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Appraisal of the Accuracy of U. S. Geological Survey Ore Reserve Estimates for Uranium-Vanadium Deposits on the Colorado Plateau

By A. L. Bush, and H. K. Stager,

Trace Elements Investigations Report 288

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A. L. Bush and H. K. Stager

February 1954

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This preliminary report is distributed without editorial and technical review for conformity with official standards and nomenclature. It is not for public inspection or quotation.

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

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APPRAISAL OF THE ACCURACY OF U. S. GEOLOGICAL SURVEY ORE RESERVE ESTIMATES FOR URANIUM-VANADIUM DEPOSITS ON THE COLORADO PLATEAU

By A. L. Bush and H. K. Stager

ABSTRACT

The U. S. Geological Survey has made estimates of the reserves of uranium and vanadium in the carnotite deposits explored by Geological Survey drilling on the Colorado Plateau. This report presents an appraisal of the accuracy of the reserve estimates for deposits in the Uravan mineral belt, the causes of inaccuracy, and the significance of the estimates in terms of the total known reserves of the region.

The appraisal was confined to deposits that contain ore reserves of 1,000 short tons or more, classed as indicated and inferred reserves. To be classed as an ore reserve, the mineralized rock must be in masses 1 foot or more thick, containing 0.10 percent or more U_3O_8 or 1.0 percent or more V_2O_5. Reestimates of the amount of material in the ground at the time of the original estimate were made for more than 30 deposits. This was done where information on size and grade, additional to that used at the time of the original estimate, was available. This information included production data (both tonnage and grade) and additional points of exposure, in mine workings and drill holes. The reestimated reserves (revised reserves) include production since the original reserve estimates, and, therefore, can be compared with the original estimates, to furnish a measure of the accuracy of the original estimates. This measure of accuracy is expressed as a realization ratio, the ratio of revised to original reserves.

The reappraisal indicates that for individual deposits the original reserve estimates of both tonnage and grade range from large overestimates to very large underestimates. However, the original reserve estimate for the total reserves of all the deposits studied in the Uravan mineral belt is a very small underestimate. For the deposits studied in the mineral belt, the revised ore reserves are about 15 percent greater than originally estimated. In terms of grade, the original estimate was 0.35 percent U_3O_8 and 1.80 percent V_2O_5. The revised estimate is 0.35 percent U_3O_8 and 1.87 percent V_2O_5. Primarily as a function of the increased tonnage of reserves, the amount of contained U_3O_8 is about 15 percent greater, and the amount of contained V_2O_5 is about 20 percent greater than originally estimated.

All of the individual deposits contained more than half the amount of ore originally estimated. A little more than 25 percent of the deposits contain over twice as much ore as originally estimated. The errors in estimation for individual deposits are mutually compensating; as more deposits are grouped into a single estimate, the amount of error decreases both in tonnage and grade.

The ranges of individual error in the original estimates and the average error are greatest for deposits originally estimated to be in the less-than-5,000 short ton class, smaller in the 5,000-10,000 short ton class and least in the 10,000-50,000 short ton class. Similarly the ranges of individual error and the average error are greatest where the drilling is wide-spaced and the amount of information is least.

The general source of error in the original estimates is the restricted number of points of observation (mostly drill holes) on which the estimates are based. This is complicated by the variation of the ore deposits from an idealized uniformly tapering layer both in plan and in section, and by the erratic distribution of metal values within the deposit. No mathematical correction can be applied to the reserve estimate to compensate for this sampling error. Within the framework of the exploration done by the Geological Survey, increased density of drilling alone can provide better definition of these variations.

As the deposits studied in the mineral belt represent a fair sample of all the uranium-vanadium deposits in the Morrison formation that the Geological Survey is finding, the realization percentages given above can be applied with reasonable confidence to the total of the estimates of known reserves for all of the deposits found by the Geological Survey. This total estimate is one of the Geological Survey's major objectives in the exploration work. As the error in the original estimate of total reserves for the deposits studied in the mineral belt is small, the methods of exploration and estimation being used are adequate to achieve a realistic appraisal of the total uranium-vanadium reserves of the region.

INTRODUCTION

Since November 1947, the U. S. Geological Survey has been conducting diamond- and wagon-drill exploration for uranium-vanadium deposits on the Colorado Plateau. Much of this exploration has been in southwestern Colorado, within the area described by Fischer and Hilpert (1952) as the Uravan mineral belt (fig. 1). In this belt, most of the deposits are in lenticular sandstone beds in the upper part of the Salt Wash member of the Jurassic Morrison formation.

An intergral part of the Geological Survey exploration program, has been the estimation of the total reserves of uranium and vanadium in the explored deposits. The individual reserve estimates serve as a basis for the leasing of deposits on Government-controlled land and collectively are useful as a measure of expectable production.

The present study has been undertaken to: 1) determine the accuracy of the reserve estimates; 2) to investigate the causes of inaccuracy and the possibility of correction of these inaccuracies; and 3) to determine the significance of the estimates in terms of total known reserves of the region.

This work has been done on behalf of the Division of Raw Materials of the U. S. Atomic Energy Commission.

METHOD OF STUDY

It is obvious that the accuracy of a reserve estimate can best be determined when the reserve block (the ore body) has been completely mined out. Only then can direct comparison be made between the estimated content and the actual content, as to both tonnage and grade. Very few deposits on the Colorado Plateau, for which the Geological Survey has made reserve estimates, have been entirely or even significantly depleted. In this sense this study is premature. However, interest is in the present content of the deposits, as well as in the accuracy of the original estimate, not in a post-mortem knowledge of what the content or accuracy was. The study must take the form, therefore, of a reestimate of the total reserves of the deposit that existed at the time of the original estimate. This reestimate (the revised reserve estimate) is based upon the production from the deposit since the original reserve estimate and upon consideration of the

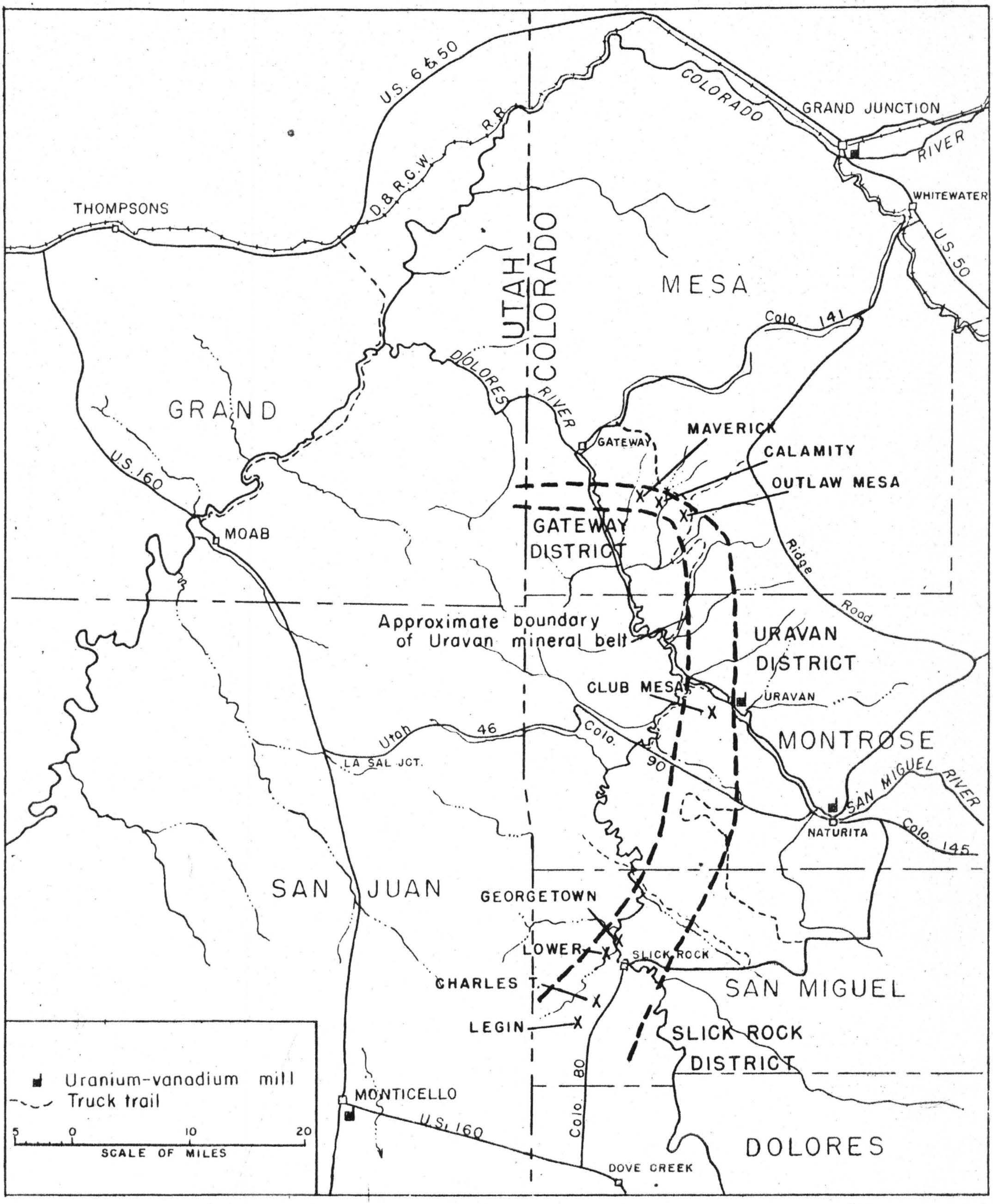


Figure 1. MAP OF PART OF THE COLORADO PLATEAU SHOWING LOCATION OF THE URAVAN MINERAL BELT AND OF CLAIM GROUPS STUDIED

additional information available. By comparing the revised reserve estimate with the original reserve estimate, an expression of the accuracy of the original estimate is obtained. The definitions of reserves and the methods used in calculations are described in the appendix.

