before a regression analysis is undertaken, it is desirable to plot and contour the assay values by hand to obtain a general impression of their distribution. Assay contour maps prepared in this way (figs. 4 to 6) indicate that assays for uranium and vanadium define a reasonably regular dome in the northern part of the mine, whereas they are erratic to the south. Therefore, the entire mine area was divided into a northern and southern area as shown by figure 3. Significantly, the contour maps drawn by one of the writers in 1953 have not been subsequently altered with results of the statistical analysis.

Linear and quadratic regression surfaces were fitted to three sets of weighted-average assays: To those at all 79 sample points, to those at the 47 points in the northern area, and to those at the 32 points in the southern area. The independent variables (x and y) were the arbitrarily established mine coordinates; the dependent variables (w_1, w_2, w_3) were weighted uranium assays, weighted vanadium assays, and weighted lime assays at each sample point.

Nine quadratic surfaces and the corresponding nine linear surfaces were fitted and evaluated to form the basis of the summary in table 1. The regression analyses used for the evaluation are presented in tables 2 to 4, and contour maps of four of the surfaces are reproduced in figures 7 to 10. Figures 7 and 8 are quadratic surfaces for uranium and vanadium in the northern area. The surfaces are domes that are very similar to one another. Figure 9 is a quadratic surface for lime over the entire area; the surface is a saddle with the predominant trend an increase in lime to the southwest. Figure 10, a linear surface for lime over the entire area indicating an increase to the southwest, is included for comparison with figure 9. The surface is not changed very much when quadratic terms are added to the linear terms because the linear component of the sum of squares is more than four times as large as the quadratic component (table 4).

TABLE 1. - Summary of regression analyses

Area	Uranium	Vanadium	Lime
Northern..	Quadratic trend: dome with a peak near N-378, E-147.	Quadratic trend: dome with a peak near N-365, E-190.	Linear trend with a strike of N 24 W.
Southern..	No reliable evidence of trend.	No reliable evidence of trend.	Linear trend with a strike of N 74 W.
Entire....	Questionable quadratic trend: dome with a peak near N-247, E-158.	Questionable quadratic trend: dome with a peak near N-289, E-192.	Primarily linear trend with a strike of N 45 W.

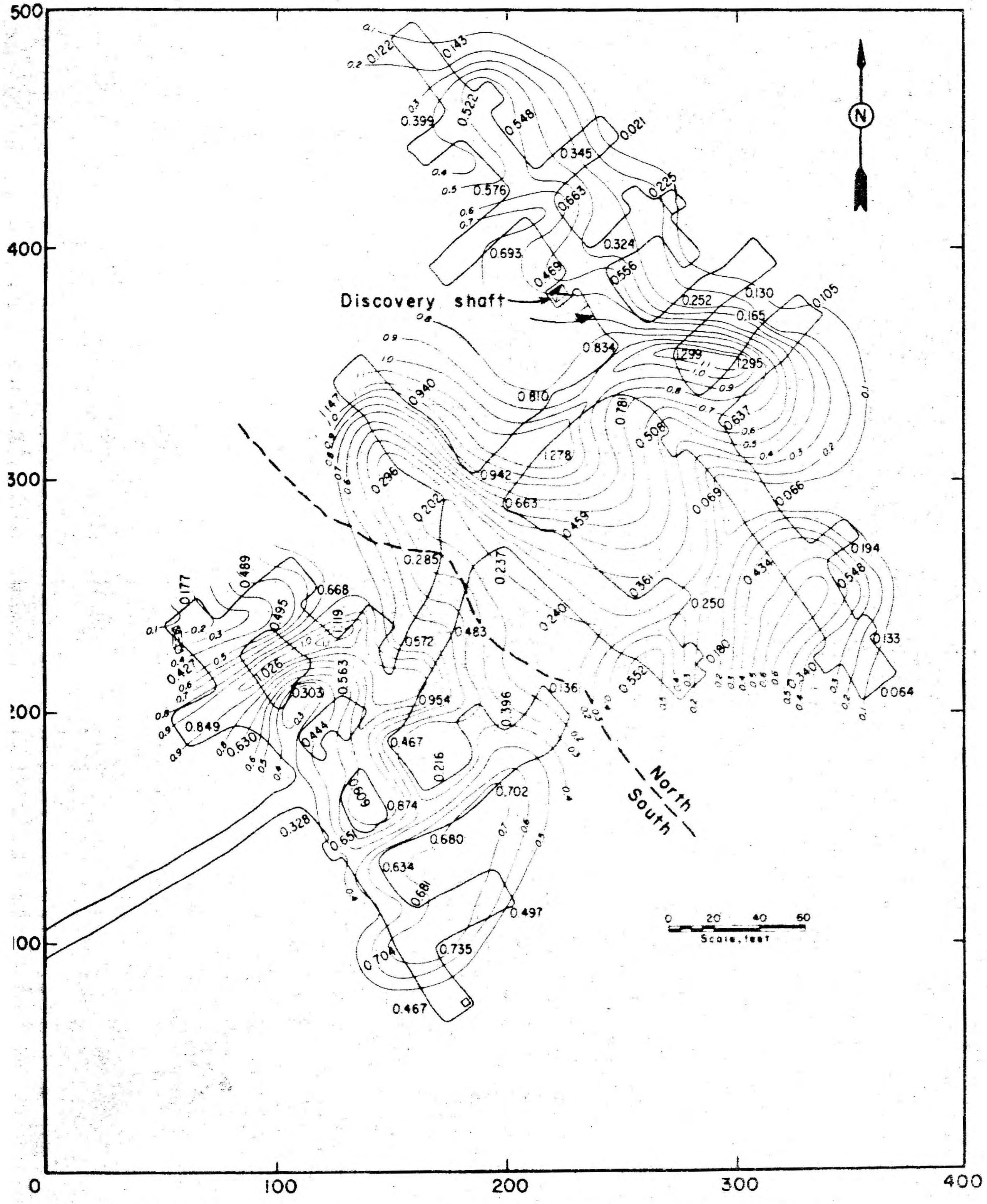

FIGURE 4. - Assay Map Showing Contours Based on Weighted Uranium Assays.

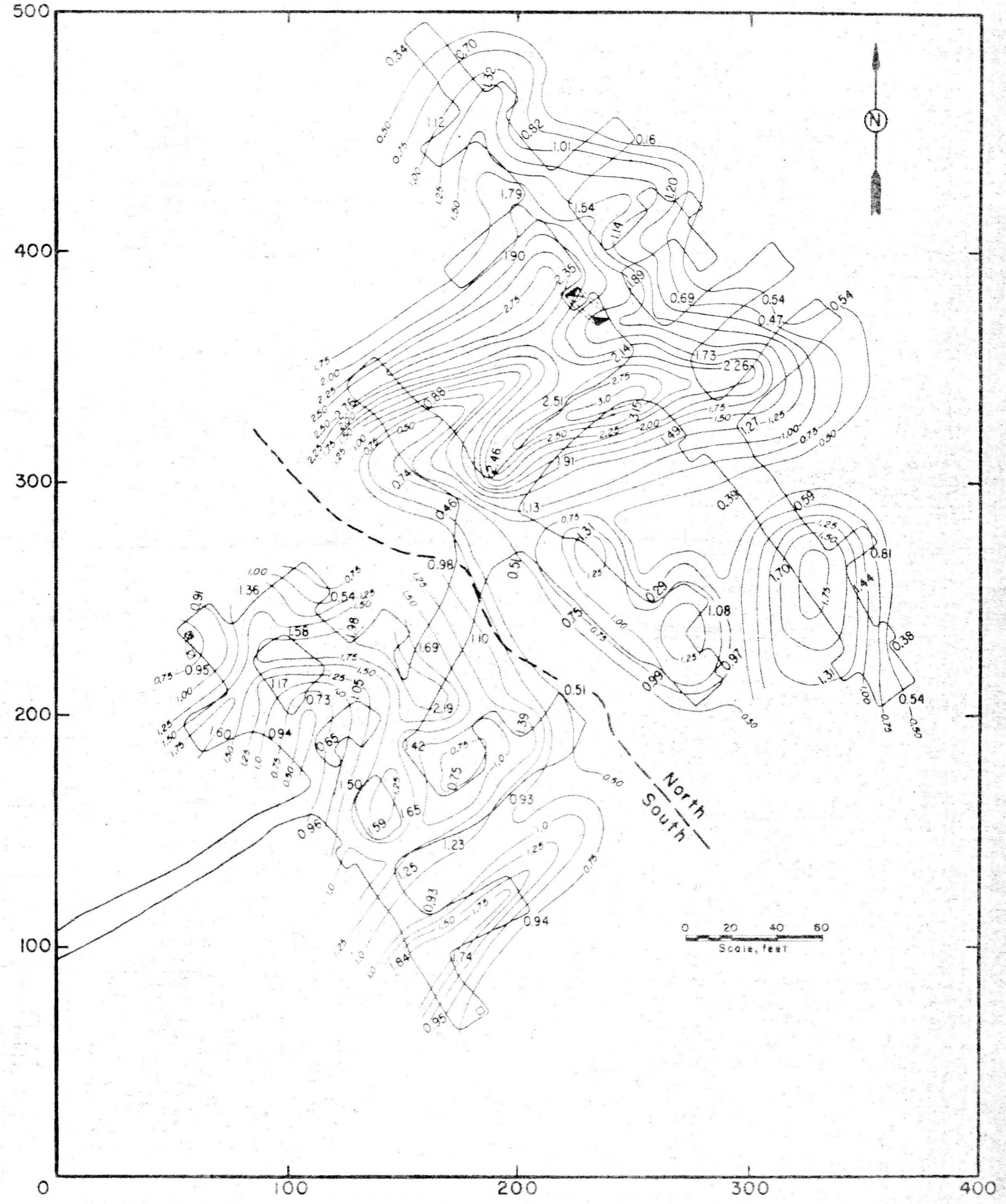

FIGURE 5. - Assay Map Showing Contours Based on Weighted Vanadium Assays.