In general the deposits that are important in terms of significant production potential are those that contain 1,000 tons or more of ore. (All tons in this report are short tons.) The study was confined to these deposits, although a few deposits, containing 800 to 1,000 tons of ore also were included. At the present time, the Geological Survey has explored some 70 deposits in the Uravan mineral belt which fall in this category.

No meaningful reappraisal of the reserves in these 70 deposits can be made unless information has been developed additional to that available at the time of the original reserve estimate. Such information includes additional drilling and/or a significant amount of mining and development. In general, deposits were excluded from the study if production, since the time of the original reserve estimate, was less than 25 percent of the original reserve estimate _/. A few deposits with production less than 25 percent were included where information from additional drilling was available. Under these requirements, 37 of the 70 deposits mentioned above were included in the study.

The character of the production data for some deposits is such that it is not possible to assign production accurately. This necessitated grouping of some of the deposits and inclusion of a few additional deposits, smaller than 1,000 tons, in some of the groups. The grouping reduced the number of usable cases to 30.

All these deposits were mapped, at scales generally of 1:480 or 1:600, to obtain information on extent of development, habits, thicknesses, and grades of the deposits and ore bodies, and their general trends. This information, plus the additional drilling information, was compiled on maps showing the original information available (drill holes, mine workings, ore deposit boundaries, and reserve block locations). On the basis of the additional information, the boundaries of the deposits and the location and size of the original reserve blocks were redefined. Thus the revised reserve blocks include the material in the ground at the time of the original reserve estimate.

_/ Among the deposits excluded for this reason was the AEC lease to Barkley and Co. on reserve block 6, Club Mesa claim group, Montrose County, Colo. At the time of field examination (January-March 1953), this deposit had produced less than 1,000 tons of an estimated reserve of 13,000 tons.

The revised reserve blocks have been depleted to varying degrees by mining since the date of the original reserve estimate. The depletion, which is measured by the tons of ore produced, can also be expressed as a percentage of the revised reserve block. Thus the content of the revised reserve block can be expressed in terms of tons of material present in the ground at the time of the original estimate. By comparing the revised estimate with the original estimate, an expression of the accuracy of the original estimate can be obtained.

In general, experience has shown that after 1,000 to 1,500 tons of ore has been produced from a deposit, or in the case of small (less than 5,000 tons) deposits, after about 25 percent of the ore has been mined, the cumulative grade of the production is a fair representation of the overall grade of the deposit. Production was less than 1,000 tons in only four of the 30 cases studied, and represented less than 25 percent of the reserves in only two of these cases. Numerous exceptions to this generalization existed, particularly where a deposit was "high-graded" in the early stages of mining. The production grade, in many cases, is probably slightly higher than the overall grade of the deposit. The difference in grade was not considered critical, however, and the grade of ore produced was used in most cases as the grade of the reserves in the revised reserve estimate. The validity of this assumption appears to be borne out by the extremely close correspondence of the average U_3O_8 and V_2O_5 grades of the original reserve estimate for all the deposits studied (0.35 percent U_3O_8 and 1.80 percent V_2O_5) with the average grade for the production from those deposits (0.35 percent U_3O_8 and 1.87 percent V_2O_5).

The mines were mapped as of their state of development on December 31, 1952. To correlate with this extent of the mining, production data were used with the same cutoff date.

About half the deposits were mapped and their reserves reappraised by Stager, and the other half by Bush. Stager was responsible for the work at the Calamity, Maverick, and Outlaw claim groups; Bush was responsible for the work at the Club, Georgetown, Lower, Charles T., and Legin claim groups (fig. 1).

CHARACTER OF DATA

The original reserve estimates were based largely on drill-hole data, supplemented in some cases by exposures in mine workings and natural outcrops. In general, the amount of information available for the reserve estimate is a function of the drill-hole spacing. A major objective of the Geological Survey's exploration work is the discovery of ore deposits, and the estimation of their size, in terms of reserves that are not more precise than the indicated class. At this level of precision, the spacing of drill holes is designed to outline the limits and to indicate the order of magnitude of the deposits with a minimum of drilling. This drill-hole pattern is controlled by the geologic interpretation of the ore deposit and its expected habits.

Commonly the drill-hole pattern consists of four drill holes at a spacing of 50 feet around a discovery hole, with additional drilling at a spacing of 100 feet to follow and outline the ore deposits. In other cases, six drill holes at a spacing of 50 feet around the discovery hole were used, in places supplemented by other drill-holes at the same spacing, with additional drilling at a spacing of 100 feet. Elsewhere lines of holes were drilled at intervals of 100 to 200 feet apart, across the trend of the deposit, with holes on 50-foot centers along the lines.

Chemical assays for V_2O_5 and U_3O_8 are available for all the mineralized rock cored in the drilling. Although core recovery varies from hole to hole, as well as from one lithologic unit to another within a single hole, the average core recovery for mineralized rock is probably about 80 percent. The core recovery for barren sandstone is usually better and in many units is 95 to 100 percent. The position and thickness of the mineralized rock, therefore, can often be determined with considerable accuracy, despite core loss within the unit. The grade can be seriously distorted by core loss, however, as the richer material is commonly fine and friable. A partial correction for the loss of the richer material may be made through the use of gamma-ray data obtained by probing the drill holes.

The revised reserve estimates are invariably based on additional information. The habits of the deposit can be studied in new or expanded mine workings, the boundaries of the deposit are exposed in places, additional drilling in many cases is available so that the extent and average thickness of the deposit are better known, and the production records give a strong basis for the assignment of grades to the unmined ore.

Generally, the data available for additional drilling done by the mine operator are less reliable than for Geological Survey drilling. Drill-hole locations may be less accurately recoverable, chemical assays on the core are usually lacking, and data on the position and thickness of the mineralized material, both in core and noncore drilling, may be somewhat less reliable. Many of these disadvantages, however, are at least partially compensated by the greater density of drilling. In some cases a major weakness exists in the production record. Frequently the ore from several deposits on a claim, or a group of claims, is grouped and attributed to a general area, rather than to a specific deposit. It thus becomes impossible to assign the production accurately to the individual deposit, and the reliability of the revised reserve estimate is weakened thereby.

ACCURACY OF ORIGINAL ORE RESERVE ESTIMATES

The basic tool in the assessment of the accuracy of the original estimate is the realization ratio, the ratio of the revised estimate to the original estimate. Realization ratios have been calculated for each deposit (or each case studied) in terms of: 1) tonnage ratio; 2) grade ratio, U_3O_8; 3) content ratio, U_3O_8; 4) grade ratio, V_2O_5; 5) content ratio, V_2O_5. Ratios have also been calculated for each large group of deposits, for each district, and for all the deposits studied in the mineral belt. These data are presented in table 1.

Errors in the original reserve estimates decrease generally, as the number of deposits included in the estimate is increased, due to compensation of individual errors. Estimates on individual deposits range widely in accuracy, from large overestimates to very large underestimates. Estimates for the mineral belt, however, are well within the limits of accuracy expected, constituting a small underestimate for tonnage, contained U_3O_8, and contained V_2O_5. The progression is orderly, the error is greatest on individual deposits, less on large groups of deposits, still less by districts, least for the entire mineral belt.

For the entire mineral belt, this study indicates that the tonnage of the revised estimate is about 15 percent more than originally estimated. There is also about 15 percent more U_3O_8 and about 20 percent more V_2O_5 in the revised reserves than in the reserves originally estimated. Expressed in terms of grade, in the revised reserves the average U_3O_8 grade (0.35 percent) is the same as the original estimate and the average V_2O_5 grade (1.87 percent) is slightly higher than the original estimate (1.80 percent).

The Geological Survey's reports on carnotite reserves of the Colorado Plateau (See Unpublished reports.) have included the following statement (some with minor changes in wording): "Because of the variations in thickness and grade of ore and the scarcity of sample data, the indicated reserves in any single reserve block might actually amount to as much as twice or as little as one-half the calculated tonnage. The limit of error of the total tonnage for several blocks, however, is apt to be considerably lower, perhaps not more than 25 percent of the calculated tonnage. The limit of error in the tonnage figures for inferred reserves, of course, is apt to be higher than for the indicated reserves. The possible limit of error in the calculated or estimated grade for both indicated and inferred reserves probably is somewhat smaller than the possible limit of error in the tonnage figures."

Tonnage

The data presented in table 1 and figure 2 show that the above-quoted statement is substantially correct. The comparison shows that all of the deposits studied actually contained (according to the revised estimate) more than one-half the originally calculated tonnage of both indicated and inferred reserves. The only deviation from the statement is that a little over one-quarter of the deposits appears to contain more than twice the amount of indicated and inferred reserves. Analysis of these observations is complicated by the fact that the above-quoted statement applies only to indicated reserves, whereas the revised estimate covers both indicated and inferred reserves, and is based on production that has come from both classes of reserves. The type of information on which the inferred reserves are based allows for greater errors than for indicated reserves. This fact suggests that exclusion of the inferred reserves and of the production from these reserve blocks would tend to decrease the error for indicated reserves, rather than to increase it.

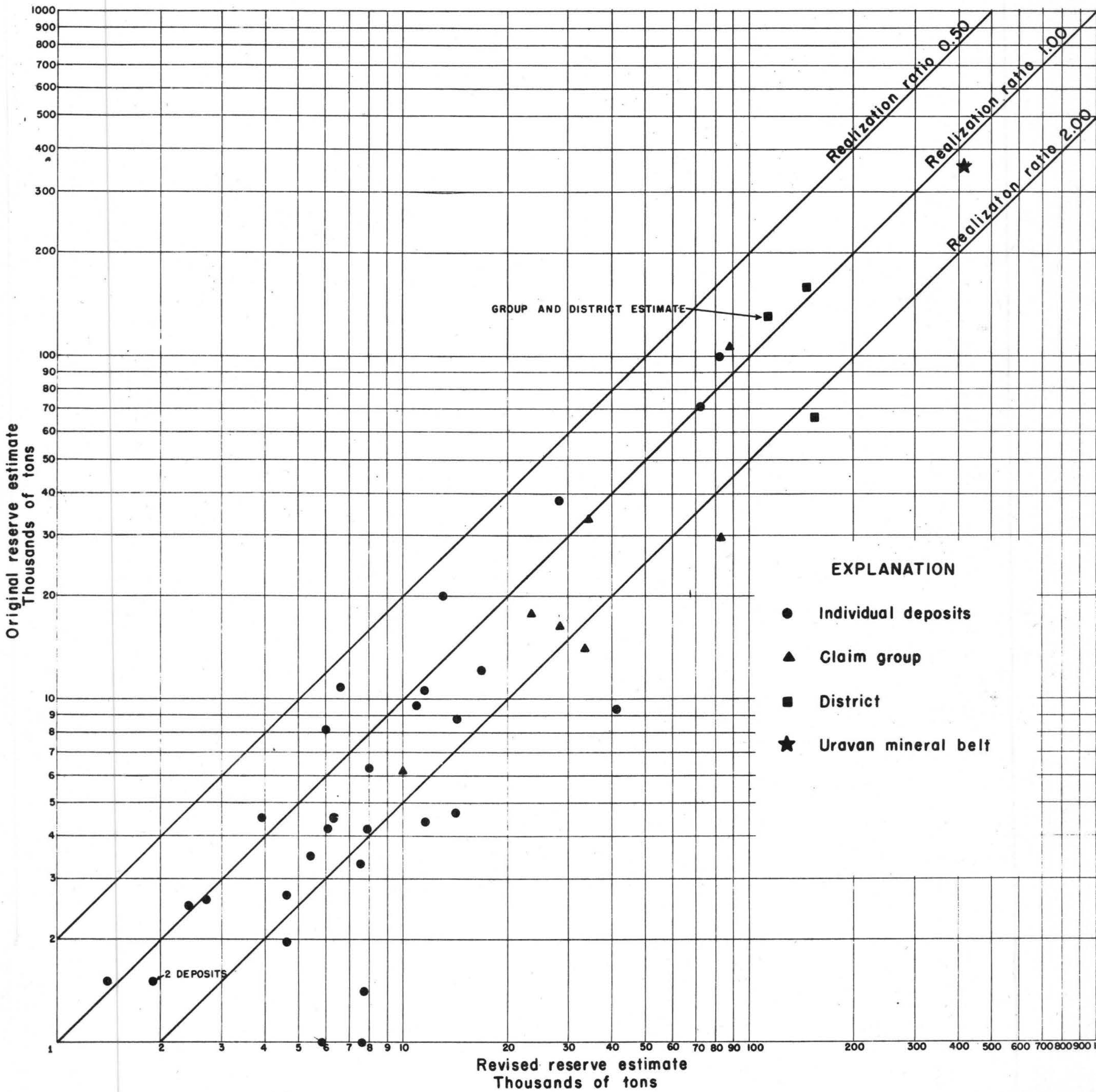


Figure 2. GRAPH SHOWING VARIATION IN ACCURACY OF ORIGINAL TONNAGE RESERVE ESTIMATES

The limits of error are smaller for groups of deposits than they are for single deposits. In four of the eight large groups, the realization ratios for tonnage of indicated and inferred reserves fall between 0.8 and 1.3. The other four all contain from one and one-half to a little less than three times the originally calculated tonnage of indicated and inferred reserves. Again, exclusion of inferred reserves and production from these reserve blocks would probably decrease the error.

Considered by districts, the realization ratio for two of the three districts is 0.9; the third contains over twice as much reserves as originally calculated. For all the deposits studied in the mineral belt the realization ratio is about 1.15.

Grade

In general, the range of error and the limit of error in U_3O_8 and V_2O_5 grades are considerably smaller than those for the tonnage of ore (table 1 and figs. 3 and 4). On an individual basis, almost three-quarters of the deposits have U_3O_8 grade realization ratios between 0.5 and 1.5, and seven-tenths of the deposits have V_2O_5 grade realization ratios between 0.75 and 1.25. By groups, the U_3O_8 realization ratios of six of the eight groups are between 0.5 and 1.5 (a seventh has a ratio of 1.6) and five of the eight groups are between 0.75 and 1.25. The V_2O_5 realization ratios of all eight groups are between 0.85 and 1.1, and for six of the eight groups are between 0.95 and 1.05. By districts, both the U_3O_8 and V_2O_5 realization ratios are between 0.85 and 1.1. For all the deposits studied in the mineral belt, the U_3O_8 and V_2O_5 realization ratios are 1.0 and 1.05 respectively.

Variation with size of deposit

A study was made of the accuracy of the original reserve estimates grouped by size of the ore deposits (table 2 and figs. 2, 5, and 6). The deposits were classed into four categories: 1) less than 5,000 tons; 2) 5,000-10,000 tons; 3) 10,000-50,000 tons; and 4) more than 50,000 tons. The distribution of deposits in these classes is such that there are probably sufficient cases in categories 1, 2, and 3 to warrant some generalizations. With only two cases in category 4, it is not possible to make significant generalizations.