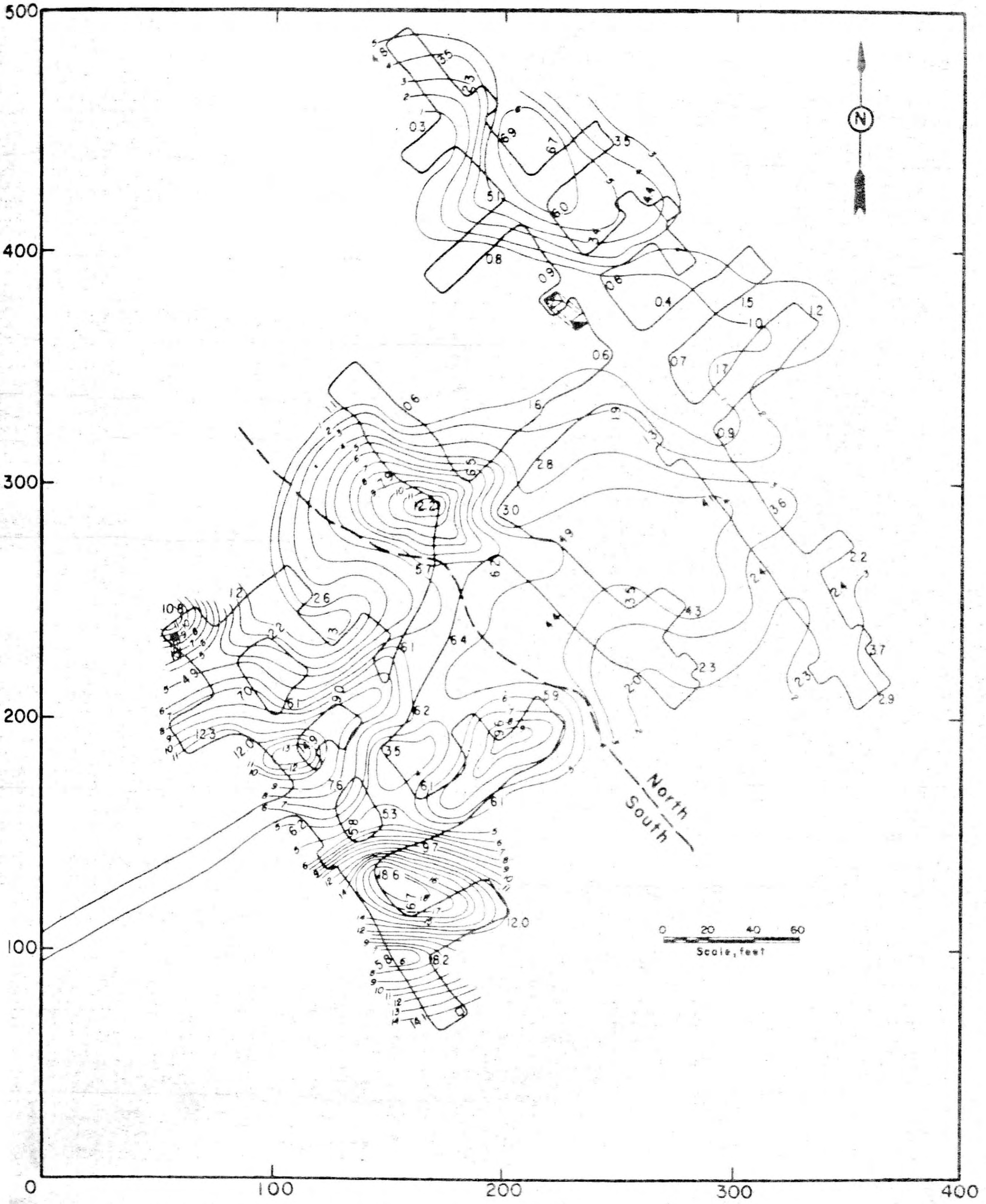

FIGURE 6. - Assay Map Showing Contours Based on Weighted Lime Assays.

TABLE 2. - Weighted-average uranium assays: Analyses of variance for quadratic and linear fits

Area	Source of variation	Sum of squares	Degrees of freedom	Mean square	F	F(0.05)
Northern (47 points).	Linear terms...	0.5778	2	0.2889	3.85	3.23
	Quadratic terms	1.7798	3	.5933	7.92	2.84
	Error..........	3.0730	41	.0750		
Southern (32 points).	Linear terms...	.0901	2	.0450	.860	3.37
	Quadratic terms	.2783	3	.0928	1.77	2.98
	Error..........	1.3619	26	.0524		
Entire (79 points).	Linear terms...	.6505	2	.3253	3.90	3.13
	Quadratic terms	.6350	3	.2117	2.54	2.74
	Error..........	6.0742	73	.0832		

TABLE 3. - Weighted-average vanadium assays: Analyses of variance for quadratic and linear fits

Area	Source of variation	Sum of squares	Degrees of freedom	Mean square	F	F(0.05)
Northern (47 points).	Linear terms...	1.1045	2	0.5522	1.79	3.23
	Quadratic terms	9.6634	3	3.2211	10.42	2.84
	Error..........	12.6738	41	.3091		
Southern (32 points).	Linear terms...	.0697	2	.0349	.185	3.37
	Quadratic terms	.6789	3	.2263	1.20	2.98
	Error..........	4.8962	26	.1883		
Entire (79 points).	Linear terms...	.4663	2	.2332	.656	3.13
	Quadratic terms	2.6895	3	.8965	2.52	2.74
	Error..........	25.9347	73	.3553		

TABLE 4. - Weighted-average lime assays: Analyses of variance for quadratic and linear fits

Area	Source of variation	Sum of squares	Degrees of freedom	Mean square	F	F(0.05)
Northern (47 points).	Linear terms...	39.05	2	19.52	4.11	3.23
	Quadratic terms	28.93	3	9.64	2.03	2.84
	Error..........	194.65	41	4.75		
Southern (32 points).	Linear terms...	169.38	2	84.69	5.93	3.37
	Quadratic terms	33.02	3	11.01	.771	2.98
	Error..........	371.07	26	14.27		
Entire (79 points).	Linear terms...	508.08	2	254.04	29.64	3.13
	Quadratic terms	117.70	3	39.23	4.58	2.74
	Error..........	625.66	73	8.57		

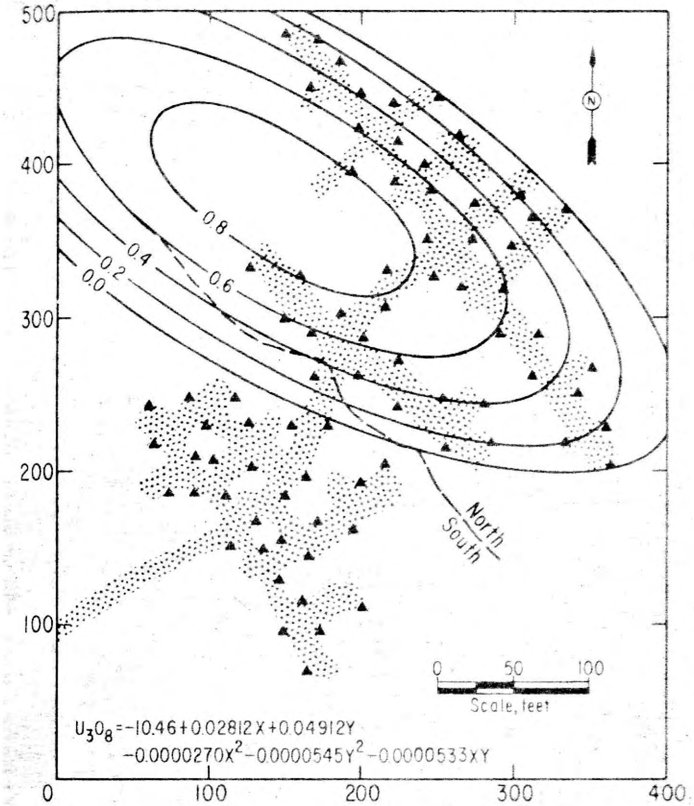

FIGURE 7. - Quadratic Surface Representing Weighted Uranium Assays in Northern Area.

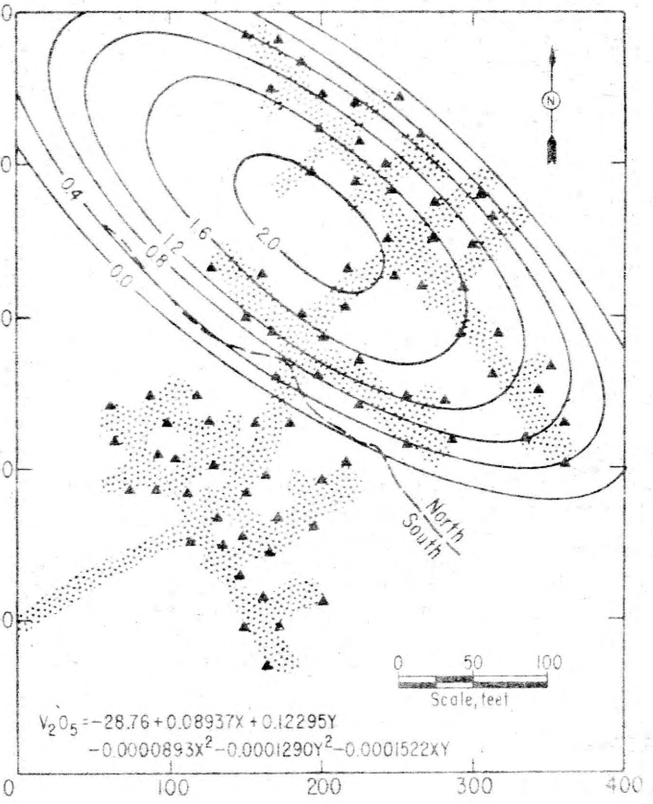

FIGURE 8. - Quadratic Surface Representing Weighted Vanadium Assays in Northern Area.

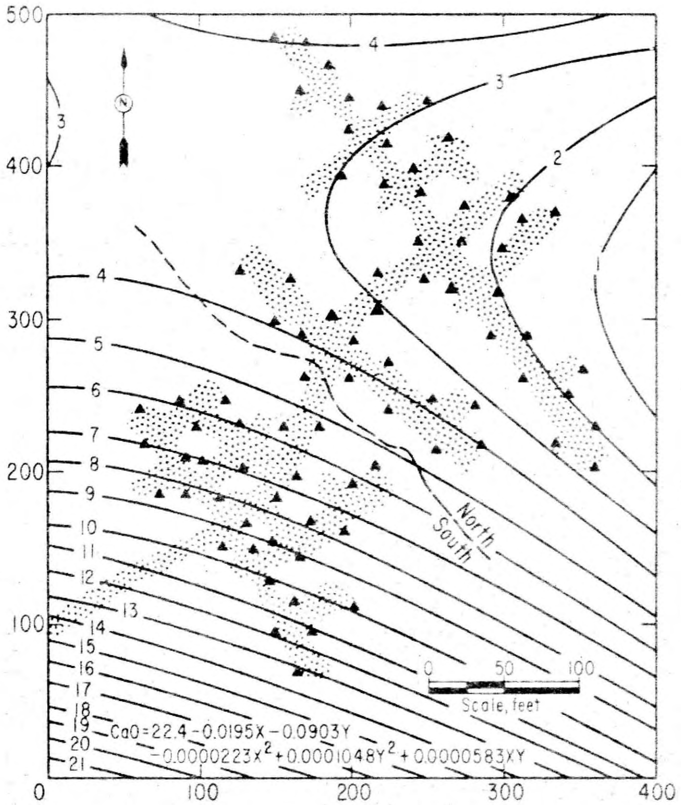

FIGURE 9. - Quadratic Surface Representing Weighted Lime Assays in Entire Area.

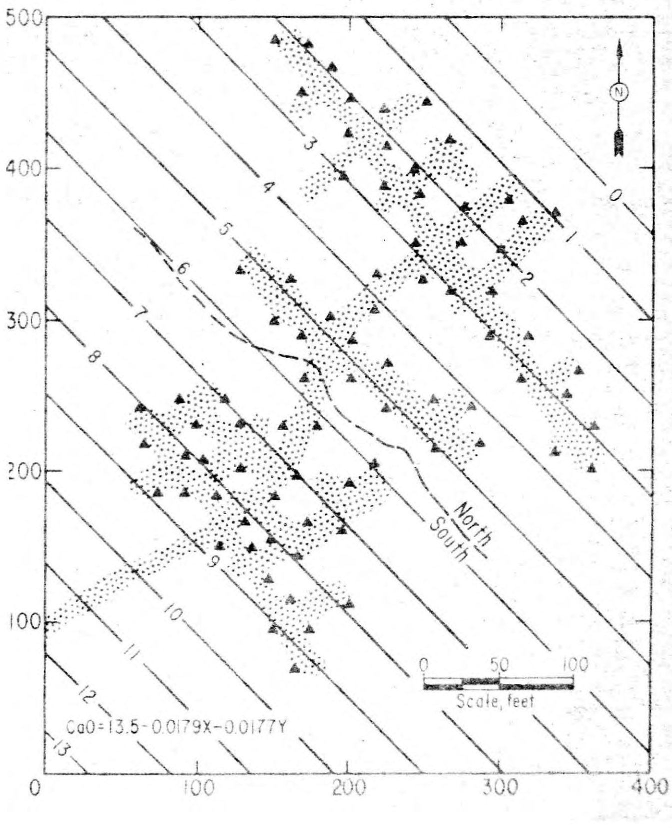

FIGURE 10. - Linear Surface Representing Weighted Lime Assays in Entire Area.

The regression surfaces, particularly those for uranium and vanadium in figures 7 and 8, correspond rather well to those delineated by hand-contouring in figures 4 and 5. This correspondence indeed shows that the preliminary hand-contouring was helpful in defining the northern and southern areas. Several alternative north-and-south divisions of the assay data yielded groups of data from which essentially similar analytic results were obtained.

For each metal, the dependent variables chosen for analysis were the 79 weighted-average assays. Alternatively, for each metal the 79 unweighted-average assays or the 225 original assays could have been used. From the available data, it is impossible to decide which of these dependent variables (weighted-average assays, unweighted-average assays, or original assays) is most appropriate, but because essentially the same results are obtained whichever one is chosen, the choice of dependent variable is not important for these data. For illustration of this point, surfaces and equations for uranium in the northern area fitted to the three kinds of dependent variables are presented in figures 7, 11, and 12. With variability implicit in the data taken into account, comparison of the three sets of equations and surfaces with one another shows that all three sets are the same.

The quadratic surface for uranium, figure 7, predicts an increase in uranium to the northwest. This prediction is borne out by figure 2, which shows that the mine was subsequently extended in this direction. The lack of apparent trend for uranium in the southern area implies that there is no reason from this analysis to expect the ore to fall off, no matter which way the mine is extended from the original sampled area. This prediction is also borne out by figure 2, which shows that the mine was extended from the southern area to the south and east away from the surface outcrop.

Because the distribution of vanadium and lime beyond the sampled area is not evident from the pattern of the mine workings, figure 2, and is not known to the authors, predictions regarding these metals have not been checked.

Correlations Among Assays

Correlations among assays (weighted and unweighted) for the three metals are given in table 5. Correlations between uranium and vanadium are fairly high, whereas correlations of these metals with lime are low. The fitted surfaces (figs. 7 to 10) show that these results are to be expected, because the surfaces for uranium and vanadium are similar and unlike those for lime.

The correlations among metals at Mi Vida are similar to correlations among the same metals at the Frenchy Incline uranium mine, San Miguel County, Colorado. From 114 samples of drill core from the Frenchy Incline mine, Miesch[7] calculated correlations using logarithms of chemical assays. Between uranium and vanadium, the correlation was 0.70; between uranium and lime, the correlation was -0.17; and between vanadium and lime the correlation was -0.38. At Mi Vida, the logarithmic correlations were 0.82, -0.08, and -0.16, given in

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Personal communication from A. T. Miesch, geologist, U. S. Geological Survey, Denver, Colo.

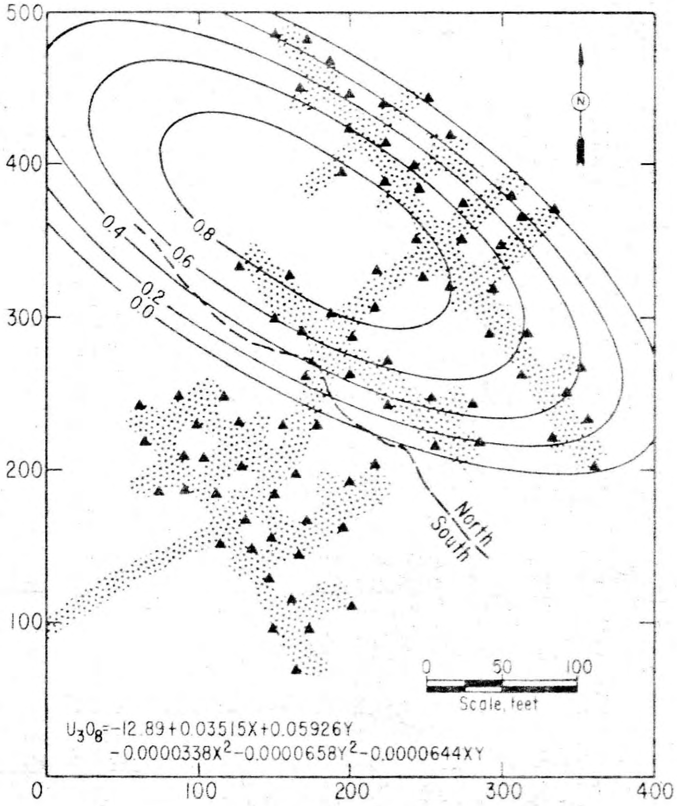

FIGURE 11. - Quadratic Surface Representing Original Uranium Assays in Northern Area.

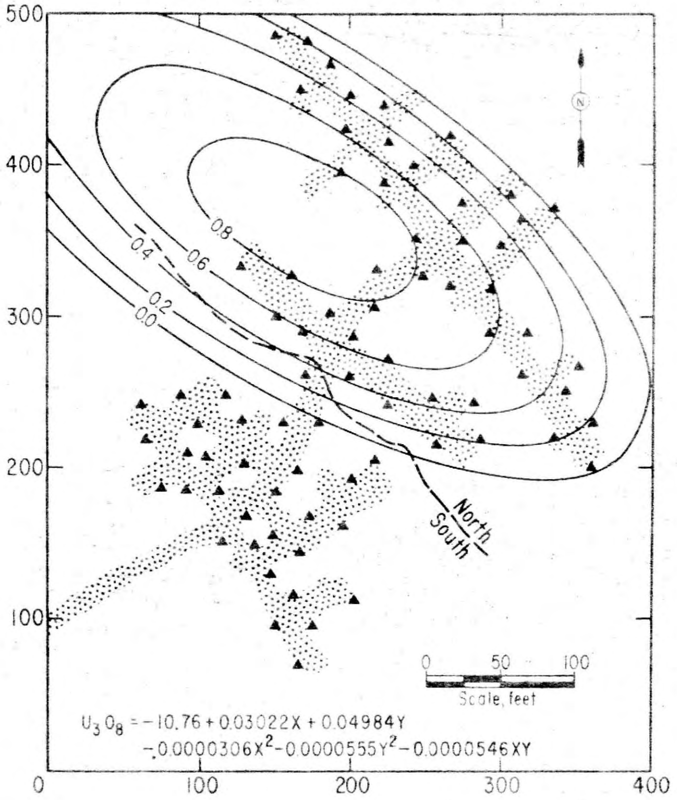

FIGURE 12. - Quadratic Surface Representing Unweighted Averaged Uranium Assays in Northern Area.

the same order as the three values for French Incline. The Frenchy Incline mine is typical of deposits in the Uravan mineral belt: Mineralization consists of carnotite and vanadium-clays in the Salt Wash member of the Morrison formation.

TABLE 5. - Correlations among assays

Items correlated	Northern area		Southern area		Entire area	
	Weighted-average assays at each of 47 sample points	Unweighted assays from each of 133 original samples	Weighted-average assays at each of 32 sample points	Unweighted assays from each of 92 original samples	Weighted-average assays at each of 79 sample points	Unweighted assays from each of 225 original samples
Uranium and vanadium..	[1]0.77	[1]0.75	[1]0.64	[1]0.76	[1]0.73	[1]0.75
Uranium and lime......	[1]-.26	-.03	-.05	-.14	-.02	-.05
Vanadium and lime......	[1]-.30	-.11	[1]-.25	[1]-.25	[1]-.21	[1]-.17

[1] These correlations may be regarded as differing from zero. (The hypothesis $\rho = 0$ is rejected using a 5-percent level of significance.)

Adequacy of Quadratic Fit

The fitted surfaces described in the last section are linear and quadratic. The data could be fitted mathematically in other ways. For example, a higher order polynomial, such as a cubic or quartic equation, could be used. Therefore, an examination of the adequacy of the quadratic fit is desirable. Although any such examination must include some subjective element (5, p. 293), some valid conclusions may be drawn.

The adequacy of fit may be investigated by comparing the local variability with the variability unexplained by the regression equation. If these two quantities are similar in size, the quadratic fit may be considered adequate. Conversely, if the variability unexplained by the regression equation is much larger than the local variability, a more complicated fit could be useful.