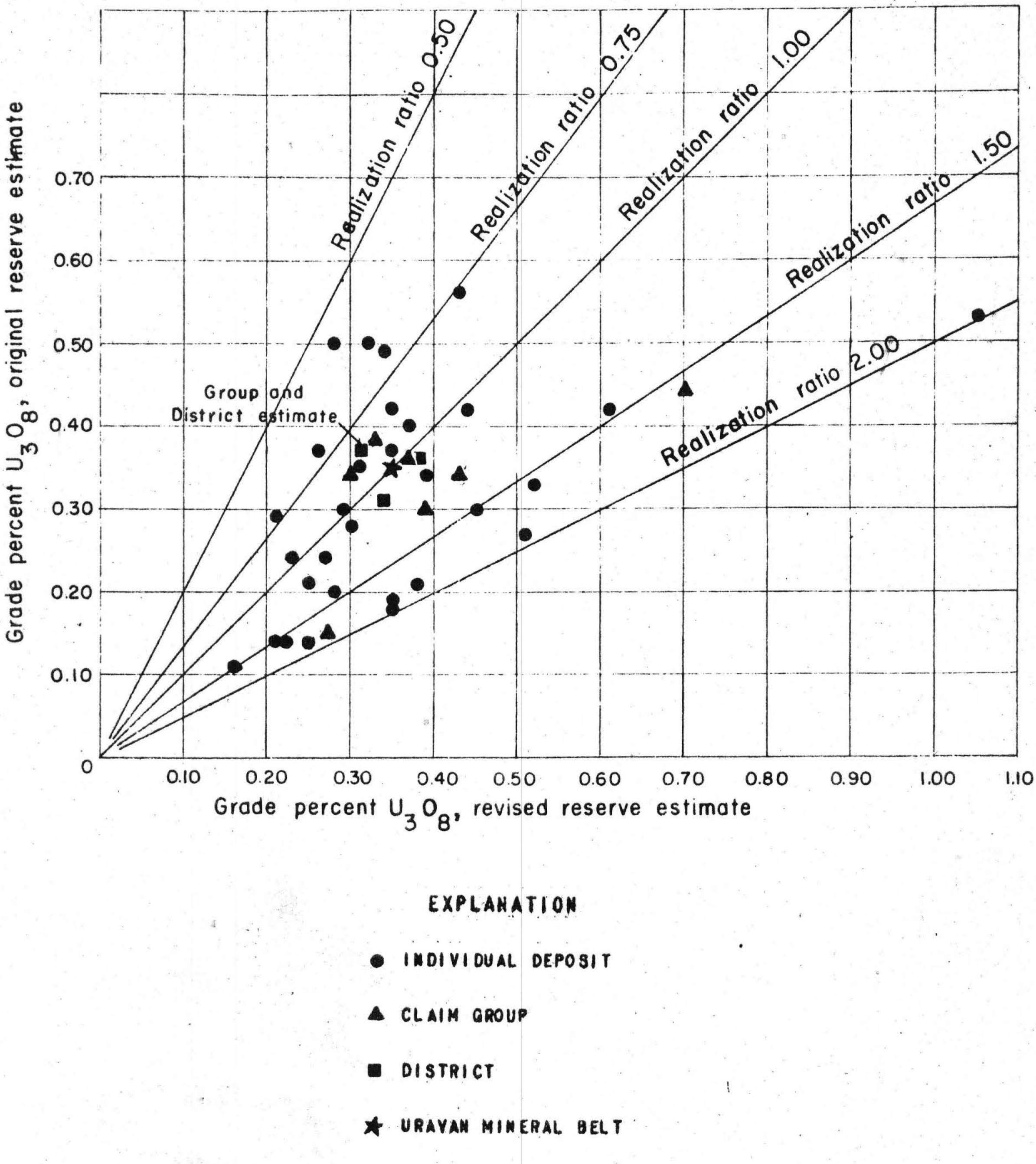
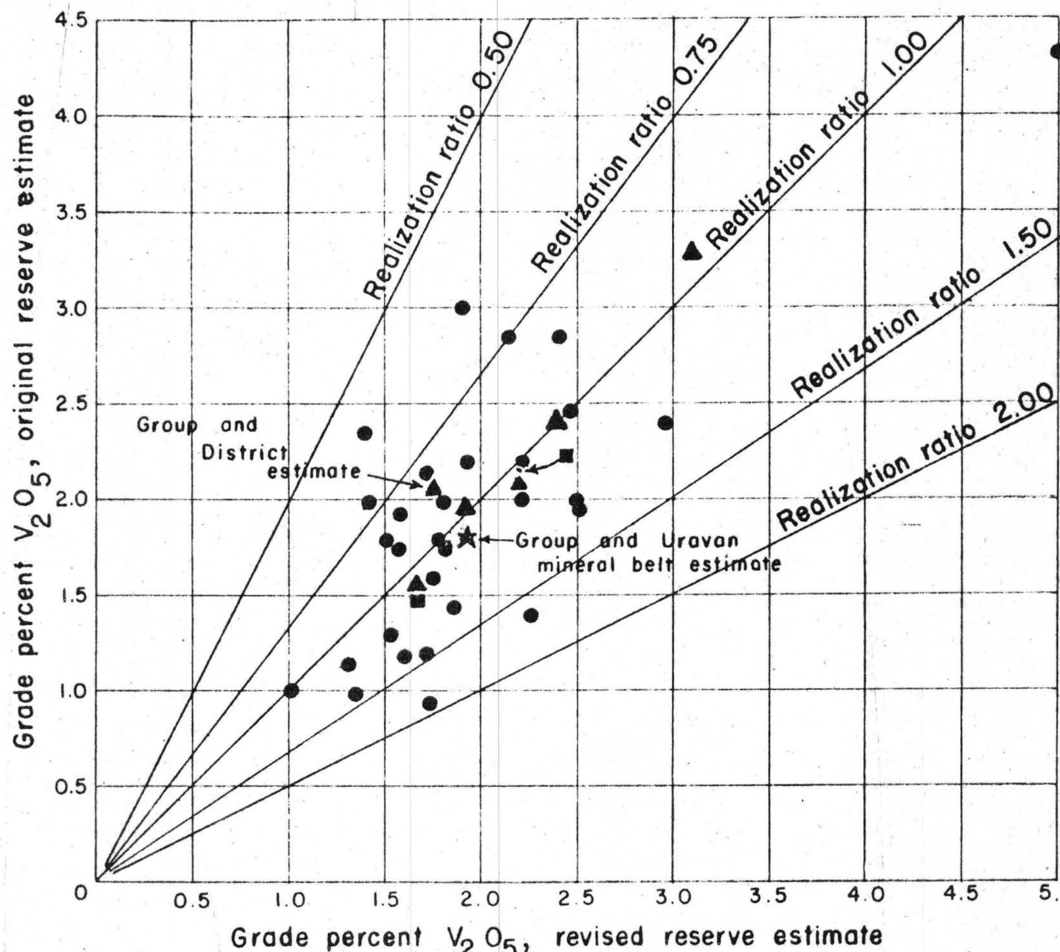