For these assay data from the Mi Vida mine, the local variability can readily be measured because many of the 79 sample points were sampled more than once. Hence, the assays of the two to six samples at each of these points can be used to estimate the fluctuation at each point. In statistical terms, a within-sample-point variance is calculated for each point sampled more than once, and the resulting variances are combined using their degrees of freedom as weights to find a measure of local variability which is the average within-sample-point variance.

Through an analysis of variance, a measure of the amount of deviation from the quadratic fit may be obtained that is independent of the within-sample-point variation. The variation among the sample points (among-sample-points variation) can be divided into the part explained by fitting the quadratic surface and the remainder which corresponds to deviations from the quadratic fit. Adequacy of quadratic fit is investigated by comparing the deviations from the quadratic model with the within-sample-point variation. Tables 6 to 8 give the results of the analyses; because all of the tables are constructed in the same way, only table 6 is described in detail.

TABLE 6. - Uranium assays: Analyses of variance to assess adequacy of quadratic fit

Area	Source of variation	Sum of squares	Degrees of freedom	Mean square	F	F(0.05)
Northern (47 points).	Among-sample-points variation.	20.0256	46			
	Regression..........	8.6387	5			
	Deviation from quadratic model.	11.3869	41	0.2777	0.64	1.53
	Within-sample-point variation.	37.1342	86	.4317		
Southern (32 points).	Among-sample-points variation.	4.4783	31			
	Regression..........	.7152	5			
	Deviation from quadratic model.	3.7630	26	.1447	.44	1.68
	Within-sample-point variation.	19.6870	60	.3281		

TABLE 7. - Vanadium assays: Analyses of variance to assess adequacy of quadratic fit

Area	Source of variation	Sum of squares	Degrees of freedom	Mean square	F	F(0.05)
Northern (47 points).	Among-sample-points variation.	74.7614	46			
	Regression..........	31.9434	5			
	Deviation from quadratic model.	42.8180	41	1.0443	1.28	1.53
	Within-sample-point variation.	70.3391	86	.8179		
Southern (32 points).	Among-sample-points variation.	17.0772	31			
	Regression..........	.7622	5			
	Deviation from quadratic model.	16.3150	26	.6275	.42	1.68
	Within-sample-point variation.	89.7404	60	1.4956		

TABLE 8. - Lime assays: Analyses of variance to assess adequacy of quadratic fit

Area	Source of variation	Sum of squares	Degrees of freedom	Mean square	F	F(0.05)
Northern (47 points).	Among-sample-points variation.	816.28	46			
	Regression..........	256.15	5			
	Deviation from quadratic model.	560.13	41	13.66	1.78	1.53
	Within-sample-point variation.	658.64	86	7.66		
Southern (32 points).	Among-sample-points variation.	1603.95	31			
	Regression..........	684.38	5			
	Deviation from quadratic model.	919.57	26	35.37	1.16	1.68
	Within-sample-point variation.	1832.94	60	30.55		

In table 6, the analysis for unweighted uranium assays in the northern area is based on 47 sample points and 133 assays. The among-sample-points variation (as measured by the among-sample-points sum of squares) has 47 minus 1, or 46 degrees of freedom. These degrees of freedom are partitioned into 5 degrees of freedom for the quadratic regression model and into 41 degrees of freedom for the deviation from the quadratic regression model. The within-sample-point variation (as measured by the within-sample-point sum of squares) has (133 minus 46) minus 1, or 86 degrees of freedom. The size of the mean square with 41 degrees of freedom corresponding to deviation from the quadratic model is then compared with the size of the mean square with 86 degrees of freedom corresponding to the within-sample-point variation. This comparison is done by calculating F, which is equal to 0.64. The F-test value to detect an inadequate fit has 41 and 86 degrees of freedom; with a 5-percent significance level, its critical value is 1.53, which of course implies that the quadratic model is adequate, for the within-sample-point variation is no smaller than the variation associated with deviation from the quadratic model. The analysis may be regarded as one with unequal numbers of replications at each sample point, the number of treatments being equal to the number of sample points; the procedure is described in standard statistical texts, for example in the one by Li (2, p. 175).

When the calculations described above are performed and the results are tabulated (tables 6 to 8), the deviations from the quadratic model compare in size with the within-sample-point variances. Therefore, the conclusion may be drawn that the quadratic model does afford an adequate fit to these data because the two types of variability are of the same general size within the expected limits of statistical fluctuation. The quadratic model appears to provide an adequate fit in all cases, with the single exception of lime in the northern area. Actually, the lack of fit for lime may be apparent rather than real because, in a series of F-tests, having one calculated F value barely exceed the test F value is not surprising, even if there were no effect. Moreover, even if the model were inadequate for lime, there is no obvious geological or mining advantage in pursuing a more complicated analysis, since the lime appears to be essentially unrelated to the valuable constituents.

The analysis of variance just described indicated a substantial residual assay variation of points, based on the model that two to six samples taken at each point could be regarded as random samples at each point. Therefore, an attempt was made to reduce this residual assay variation by determining whether recognizable stratification exists at the sample points. Because the deposit is bedded and because the sampling was done with regard to this bedding, with a single sample cut across a single bed, it was possible to determine whether there was any recognizable stratification, for instance with higher assays in the higher beds. The data were not ideal for this purpose, because maps correlating beds from one sample point to another were not available, and because a variable number of samples were taken at the different points. But the data were good enough to make an adequate test.

Of the 79 sample points, 56 were available where 3 samples had been cut and identified as to top, middle, or bottom bed (fig. 13). For each metal, the 168 (3 times 56) assays at these points were subjected to an analysis of variance, with results given in tables 9 to 11. In the analysis of variance format employed, the sum of squares due to position (sample point location)

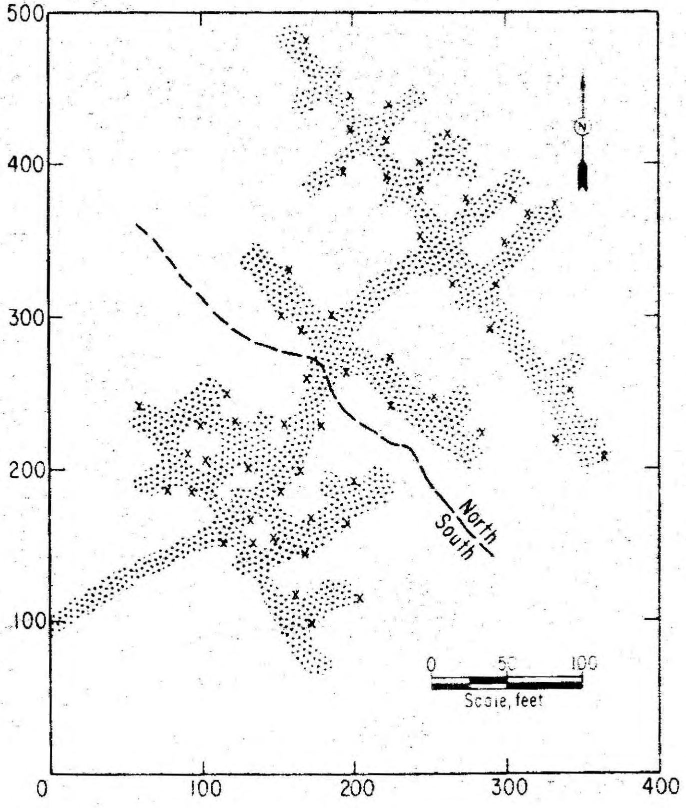

FIGURE 13. - Map of Sample Points Where Three Samples Were Cut.

has 56 minus 1 or 55 degrees of freedom; the sum of squares due to stratification has 3 minus 1, or 2 degrees of freedom; and the error sum of squares has (168 minus 55) minus 2, minus 1, or 110 degrees of freedom. The F-test value to detect stratification has 2 and 110 degrees of freedom, and with a 5-percent significance level, its critical value is 3.08. Tables 9 to 11 show no reliable evidence of stratification for any of the metals, or, in other words, that from these data it is impossible to distinguish among the top, middle, or bottom beds.

TABLE 9. - Uranium assays from 56 points that were sampled in 3 places: Analysis of variance to investigate possible stratification

	Sum of squares	Degrees of freedom	Mean square	F	F(0.05)
Position.......	14.3992	55	0.2618		
Stratification..	.6256	2	.3128	1.16	3.08
Error..........	29.6546	110	.2696		

TABLE 10. - Vanadium assays from 56 points that were sampled in 3 places: Analysis of variance to investigate possible stratification

	Sum of squares	Degrees of freedom	Mean square	F	F(0.05)
Position.......	52.7971	55	0.9599		
Stratification..	.064	2	.032	0.03	3.08
Error..........	111.2015	110	1.01		

TABLE 11. - Lime assays from 56 points that were sampled in 3 places: Analysis of variance to investigate possible stratification

	Sum of squares	Degrees of freedom	Mean square	F	F(0.05)
Position.......	2,001.90	55	43.1		
Stratification..	103.61	2	51.8	2.52	3.08
Error..........	2,631.09	110	20.6		

From these analyses of variance (tables 6 to 11), it may be concluded that the residual mean square variances presented in tables 2 to 4 represent the smallest unexplained variability that can be found with these data. In particular, these analyses indicate no evident breakdown that will make the quadratic model appear to be an inadequate fit in the presence of so much variability.

Frequency Distributions of Assay Residuals

When a quadratic or other mathematical surface is fitted to assays, the fitted surface generally does not correspond exactly to the observed assays at the sample points because of the within-sample-point variation and because the fit is not perfect. Rather, there is a residual variation of the surface from each observed assay, measured by the vertical distance at each sample point between the elevation of the assay above the datum plane and the elevation of the surface above the datum plane. This residual variation, named the assay residual, is positive if the observed assay at a point is above the fitted surface, and is negative if the observed assay is below.

Frequency distributions of weighted assay residuals for uranium, vanadium, and lime, are plotted in figures 14 to 16. For each metal, the residuals were calculated separately for the northern and southern areas. The calculation is done with a program that reads the appropriate quadratic coefficients, x-y coordinates, and weighted assays into a computer. The computer prints out a listing that records for each sample point the x-y coordinates, the observed weighted assay value, the assay value predicted by the quadratic equation, and the residual.

The three distributions (figs. 14 to 16) are reasonably symmetric and resemble normal distributions, although their tails are somewhat longer than those for normal distributions. They certainly are nearly enough normal so that statistical tests based on the normal distribution are valid. The symmetry of the distributions was established by means of Chi-square tests, applied singly to each of the 3 sets of 79 weighted assays and jointly to the combined 237 (3 times 79) weighted assays. Each test led to accepting the hypothesis that there are as many negative as positive residuals, with the assumption that the residuals are randomly distributed.