Figure 3. GRAPH SHOWING VARIATION IN ACCURACY OF ORIGINAL RESERVE ESTIMATES OF GRADE PERCENT U_3O_8



EXPLANATION

● INDIVIDUAL DEPOSIT

▲ CLAIM GROUP

■ DISTRICT

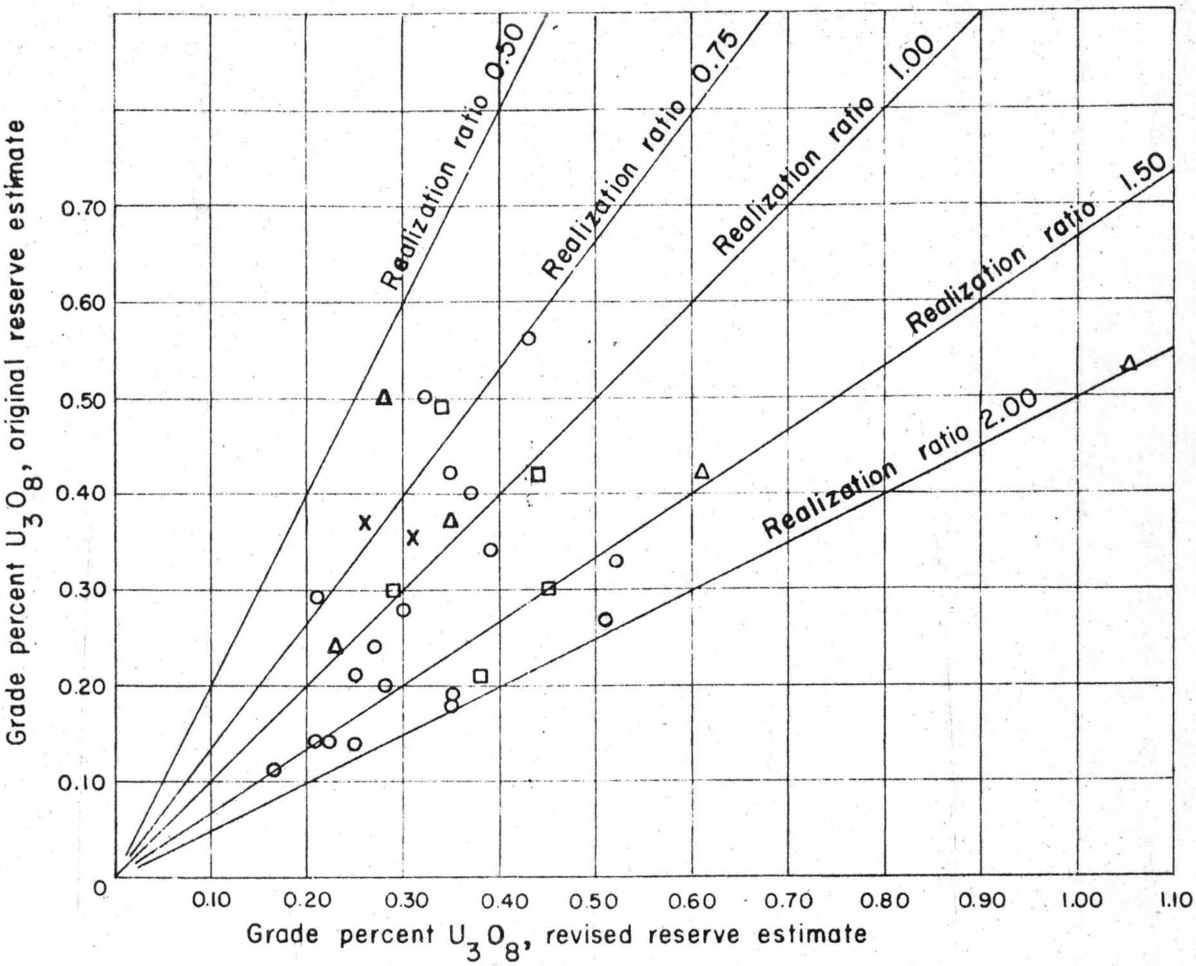
★ URAVAN MINERAL BELT

Figure 4. GRAPH SHOWING VARIATION IN ACCURACY OF ORIGINAL RESERVE ESTIMATES OF GRADE PERCENT V_2O_5

Table 2. Variation in accuracy of original reserve estimates, grouped by size of deposit

Deposit class	Original reserve estimate[1]					Revised reserve estimate[1]					Realization ratios[2]				
	Short tons	Pounds		Percent		Short tons	Pounds		Percent		Tonnage	Content		Grade	
		U_3O_8	V_2O_5	U_3O_8	V_2O_5		U_3O_8	V_2O_5	U_3O_8	V_2O_5		U_3O_8	V_2O_5	U_3O_8	V_2O_5
Less than 5,000 tons (18 cases)	50,740	278,750	1,815,100	0.27	1.79	103,900	676,800	4,112,100	0.33	1.98	2.05	2.45	2.25	1.20	1.10
5,000-10,000 tons (5 cases)	42,160	343,350	2,210,400	0.41	2.62	80,300	696,400	4,060,900	0.43	2.53	1.90	2.05	1.85	1.05	0.95
10,000-50,000 tons (5 cases)	91,610	661,950	3,427,500	0.36	1.87	76,200	604,000	2,746,000	0.40	1.80	0.85	0.90	0.80	1.10	0.95
More than 50,000 tons (2 cases)	169,875	1,217,700	5,337,100	0.36	1.57	154,100	883,200	4,567,800	0.29	1.48	0.90	0.75	0.85	0.80	0.95

1/ Includes indicated and inferred reserves.
2/ Ratio of revised reserve estimate to original reserve estimate.



EXPLANATION

O	DEPOSIT LESS THAN 5,000 TONS
Δ	DEPOSIT 5,000 - 10,000 TONS
□	DEPOSIT 10,000 - 50,000 TONS
X	DEPOSIT MORE THAN 50,000 TONS

Figure 5. GRAPH SHOWING VARIATION IN ACCURACY OF ORIGINAL RESERVE ESTIMATES OF GRADE PERCENT U_3O_8, CLASSED BY SIZE OF DEPOSIT

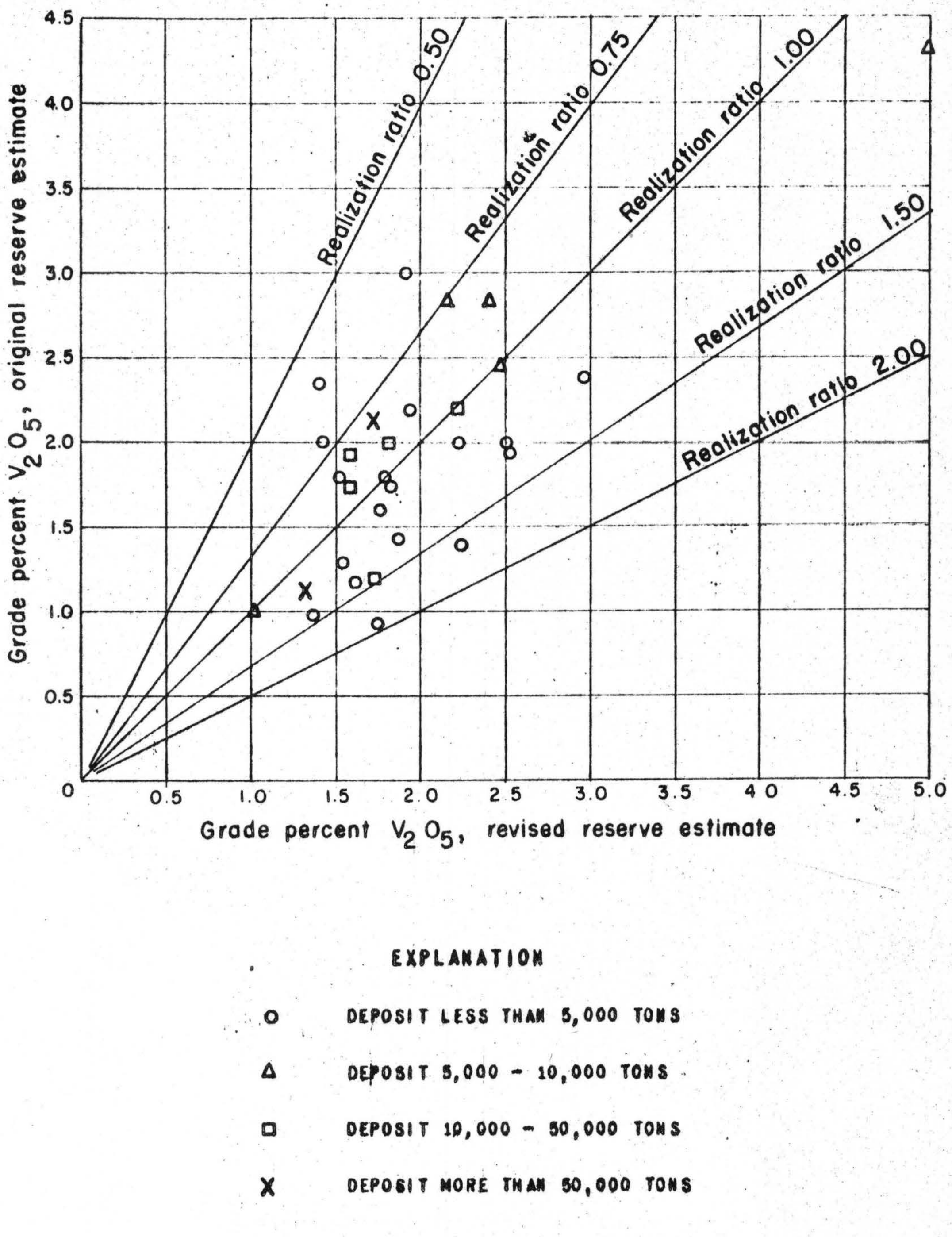


Figure 6. GRAPH SHOWING VARIATION IN ACCURACY OF ORIGINAL RESERVE ESTIMATES OF GRADE PERCENT V_2O_5, CLASSED BY SIZE OF DEPOSIT

On the basis of the size of the reserve block as originally estimated, deposits thought to be in the less than 5,000 ton class are underestimated in tonnage in about nine-tenths of the cases, and underestimated in both U_3O_8 and V_2O_5 grade in about two-thirds to three-quarters of the cases. In the 5,000-10,000 ton class, tonnage is underestimated in four-fifths, and both U_3O_8 and V_2O_5 grades are underestimated in three-fifths of the cases. In the 10,000-50,000 ton class tonnage is underestimated in two-fifths, U_3O_8 grade in three-fifths, and V_2O_5 grade in two-fifths of the cases. The relative amount of error represented by the average realization ratios for each class decreases from the less than 5,000 ton class to the 10,000-50,000 ton class.

Variation with density of drilling

An analysis was made of the accuracy of the original reserve estimates grouped by the density of drilling (table 3 and fig. 7). As is to be expected, denser drilling permitted more accurate reserve estimates. The density of drilling by the Geological Survey has been described briefly in the section on "Character of Data". Most of the 70 deposits drilled by the Geological Survey in the mineral belt were explored under a drilling plan (Type A) consisting of four drill holes at a spacing of 50 feet around the discovery hole, followed by other drill holes at a spacing of 100 feet (fig. 8). Other deposits were explored (Type B) by six drill holes at a spacing of 50 feet around the discovery hole, followed by other drill holes at the same spacing, with additional drilling at a spacing of 100 feet on some deposits (fig. 9).