The reason for preparing frequency distributions of the weighted assay residuals rather than frequency distributions of the weighted assays is that the trends in the data, shown by the fitted quadratic surfaces, distort the frequency distributions of the weighted assays. The distortion results from the details of the sampling. When the effect of trend is removed, in the manner described, the residuals indicate the basic distribution that exists. Actually, the trend was effectively removed only for the northern area. Because there was no measurable quadratic trend for uranium and vanadium in the southern area, merely substracting the mean from assays for these metals yields essentially the same results, as shown by frequency distributions made in this way but not presented in this report.

The distortion of the frequency distributions of observed assays is removed to an extent indicated by a comparison of figure 14, a frequency distribution of weighted assay residuals for uranium, with figure 17, a frequency distribution of weighted uranium assays. Figure 14 is a symmetric, although somewhat long-tailed distribution that resembles a normal distribution. In contrast, figure 17 is a highly skewed distribution. Figure 14 is the more informative because the trend variation of the assays with respect to location is taken into account. If there were no discernable trend, the average value for uranium would be the same everywhere in the sampled area, and the outlined procedure would be unnecessary; however, where trend is present, it must be removed to make a satisfactory examination of the basic underlying frequency distribution.

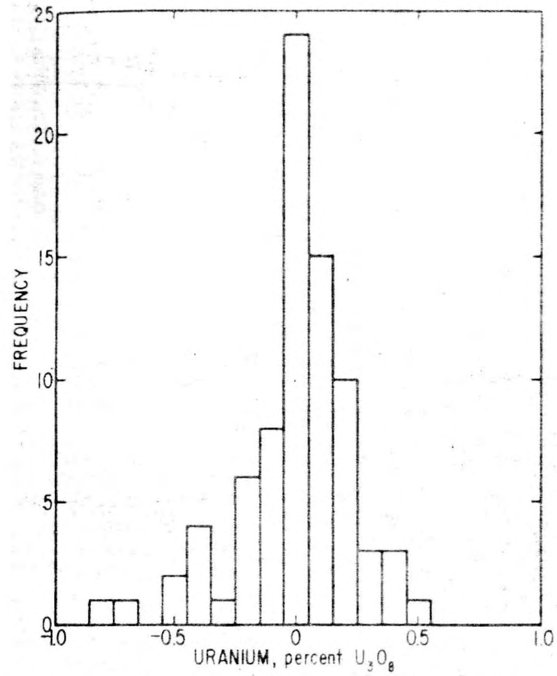

FIGURE 14. - Frequency Distribution of Uranium-Assay Residuals From Quadratic Surfaces Representing Weighted Assays in Northern and Southern Areas.

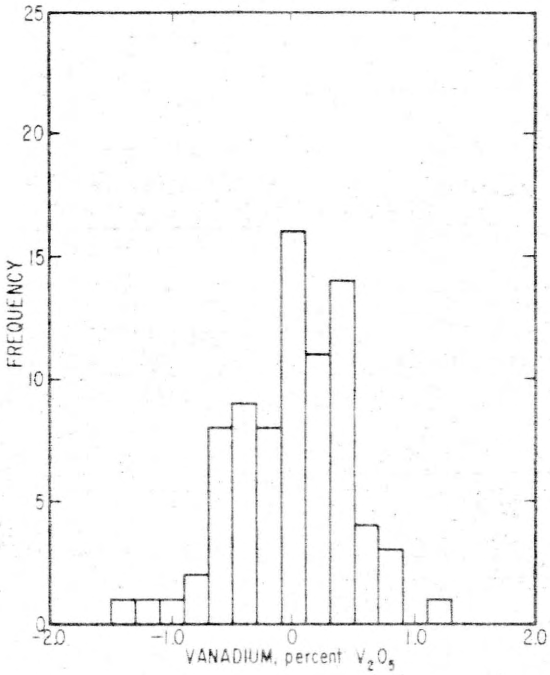

FIGURE 15. - Frequency Distribution of Vanadium-Assay Residuals From Quadratic Surfaces Representing Weighted Assays in Northern and Southern Areas.

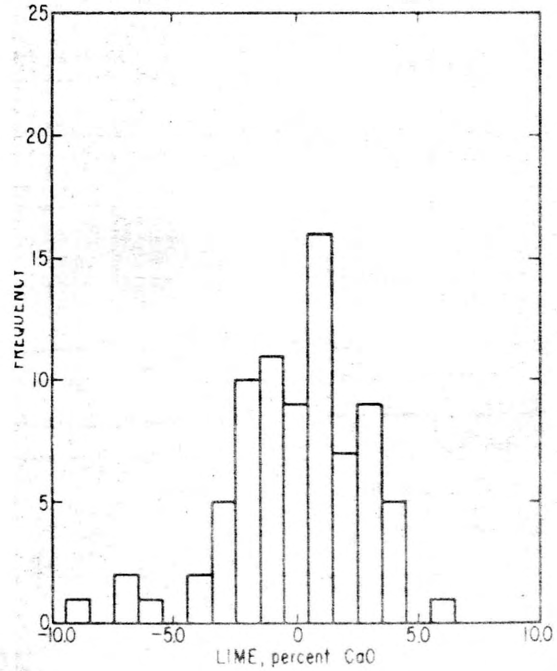

FIGURE 16. - Frequency Distribution of Lime-Assay Residuals From Quadratic Surfaces Representing Weighted Assays in Northern and Southern Areas.

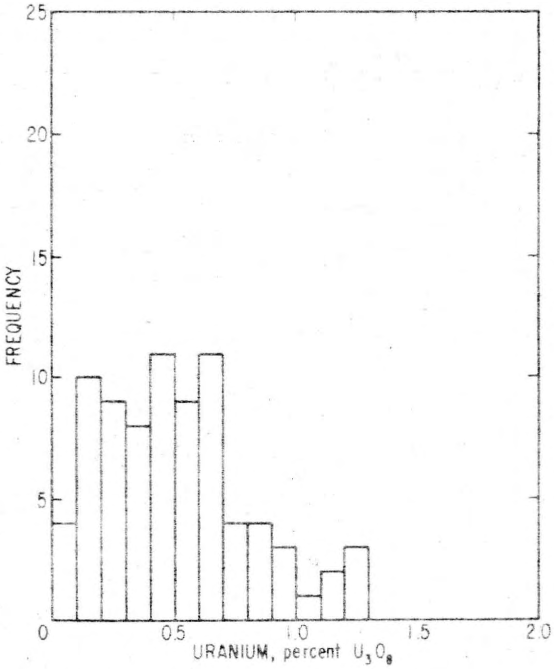

FIGURE 17. - Frequency Distribution of Weighted Uranium Assays.

Grade Estimation

For each metal, the grade estimates presented in this section are calculated from the 79 values for weighted average grade at the 79 sample point Estimates based on the 225 original assays and on the 79 values for unweight average grade are similar.

Two types of estimates are presented: point estimates, which give the familiar estimated average value, and interval estimates, which give confidence limits between which the true grade can be expected to fall. An interval estimate is in the following form: "The true grade is not lower than a certain value and is not higher than another certain value." Such estimates will be correct in a specified percentage of times they are made. A particular estimate is, of course, either right or wrong.

For these data, the appropriate point estimates are the arithmetic averages of the 79 weighted-average assays. This statement is true whether or n trends exist in the data. Although a point estimate of grade does not requir any knowledge about trends in these data, the interval estimate can be improv if trends are recognized, because the effects of the trend can be taken into account, and thus the unexplained variability of the data can be reduced. Th procedure used is outlined as follows: The confidence interval estimate is

$$\bar{x} \pm t \frac{s}{\sqrt{n}}$$

where $\bar{x}$ is the arithmetic average of the weighted assays, t is a constant dependent on the number of samples and the desired degree of risk (for example, 19 chances out of 20 of being right), s is the standard deviation, and n is the number of samples. All of these terms, except the standard deviation s, remain constant whether or not trend is present. If trend is disregarded, standard deviation measures the deviation of individual weighted assay values at sample points from a horizontal plane whose elevation is equal to $\bar{x}$. But if trend is taken into account, standard deviation measures the smaller deviation of individual weighted assay values at sample points from the fitted trend surface, which is a curved or inclined plane surface.

The above procedure requires the assumption that the original assay values taken at the points are random. This requirement is a statistical one that any sample had an equally likely chance of being taken as any other sample. Because these samples could be taken only in the workings, and the sample points were selected to obtain a nearly equal spacing, the samples are not, in fact, random. But, the assumption that they behave as random samples is probably satisfactory. This assumption may be made because the sampling was done following good engineering practice, rather than introducing an obvious bias such as taking more samples in the high-grade areas than in the low-grade ones.

In table 12, interval estimates taking trend into account are presented for the three metals in the northern, southern, and entire areas. For the northern and southern areas, the standard deviations used to make the estimates are the square roots of the error mean squares from tables 2 to 4. For the entire area, the standard deviations used are the square roots of the pooled error variances from the northern and southern areas combined, using the degrees of freedom for error (number of sample points minus six) as weighting factors.

TABLE 12. - Estimates of grade for uranium, vanadium, and lime: Computed taking into account effect of trend in assays

Metal	Area	Number of points	Mean	Confidence limits	
				Lower	Upper
Uranium (U_3O_8), percent.	Entire mine....	79	0.510	0.452	0.568
	Northern area..	47	.468	.387	.549
	Southern area..	32	.570	.487	.653
Vanadium (V_2O_5), percent.	Entire mine....	79	1.22	1.10	1.34
	Northern area..	47	1.23	1.07	1.39
	Southern area..	32	1.21	1.05	1.37
Lime (CaO), percent.	Entire mine....	79	4.99	4.34	5.64
	Northern area..	47	3.10	2.46	3.74
	Southern area..	32	7.77	6.39	9.15

Notably, the interval estimates taking trend into account can be calculated in the direct manner described in the last paragraph only when the arithmetic average of the weighted assays is an appropriate estimate of the average desired. In particular, this requirement implies a sampling scheme whose "center" is at the right location, and whose sample points are spaced so that all areas of interest have an equal chance of being sampled. For example, if the Mi Vida sample points were concentrated in one working place rather than spread out more or less uniformly, the arithmetic average might not be appropriate. If the arithmetic average is inappropriate, then it must be adjusted with use of the trend surface, and a more complicated formula is necessary for calculating confidence limits (3, p. 24).

In table 13, the interval estimates taking into account trend may be compared with those made neglecting trend. Removal of the trend affords a measurable reduction in the length of the confidence interval. The amount of reduction stems from the amount of trend that is found.

The estimates of grade are in good agreement with ore-production records. Ore production, as recorded on ore-settlement sheets received by the company up to July 15, 1953, shortly after the date the Bureau's sampling was completed, totaled 16,000 tons, averaging 0.51 percent uranium (U_3O_8) and 1.26 percent vanadium (V_2O_5).

TABLE 13. - Estimates of grade for uranium, vanadium, and lime: Computed without regard to trend in assays

Metal	Area	Number of points	Mean	Confidence limits	
				Lower	Upper
Uranium (U_3O_8), percent.	Entire mine....	79	0.510	0.441	0.579
	Northern area..	47	.468	.367	.569
	Southern area..	32	.570	.485	.655
Vanadium (V_2O_5), percent.	Entire mine....	79	1.22	1.08	1.36
	Northern area..	47	1.23	1.02	1.44
	Southern area..	32	1.21	1.06	1.37
Lime (CaO), percent.	Entire mine....	79	4.99	4.09	5.89
	Northern area..	47	3.10	2.40	3.80
	Southern area..	32	7.77	6.22	9.32

DISCUSSION

Through the use of statistical methods, particularly regression analysis, more information was extracted from the Mi Vida assay data than would have been obtained conventionally from the same amount of data. More information also could have been obtained through taking additional samples following the procedures used by the Bureau engineers in 1953 and treating the assay results conventionally. Whether or not the statistical analysis is worthwhile depends on comparing its cost with the cost of additional sampling and assaying.

In a given situation, the cost of sampling and assaying is well known. Of course, the cost of sampling in accessible workings such as those at the Mi Vida mine in 1953 is very different from the cost of sampling in workings that need to be cleaned out or in sampling in drill holes when additional samples require additional holes. Because the time requirements are not large, the cost of the statistical analysis depends mainly on whether a suitably trained man is available. If a computer is not available, computer time can be rented or the calculations can be done with a desk calculator. However, it would be a mistake to treat such analyses in a completely routine fashion.

It is interesting to note that the discovery diamond-drill hole was bored close to the center of the dome defined by the uranium assays (fig. 4). It could scarcely have been better located.

The work described in this report lends no support to the commonly held view that assays should be weighted by the width of the bed, vein, or other ore body sampled, since the results of analyses using weighted and unweighted assays are essentially the same. The work, however, does lend support to the view that assays should be weighted by an area of influence when trends exist in the data. Indeed, utilization of regression analysis to define trends is essentially a mathematical refinement of the area of influence concept familiar in the mining literature on sampling and evaluation.

CONCLUSIONS

Through statistical analysis of the assay data from the Mi Vida mine, the following conclusions may be drawn:

1. By the method of regression anslysis, the grade of the sampled part of the Mi Vida ore body may be estimated within specified limits, and the direction that the mine should be extended may be predicted.

2. Regression analysis appears to be a generally useful method of appraising assay data from ore bodies.

3. An analysis of variance shows no evidence for stratification of the ore with regard to location of each sample point in the upper, middle, or lower bed.

4. The Mi Vida ore body can be divided into a northern and southern part with different metal distributions.

5. Frequency distributions of assay residuals afford more useful summaries of metal distributions than do frequency distributions of assays without regard to trend.

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APPENDIX A.--ORIGINAL SAMPLE AND ASSAY DATA

Sample number	Sample width, feet	Assay, percent			Description of sample
		U_3O_8	V_2O_5	CaO	
147...	1.2	0.064	0.12	29.1	Mudstone and sandstone with much calcite; gray.
148...	2.6	.758	2.22	3.7	Sandstone with mudstone streaks, spotted with vanadium and some yellow uranium minerals, much calcite, brown to black.
149...	3.7	.112	.34	.5	Massive sandstone spotted with vanadium, tan.
150...	1.4	.269	.91	11.9	Sandstone with bands of vanadium stain, tan.
151...	3.6	.265	.92	10.6	Massive sandstone with vanadium stain, tan to gray.
152...	4.5	.991	2.15	3.9	Platy mudstone and sandstone highly mineralized with vanadium and uranium, gray to green.
153...	3.4	.684	1.84	4.2	Massive sandstone with spotted vanadium stain, tan to gray.
154...	4.5	.702	1.66	1.0	Alternate layers of sandstone and mudstone, trace of vanadium and uranium, brown to
155...	4.5	.069	.86	5.5	Massive sandstone spotted with vanadium stain, tan to gray.
156...	3.7	1.01	4.30	3.7	Sandstone highly mineralized with uranium and vanadium, yellow and red minerals visible, strong vanadium stain, tan to black.
157...	4.2	1.81	2.51	1.6	Alternate layers of sandstone, much vanadium stain, red mineral visible, much calcite, brown to black.
158...	5.0	.193	.36	11.9	Massive sandstone spotted with vanadium stain, gray.
159...	3.7	.793	2.80	1.2	Massive sandstone with vanadium stain, dark gray.
160...	4.2	.885	2.06	2.1	Sandstone with mudstone layers and clay nodules, much vanadium stain, gray.
161...	4.0	.038	.28	14.9	Massive sandstone with slight vanadium stain, light gray.
162...	5.0	1.15	2.21	1.8	Massive sandstone with platy mudstone, highly mineralized with vanadium and uranium, dark-gray.
163...	4.4	.082	.71	7.6	Fractured sandstone with some vanadium stain, gray.
164...	4.2	.108	.18	10.5	Massive sandstone with some vanadium stain, tan to gray.
165...	4.4	.155	.76	1.0	Alternate sandstone and mudstone with clay nodules, slight vanadium stain, gray.

Sample number	Sample width, feet	Assay, percent			Description of sample
		U_3O_8	V_2O_5	CaO	
166...	4.6	0.354	0.76	9.7	Massive sandstone with slight vanadium stain, light-gray.
167...	5.5	.331	1.34	6.1	Platy to massive sandstone spotted with vanadium stain, gray.
168...	3.6	.046	.34	9.7	Massive sandstone with slight vanadium stain, light-gray.
169...	4.7	.130	.65	6.7	Platy sandstone and mudstone with vanadium stain, gray.
170...	4.0	.428	.36	21.0	Fractured sandstone with strong mineralization, light to dark gray--some black.
171...	4.8	.251	1.46	5.1	Massive sandstone with slight vanadium stain, light-gray.
172...	4.4	.773	2.63	6.1	Platy mudstone and sandstone highly mineralized with vanadium and uranium, yellow and red minerals visible, gray to black.
173...	2.0	2.97	4.49	10.7	Sandstone, highly mineralized, much vanadium stain, black.
174...	4.0	.293	.78	3.7	Massive sandstone with vanadium stain, gray to black.
175...	5.0	.959	1.41	3.0	Fractured sandstone with vanadium and uranium stain, gray to black.
176...	3.7	.137	.37	15.7	Massive sandstone with vanadium and uranium stain, gray to black.
177...	4.1	.318	.79	1.5	Fractured sandstone with vanadium and uranium stain, gray to black.
178...	2.8	.252	.30	.6	Highly fractured sandstone with slight vanadium stain, light gray.
179...	3.2	.559	.84	.9	Massive sandstone spotted with vanadium stain, gray.
180...	4.0	1.73	2.10	4.4	Fractured sandstone, highly mineralized with vanadium (red) and uranium (yellow) minerals visible, gray to black.
181...	1.7	.592	2.72	.9	Soft sandstone, highly mineralized with vanadium (red) and uranium (yellow) minerals visible, brown to black.
182...	1.8	2.20	2.60	4.3	Fractured sandstone, highly mineralized with vanadium and much uranium (yellow) minerals visible, gray to black.
183...	4.1	1.14	3.21	2.6	Sandstone and mudstone with clay nodules, slight mineralization, gray to green.
184...	4.0	.471	1.80	.5	Massive sandstone with vanadium and uranium stain, light to dark gray.
185...	5.0	1.15	3.32	2.2	Massive sandstone with some mudstone, highly mineralized, gray to black.
186...	3.5	.254	2.90	1.5	Massive sandstone, highly mineralized with vanadium, gray to black.
187...	2.6	1.69	2.58	1.0	Sandstone with mudstone with clay nodules, some vanadium and uranium stain, gray to green

Sample number	Sample width, feet	Assay, percent			Description of sample
		U_3O_8	V_2O_5	CaO	
188...	2.9	0.687	1.85	0.4	Fractured sandstone with much vanadium stain, dark-gray.
189...	4.7	.451	2.07	.6	Massive sandstone with much vanadium and uranium stain, dark-gray.
190...	3.0	.467	.93	.5	Massive sandstone with some vanadium and uranium stain, tan to gray.
191...	.8	1.43	3.31	.5	Platy sandstone highly stained with vanadium and uranium, dark gray.
192...	2.1	.431	2.00	.4	Massive sandstone spotted with vanadium, brown.
193...	3.1	.234	.29	.4	Do.
194...	2.5	.525	.79	.6	Do.
195...	2.3	5.11	4.95	2.0	Massive sandstone, highly mineralized with red, black, and yellow vanadium and uranium minerals.
196...	2.7	.155	.63	.4	Massive sandstone spotted with vanadium stain, tan.
197...	2.4	.085	.38	.3	Do.
198...	3.8	.427	.92	.4	Massive sandstone with much vanadium stain, black.
199...	3.4	.151	.67	1.8	Massive sandstone spotted with vanadium stain, tan.
200...	2.7	.187	.53	1.8	Do.
201...	3.0	.073	.41	.8	Do.
202...	4.3	.396	1.43	2.4	Do.
203...	2.4	.910	2.65	.8	Platy sandstone, highly mineralized, yellow and red uranium and vanadium minerals visible, gray to black.
204...	5.0	.411	.99	.7	Alternate sandstone and mudstone with vanadium and uranium stain, gray to green.
205...	4.5	.253	.54	1.0	Massive sandstone spotted with vanadium stain, tan to gray.
206...	3.4	.315	.63	.6	Alternate sandstone and mudstone spotted with vanadium stain, tan to gray.
207...	3.7	1.40	2.74	1.2	Fractured sandstone with much vanadium stain, tan to black.
208...	4.2	.050	.37	3.6	Massive sandstone spotted with vanadium stain, tan to gray.
209...	3.3	.087	.42	3.4	Massive sandstone spotted with vanadium stain, tan.
210...	4.7	.074	.38	5.0	Fractured sandstone with much vanadium stain, tan to black.
211...	5.0	.086	.43	3.4	Massive sandstone spotted with vanadium stain, tan.
212...	4.6	.044	.77	3.8	Fractured sandstone with vanadium and uranium stain, tan to gray.
213...	4.4	.320	1.31	1.8	Massive sandstone spotted with vanadium stain, tan