Of the 30 cases studied, 25 fall into these two classes of density of drilling; there are 18 cases of Type B drilling to only 7 cases of Type A drilling. The Geological Survey has used three other drilling plans, one of which is illustrated in figure 10, but with only five deposits in these three classes, generalizations are not significant. In four of the seven cases where Type A drilling information was used, the revised reserve estimate for tonnage is more than twice the original, and the range is up to eight times the original. Where Type B information was available, the revised reserve estimate was more than twice the original in only 2 of the 18 cases, and the range was up to only three times. The data also show a general increase in accuracy for both U_3O_8 and V_2O_5 grades in the cases for which more information is available.

Table 3. Variation in accuracy of original reserve estimates, grouped by density of drilling and size of deposit (see also fig. 7)

Drilling plan and deposit class	No. of cases	Original reserve estimate: Short tons	Original: Pounds U_3O_8	Original: Pounds V_2O_5	Original: Percent U_3O_8	Original: Percent V_2O_5	Revised reserve estimate: Short tons	Revised: Pounds U_3O_8	Revised: Pounds V_2O_5	Revised: Percent U_3O_8	Revised: Percent V_2O_5	Realization ratios: Tonnage	Content U_3O_8	Content V_2O_5	Grade U_3O_8	Grade V_2O_5
Type A1/																
Less than 5,000 tons	5	11,400	43,700	441,900	0.19	1.94	31,100	176,100	1,131,600	0.28	1.82	2.75	4.05	2.55	1.45	0.95
5,000-10,000 tons	2	18,080	156,650	956,200	0.43	2.64	55,400	367,800	2,617,700	0.33	2.36	3.05	2.35	2.75	0.75	0.90
Totals and weighted averages	7	29,480	200,350	1,398,100	0.34	2.36	86,500	543,900	3,749,300	0.31	2.17	2.95	2.70	2.70	0.90	0.90
Type B2/																
Less than 5,000 tons	11	34,110	208,350	1,234,700	0.31	1.81	55,300	412,200	2,410,800	0.37	2.17	1.60	2.00	1.95	1.20	1.20
5,000-10,000 tons	3	24,080	186,700	1,254,200	0.39	2.60	24,900	328,600	1,443,200	0.66	2.90	1.05	1.75	1.15	1.70	1.10
10,000-50,000 tons	4	71,610	541,950	2,727,500	0.38	1.90	63,200	528,600	2,340,400	0.42	1.85	0.90	1.00	0.85	1.10	0.95
Totals and weighted averages	18	129,800	937,000	5,216,400	0.36	2.00	143,400	1,269,400	6,194,400	0.44	2.16	1.10	1.35	1.20	1.20	1.10
Type C3/																
Less than 5,000 tons	1	830	1,850	24,100	0.11	1.45	5,900	18,900	217,100	0.16	1.84	7.10	10.20	9.00	1.45	1.25
10,000-50,000 tons	1	20,000	120,000	700,000	0.30	1.75	13,000	75,400	405,600	0.29	1.56	0.65	0.65	0.60	0.95	0.90
Totals and weighted averages	2	20,830	121,850	724,100	0.29	1.74	18,900	94,300	622,700	0.25	1.65	0.90	0.75	0.85	0.85	0.95
Type D4/																
Less than 5,000 tons	1	4,400	24,850	114,400	0.28	1.30	11,600	69,600	352,600	0.30	1.52	2.65	2.80	3.10	1.05	1.15
More than 50,000 tons	1	71,500	529,100	3,074,500	0.37	2.15	72,200	375,400	2,454,800	0.26	1.70	1.00	0.70	0.80	0.70	0.80
Totals and weighted averages	2	75,900	553,950	3,188,900	0.37	1.86	83,800	445,000	2,807,400	0.27	1.68	1.10	0.80	0.90	0.75	0.90
Type E5/																
More than 50,000 tons	1	98,375	688,600	2,262,600	0.35	1.15	81,900	507,800	2,113,000	0.31	1.29	0.85	0.75	0.95	0.90	1.10
Totals and weighted averages	1	98,375	688,600	2,262,600	0.35	1.15	81,900	507,800	2,113,000	0.31	1.29	0.85	0.75	0.95	0.90	1.10

1/ One cycle of four drill holes around discovery hole, at 50-foot spacing; subsequent holes at 100-foot spacing.
2/ One or more cycles of six drill holes around discovery hole, at 50-foot spacing; subsequent holes at 100-foot spacing.
3/ One or more cycles of drill holes around discovery hole at 100-foot spacing; subsequent holes at 100-foot spacing.
4/ One or more cycles of drill holes around discovery hole at 100-foot spacing; subsequent holes at 150 to 200-foot spacing.
5/ Drill holes 50 to 100 feet apart, along lines 200 feet apart.

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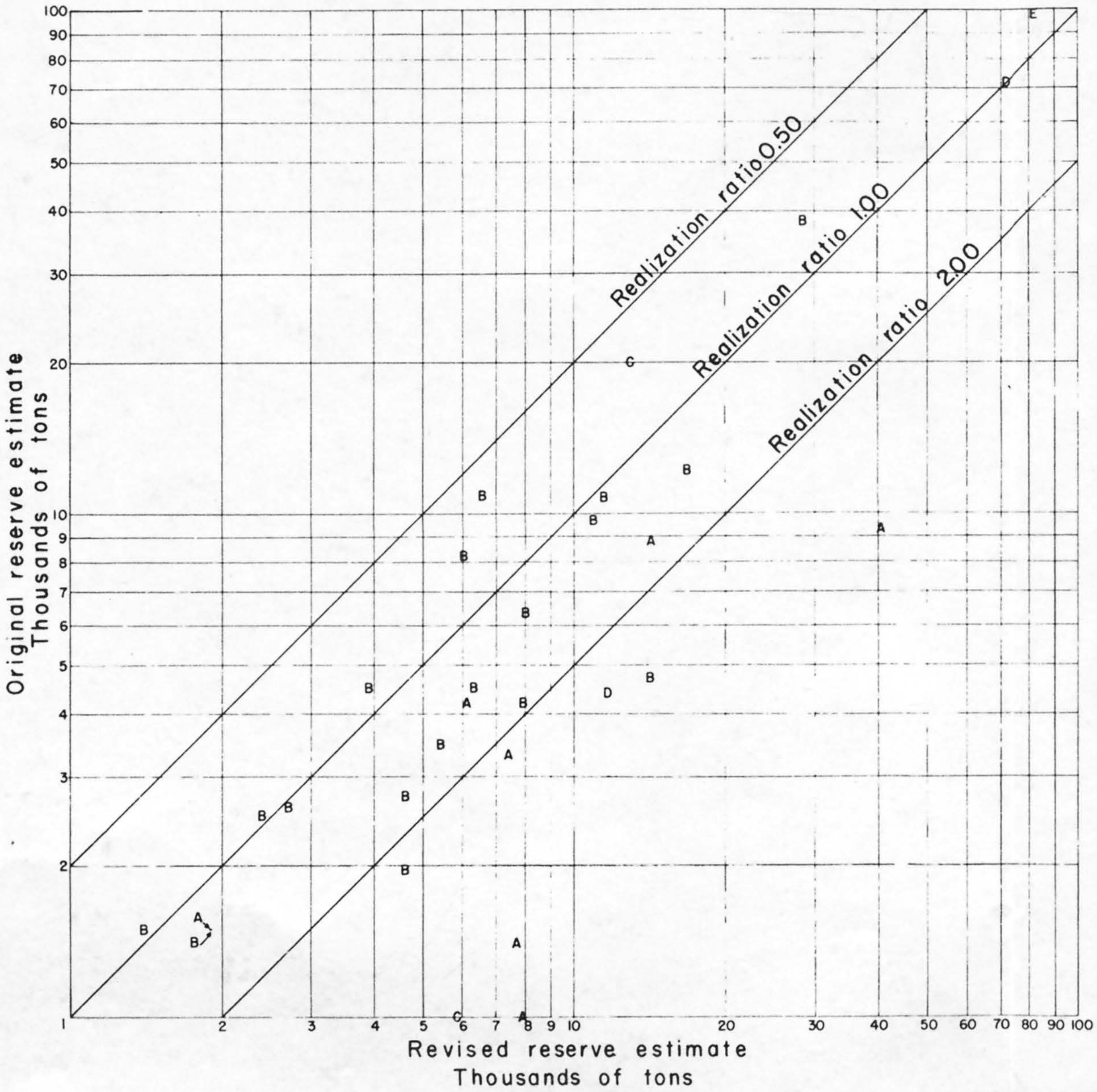

EXPLANATION
(DRILLING PLANS)

A TYPE A: ONE CYCLE OF FOUR DRILL HOLES AROUND DISCOVERY HOLE, AT 50-FOOT SPACING; SUBSEQUENT HOLES AT 100-FOOT SPACING

B TYPE B: ONE OR MORE CYCLES OF SIX DRILL HOLES AROUND DISCOVERY HOLE, AT 50-FOOT SPACING; SUBSEQUENT HOLES AT 100-FOOT SPACING

C TYPE C: ONE OR MORE CYCLES OF DRILL HOLES AROUND DISCOVERY HOLE AT 100-FOOT SPACING; SUBSEQUENT HOLES AT 100-FOOT SPACING

D TYPE D: ONE OR MORE CYCLES OF DRILL HOLES AROUND DISCOVERY HOLE AT 100-FOOT SPACING; SUBSEQUENT HOLES AT 150 TO 200-FOOT SPACING

E TYPE E: DRILL HOLES 50 TO 100 FEET APART, ALONG LINES 200 FEET APART

Figure 7. GRAPH SHOWING VARIATION IN ACCURACY OF ORIGINAL TONNAGE RESERVE ESTIMATES, FOR DEPOSITS CLASSED BY DENSITY OF DRILLING (See also table 3)

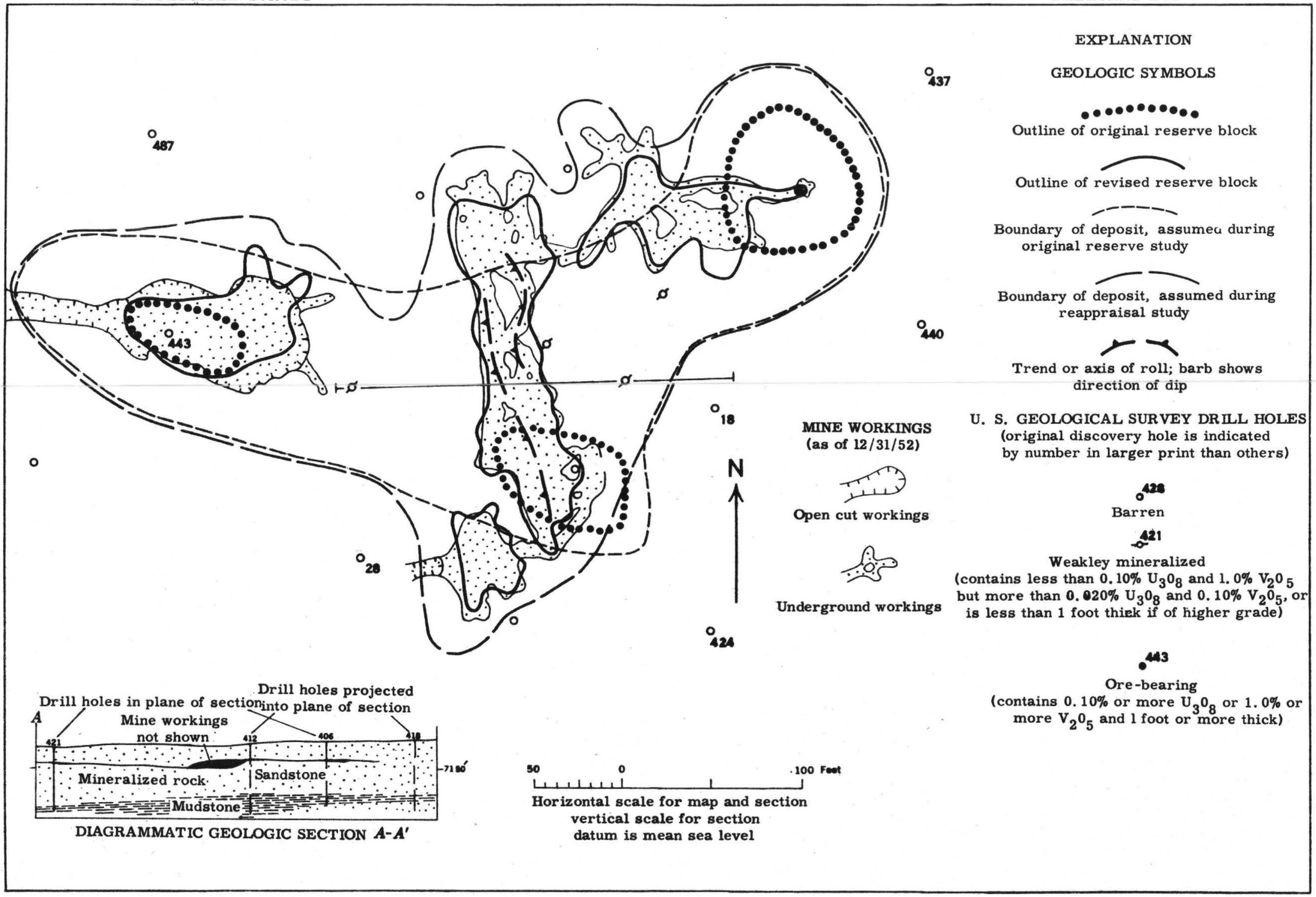

Figure 8. SKETCH MAP OF RESERVE BLOCK 20, CHARLES T. CLIAM GROUP, SHOWING LOCATION OF ORIGINAL AND REVISED RESERVE BLOCKS AND MINE WORKINGS

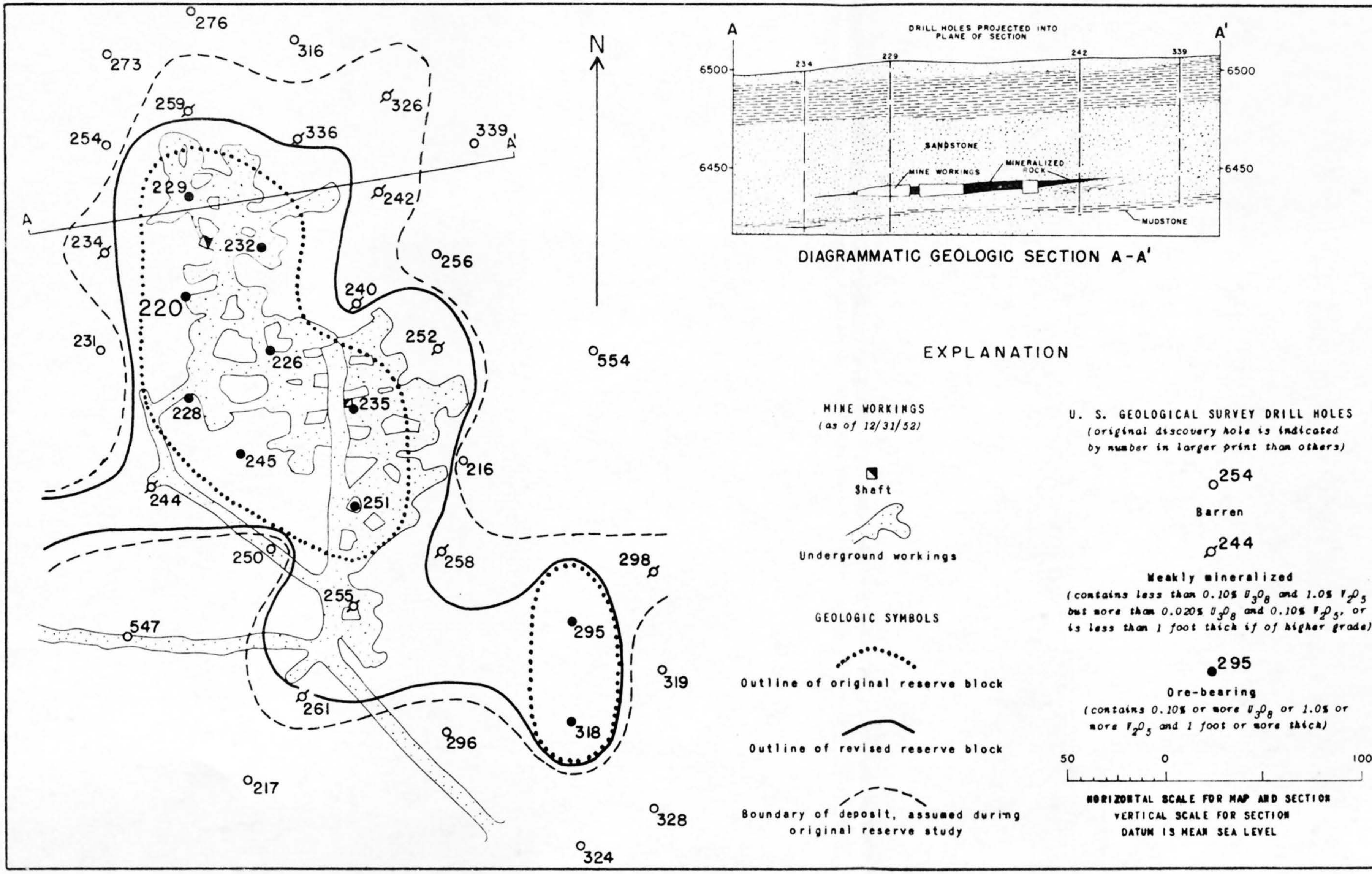

Figure 9. SKETCH MAP OF RESERVE BLOCK 13, CALAMITY CLAIM GROUP, SHOWING LOCATION OF ORIGINAL AND REVISED RESERVE BLOCKS AND MINE WORKINGS