Sample number	Sample width, feet	Assay, percent			Description of sample
		U_3O_8	V_2O_5	CaO	
214...	3.7	0.570	2.16	3.2	Fractured sandstone with vanadium and uranium stain in fractures, tan to gray.
215...	5.0	.069	.45	2.0	Massive sandstone spotted with slight vanadium stain, strong uranium stain in fractures, tan.
216...	4.5	.333	1.21	2.4	Massive sandstone spotted with vanadium stain, strong uranium stain in fractures, tan.
217...	3.7	.068	.42	.5	Massive sandstone slightly spotted with vanadium stain, tan.
218...	2.6	1.02	2.69	.8	Massive sandstone with much vanadium stain, tan to dark gray.
219...	4.7	.665	1.55	4.8	Fractured sandstone with much vanadium stain, gray to black.
220...	3.4	.770	2.56	1.2	Massive sandstone with spotted vanadium stain, tan.
221...	3.3	.042	.29	2.6	Do.
222...	4.0	.221	1.09	3.0	Do.
223...	5.0	.091	.33	3.4	Do.
224...	4.8	.176	.43	4.0	Massive sandstone with spotted vanadium stain and strong vanadium stain near bottom, uranium stain in fractures, gray to brown.
225...	2.7	.090	1.31	3.4	Massive sandstone with spotted vanadium stain, tan.
226...	2.8	.043	.23	3.8	Do.
227...	3.9	.061	.22	2.0	Do.
228...	3.6	.731	1.32	.8	Fractured sandstone, some mudstone, spotted vanadium stain, gray.
229...	4.4	.719	1.77	1.4	Alternate sandstone and mudstones, spotted and banded vanadium stain, gray.
230...	4.5	2.31	3.50	2.8	Fractured sandstone with much vanadium stain, uranium stain in fractures, brown to black.
231...	5.0	.248	.63	1.5	Fractured sandstone with spotted vanadium stain and slight uranium stain, tan to gray.
232...	3.3	.107	.41	.5	Massive sandstone with spotted vanadium stain, tan.
233...	3.3	.096	.30	.6	Fractured sandstone with spotted and banded vanadium stain, tan.
234...	3.7	.066	.47	1.5	Fractured sandstone with vanadium and uranium stain, tan to black.
235...	3.5	.044	.30	1.5	Fractured sandstone with spotted and banded vanadium stain, tan to gray.
236...	5.0	.177	.75	.8	Fractured sandstone with spotted and banded vanadium stain, tan.

Sample number	Sample width, feet	Assay, percent			Description of sample
		U_3O_8	V_2O_5	CaO	
237...	5.5	0.928	3.21	0.7	Fractured sandstone with much banded vanadium stain, gray to black.
238...	3.0	.093	.58	.5	Massive sandstone with spotted and banded vanadium stain, tan to gray.
239...	2.6	.302	.60	.5	Do.
240...	4.6	.532	1.71	2.4	Fractured sandstone with spotted and banded vanadium stain and uranium stain, tan to gray.
241...	2.6	.068	.58	4.0	Massive sandstone with spotted and banded vanadium stain, tan to gray.
242...	4.4	.258	.87	4.2	Do.
243...	2.7	.688	3.52	5.6	Fractured sandstone with vanadium and uranium stain, brown to black.
244...	3.0	.077	.47	.5	Massive sandstone with vanadium stain, tan to gray.
245...	5.0	.064	.38	6.0	Fractured sandstone, limy, with spotted and banded vanadium stain, tan to gray.
246...	4.6	1.34	2.38	5.2	Massive sandstone with spotted and banded vanadium stain, tan to gray.
47...	3.3	.180	.60	3.2	Do.
248...	3.3	.203	1.30	10.0	Massive sandstone, limy, with spotted and banded vanadium stain, tan to gray.
249...	3.8	.386	1.68	.9	Massive sandstone with spotted and banded vanadium stain, tan to gray.
250...	3.2	.548	2.45	1.4	Do.
251...	4.2	.483	2.88	.6	Massive sandstone with banded vanadium stain and slight uranium stain, tan to gray.
252...	5.0	.522	1.50	3.2	Massive sandstone with spotted and banded vanadium stain, tan to gray.
253...	2.2	.215	.88	6.0	Fractured sandstone, limy, with vanadium stain, tan to gray.
254...	4.3	.205	.51	11.2	Fractured sandstone, limy, much vanadium stain, gray to black.
255...	3.6	.035	.14	5.6	Fractured sandstone, limy, banded vanadium stain, tan to gray.
256...	4.6	.010	.18	1.8	Massive sandstone with slight vanadium stain, tan.
257...	3.8	.212	1.22	3.8	Massive sandstone with banded vanadium stain, gray.
258...	3.6	.279	1.30	4.6	Massive sandstone, limy, banded vanadium stain, tan to gray.
259...	4.2	1.16	2.72	6.6	Do.
260...	3.1	.384	1.84	.5	Massive sandstone with spotted and banded vanadium stain, tan to gray.
261...	3.0	1.11	2.22	.6	Fractured sandstone with much vanadium and uranium stain, brown to black.
262...	4.5	.627	1.72	1.2	Do.

Sample number	Sample width, feet	Assay, percent			Description of sample
		U_3O_8	V_2O_5	CaO	
263...	4.9	0.223	0.51	1.2	Massive sandstone with spotted vanadium stain, tan.
264...	1.8	.180	.30	5.6	Fractured sandstone, limy, with spotted vanadium stain, tan.
265...	4.4	1.06	1.38	13.8	Do.
266...	.8	.070	.11	8.0	Mudstone, green.
267...	3.1	.237	1.14	1.2	Massive sandstone with banded vanadium stain, gray.
268...	2.5	.050	.34	4.8	Massive sandstone with banded vanadium stain, tan to gray.
269...	.8	.112	.07	9.4	Mudstone, green.
270...	3.7	.124	.40	3.8	Massive sandstone with banded vanadium stain, tan to gray.
271...	2.8	.495	.76	.3	Fractured sandstone with much vanadium stain, gray to black.
272...	3.4	.320	1.42	.3	Do.
273...	4.2	.743	1.41	.5	Fractured sandstone with vanadium stain, tan to gray.
274...	3.8	.277	1.23	4.3	Fractured sandstone with spotted and banded vanadium stain, gray.
275...	4.9	.351	1.33	3.9	Fractured sandstone with spotted vanadium stain, tan.
276...	1.2	.645	1.43	1.8	Fractured sandstone with much vanadium stain, gray to black.
277...	3.3	.552	1.23	7.4	Fractured sandstone with spotted vanadium stain, tan.
278...	3.0	.107	.57	3.4	Do.
279...	2.5	.406	.80	1.3	Fractured sandstone with much vanadium stain, brown to black.
280...	2.2	.233	.93	9.4	Fractured sandstone with banded vanadium stain, tan to gray.
281...	4.8	.127	.44	3.9	Massive sandstone with spotted and banded vanadium stain, tan.
282...	2.5	.291	.64	2.3	Fractured sandstone with vanadium and uranium stain, gray to black.
283...	3.3	.755	1.41	3.9	Alternate sandstone and green mudstone, vanadium and uranium stain on sandstone.
284...	5.0	.081	.51	3.0	Massive sandstone with spotted vanadium stain and slight uranium stain, tan.
285...	2.5	.587	2.22	7.0	Massive sandstone with much vanadium and uranium stain, gray to black.
286...	4.2	.932	1.31	1.4	Massive sandstone with spotted and banded vanadium stain, tan.
287...	3.8	.132	.64	2.7	Fractured sandstone with spotted and banded vanadium stain and slight uranium stain, tan.
288...	3.3	.095	.40	2.0	Massive sandstone with banded vanadium stain, tan.

Sample number	Sample width, feet	Assay, percent			Description of sample
		U_3O_8	V_2O_5	CaO	
289...	4.6	0.105	0.41	2.6	Massive sandstone with banded vanadium stain, tan.
290...	2.8	.403	2.58	2.0	Soft micaceous sandstone with much vanadium stain, brown to black.
291...	4.7	.119	.59	12.9	Alternate sandstone, limy, and mudstone with slight vanadium and uranium stain, tan to green.
292...	2.8	.184	.47	4.0	Alternate sandstone and mudstone with some vanadium and uranium stain, gray to black.
293...	2.6	.738	1.31	2.9	Fractured sandstone with much vanadium stain and some high uranium streaks, brown to black.
294...	3.5	1.24	1.45	.8	Mudstone with sandstone ribs, green.
295...	5.0	.741	.51	.5	Fractured sandstone with slight vanadium stain, gray.
296...	2.0	.913	.81	.6	Fractured sandstone with much vanadium stain and some uranium stain, brown.
297...	2.7	.614	1.82	6.8	Mudstone and sandstone, vanadium and uranium stain, green to gray.
298...	4.6	.423	.98	10.1	Massive sandstone, limy, vanadium and uranium stain, gray to brown.
299...	4.5	.676	.66	9.2	Fractured sandstone, limy, much vanadium and uranium stain, brown.
300...	2.2	.144	.93	.5	Mudstone, green.
301...	4.0	1.64	2.92	1.3	Mudstone and sandstone with vanadium stain, green to gray.
302...	2.7	1.14	1.43	1.9	Alternate sandstone and mudstone with vanadium and uranium stain, green to gray.
303...	3.3	1.89	3.77	.6	Sandstone and mudstone with much vanadium stain, gray to black.
304...	1.2	.767	3.97	2.6	Mudstone with some sandstone, much vanadium and uranium stain, possibly high-grade values, brown to black.
305...	1.0	.576	3.66	1.9	Sandstone with high-grade uranium and some vanadium, black.
306...	2.7	.619	.64	.7	Sandstone with strong uranium and vanadium stain, gray to black.
307...	3.3	.277	.56	6.1	Mudstone and sandstone with vanadium and uranium stain, green to gray.
308...	3.0	.171	.77	4.6	Massive sandstone, limy, with vanadium stain, tan to gray.
309...	3.5	.442	.85	7.4	Alternate sandstone and mudstone with vanadium and uranium stain, green to gray.
310...	2.8	.256	.41	7.8	Fractured sandstone, limy, and mudstone with vanadium stain, green to gray.
311...	2.1	.606	.84	18.2	Fractured sandstone, limy, and mudstone with vanadium and uranium stain, green to

Sample number	Sample width, feet	Assay, percent			Description of sample
		U_3O_8	V_2O_5	CaO	
312...	2.0	1.18	1.77	11.4	Sandstone, limy, and mudstone, green to gray.
313...	3.1	1.01	1.18	8.6	Sandstone, limy, and mudstone with vanadium and uranium stain, green to gray.
314...	4.2	1.31	1.27	6.9	Fractured sandstone, limy, with vanadium and uranium stain, gray to brown.
315...	1.6	.310	.91	4.4	Sandstone, limy, and mudstone with vanadium and uranium stain, green to tan.
316...	1.5	.100	.17	2.4	Massive sandstone, limy, with strong vanadium stain, green to gray.
317...	3.7	1.74	3.33	9.3	Fractured sandstone, limy, with strong vanadium stain, green to gray.
318...	3.4	.211	.35	20.0	Fractured sandstone, limy, with vanadium and uranium stain, gray.
319...	3.0	.182	.46	3.6	Massive sandstone, limy, with vanadium stain, gray.
320...	3.0	.672	1.44	6.1	Fractured sandstone, limy, and mudstone with vanadium and uranium stain, gray to green.
321...	5.0	.021	.07	1.6	Mudstone, green to brown.
322...	2.9	.201	.39	27.5	Sandstone, limy, gray.
323...	1.8	.574	4.10	9.3	Sandstone, limy, and mudstone with vanadium and uranium stain, gray to black.
324...	1.8	.283	.20	2.4	Mudstone or clay, green.
325...	2.3	.614	1.58	.7	Massive sandstone, limy, with vanadium stain, gray.
326...	1.8	.191	.35	.7	Fractured sandstone with vanadium stain, gray.
327...	1.5	1.17	4.30	1.4	Sandstone with high-grade vanadium and uranium, black.
328...	1.6	.238	.72	1.0	Fractured sandstone, limy, gray.
329...	3.3	.097	.15	4.9	Massive sandstone, limy, gray.
330...	3.4	1.45	.57	1.3	Fractured sandstone with spotted vanadium stain, tan.
331...	3.0	.410	.95	1.7	Sandstone, limy, and mudstone, green to gray.
332...	2.6	.350	.88	2.2	Mudstone with sandstone, green to gray.
333...	3.0	.697	2.92	2.2	Sandstone, limy, and mudstone, with strong vanadium stain in sandstone, gray.
334...	1.7	.361	.28	2.0	Fractured sandstone with slight vanadium stain, gray.
335...	2.0	.419	.38	17.4	Fractured sandstone, limy, with vanadium stain, gray.
336...	4.7	.455	.77	13.8	Massive sandstone, limy, with vanadium and uranium stain, gray.
337...	4.0	.361	1.29	1.2	Mudstone and limestone, limy, with vanadium stain, green to gray.

Sample number	Sample width, feet	Assay, percent			Description of sample
		U_3O_8	V_2O_5	CaO	
338...	2.5	0.097	0.33	2.1	Fractured sandstone, limy, with vanadium stain, gray.
339...	3.2	.127	.39	15.5	Do.
340...	2.2	2.15	2.81	3.9	Mudstone and sandstone, green to gray.
341...	5.0	.483	.58	4.3	Fractured sandstone and a little mudstone, vanadium and uranium stain, gray.
342...	4.5	.238	.41	9.1	Fractured sandstone, limy, with some vanadium stain, gray.
343...	2.0	1.12	3.84	.7	Mudstone and sandstone with vanadium and uranium stain, gray to brown.
344...	5.0	.342	1.34	7.4	Massive sandstone with slight vanadium stain, gray.
345...	4.6	.141	.38	15.8	Do.
346...	2.7	.059	.47	4.2	Massive sandstone, limy, with slight vanadium stain, tan.
347...	4.3	.185	.54	6.9	Massive sandstone, limy, with banded vanadium stain, tan.
348...	1.8	.159	.72	8.9	Massive sandstone, limy, with slight vanadium stain, tan.
349...	3.3	1.82	3.04	6.0	Sandstone and mudstone, limy, with vanadium and uranium stain, green to gray.
350...	2.6	.171	.53	2.0	Massive sandstone, limy, with vanadium and uranium stain, gray.
351...	4.1	.030	.25	10.6	Massive sandstone, limy, gray.
352...	4.1	1.48	1.95	11.2	Mudstone and sandstone, limy, with vanadium and uranium stain, green to gray.
353...	3.3	.494	1.54	7.3	Massive sandstone, limy, with slight vanadium and uranium stain, gray.
354...	2.5	.226	.86	8.9	Alternate sandstone and mudstone with strong vanadium and uranium stain, green to gray.
355...	4.2	.122	.69	1.5	Fractured sandstone, limy, slight vanadium and uranium stain, gray.
356...	2.4	2.02	3.91	10.2	Sandstone and mudstone, limy, with strong vanadium and uranium stain, green to gray.
357...	3.5	.112	.33	15.8	Massive sandstone, limy, gray.
358...	5.0	1.00	1.90	20.6	Do.
359...	3.4	.104	.45	12.7	Massive sandstone, limy, with slight vanadium stain, gray.
360...	3.5	1.05	1.62	18.0	Sandstone and thin mudstones, limy, with vanadium and uranium stain, gray.
361...	3.2	.889	.69	19.6	Sandstone and mudstone, limy, with vanadium and uranium stain, gray.
362	4.7	.220	.36	9.1	Massive sandstone, limy, with slight vana-

Sample number	Sample width, feet	Assay, percent			Description of sample
		U_3O_8	V_2O_5	CaO	
365...	3.6	0.486	0.61	4.1	Massive sandstone, limy, with slight vanadium stain, gray.
366...	3.5	.929	3.11	7.6	Mudstone and sandstone, limy, with vanadium and uranium stain, green to gray.
367...	2.8	1.13	2.28	8.8	Massive sandstone, limy, with slight vanadium stain, gray.
368...	5.0	.095	.20	17.0	Mudstone and sandstone, limy, with vanadium and uranium stain, green to gray.
369...	2.2	.072	.18	15.1	Mudstone and sandstone, limy, with vanadium stain, green to gray.
370...	3.2	.780	1.21	12.0	Fractured sandstone with some mudstone, limy, strong vanadium and uranium stain, gray to brown.
371...	3.5	.506	1.17	10.1	Massive sandstone, limy, thin mudstone near bottom, vanadium and uranium stain, gray.

APPENDIX B.--WEIGHTED-AVERAGE ASSAYS FOR URANIUM, VANADIUM, AND LIME, MI VIDA MINE, SAN JUAN COUNTY, UTAH, AUGUST 1953

Sample width, feet	Assay, percent			North coordinate, feet	East coordinate, feet
	U_3O_8	V_2O_5	CaO		
Northern Area					
9.4	0.063	0.53	2.9	208	359
8.0	.552	.99	2.0	218	258
10.7	.340	1.31	2.3	218	332
10.7	.179	.97	2.2	221	283
9.8	.132	.37	3.6	230	355
7.7	.240	.75	4.4	244	224
7.5	.249	1.08	4.3	245	276
10.6	.361	.78	3.5	246	252
11.0	.548	1.43	2.4	253	340
8.1	.434	1.69	2.4	262	313
10.6	.237	.51	6.2	268	194
9.5	.194	.81	2.1	269	347
9.4	.459	1.30	4.8	273	222
9.6	.065	.59	3.5	287	314
9.0	.663	1.13	3.3	288	196
12.3	.202	.46	12.2	290	170
12.2	.069	.38	4.0	294	290
11.2	.941	2.46	6.4	303	186
10.1	.296	.74	7.8	305	152
10.7	1.278	1.90	2.7	310	212
11.6	.637	1.26	.9	321	292
11.7	.507	1.49	1.3	322	267
10.5	.940	.88	.6	332	156
8.1	.809	2.51	1.5	333	216
8.5	.781	3.14	1.9	334	247
8.2	1.146	2.75	1.0	336	128
12.5	1.295	2.26	1.7	348	296
13.8	1.299	1.73	.7	353	270
10.2	.833	2.13	.6	356	245
11.6	.164	.47	.9	367	310
12.2	.105	.53	1.2	372	331
8.9	.252	.68	.3	376	273
9.1	.135	.54	1.4	380	302
11.1	.555	1.88	.5	384	243
11.2	.468	2.35	.9	391	221
10.6	.692	1.89	.8	398	190
11.6	.324	1.13	3.4	401	239
11.2	.663	1.53	6.0	415	220
10.7	.225	1.19	4.3	420	261
11.6	.576	1.78	5.0	422	199
11.5	.344	1.01	6.7	441	220
6.2	.399	1.12	.3	452	166

Sample width, feet	Assay, percent			North coordinate, feet	East coordinate, feet
	U_3O_8	V_2O_5	CaO		
Northern Area--Continued					
8.2	0.020	0.16	3.4	445	245
11.1	.547	.82	6.9	446	198
8.0	.521	1.32	2.3	466	184
6.4	.143	.69	3.4	482	171
4.5	.121	.34	4.7	486	148
Southern Area					
7.8	0.466	0.94	14.0	72	167
7.1	.704	1.84	5.8	97	152
10.4	.735	1.73	8.1	98	168
8.9	.497	.93	12.0	114	198
10.1	.680	.93	16.7	115	159
8.5	.634	1.25	18.6	132	150
11.5	.680	1.22	9.8	146	165
9.1	.651	1.58	5.8	149	132
7.5	.328	.95	6.1	155	113
7.7	.874	1.65	5.3	157	147
11.7	.702	.93	6.0	165	194
9.7	.215	.74	6.1	167	168
9.5	.609	1.50	7.6	170	128
12.4	.467	1.41	3.5	186	147
8.6	.849	1.60	12.3	190	75
6.9	.630	.93	12.0	190	90
11.6	.396	1.39	9.5	191	197
12.9	.953	2.19	6.1	203	160
11.8	.563	1.05	9.0	205	127
9.8	.303	.72	6.1	206	106
7.0	.136	.51	5.8	207	216
8.9	1.025	1.17	7.0	213	91
6.0	.427	.95	4.8	220	67
8.9	1.118	1.97	1.2	230	125
11.9	.571	1.69	6.1	230	153
7.3	.495	1.57	2.1	233	99
13.6	.482	1.09	6.3	233	176
9.7	.177	.91	10.7	244	60
9.7	.668	.54	2.6	250	115
9.0	.489	1.35	1.2	251	86
14.5	.284	.98	5.6	263	169
6.7	.444	.65	14.8	186	111