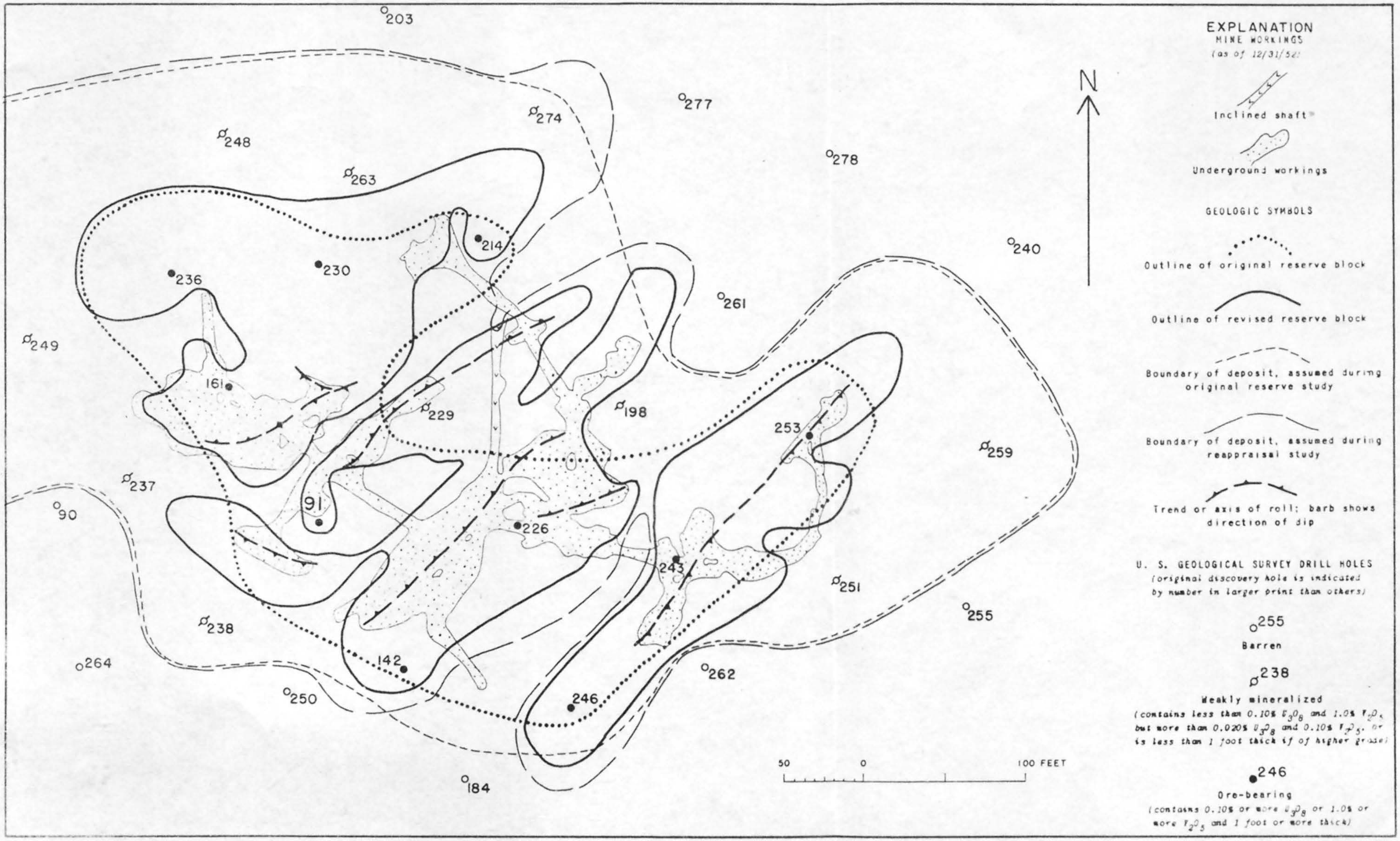

Figure 10. SKETCH MAP OF RESERVE BLOCK 1A, CLUB MESA CLAIM GROUP, SHOWING LOCATION OF ORIGINAL AND REVISED RESERVE BLOCKS AND MINE WORKINGS

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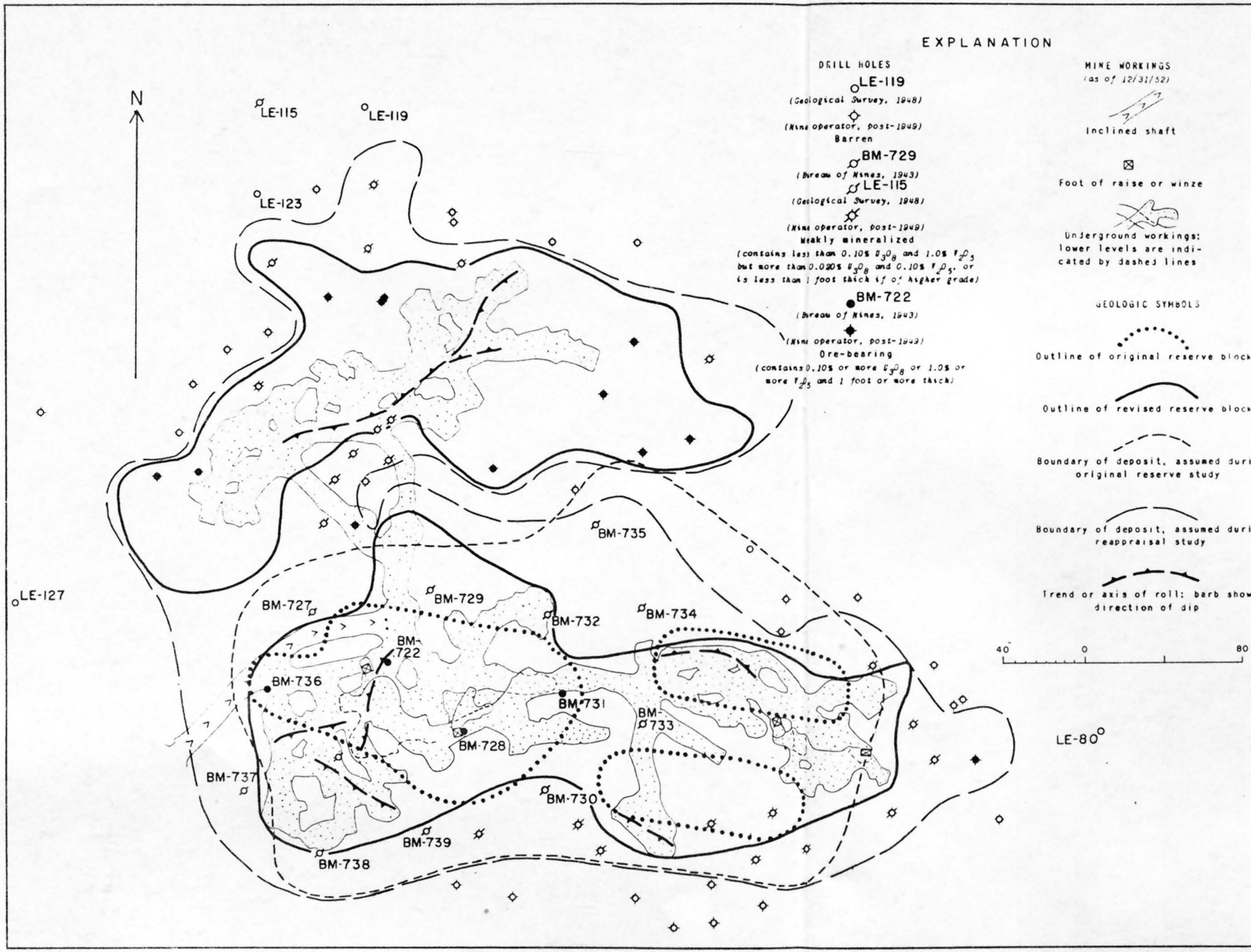

Figure 11. SKETCH MAP OF RESERVE BLOCK 15, LEGIN CLAIM GROUP, SHOWING LOCATION OF ORIGINAL AND REVISED RESERVE BLOCKS AND MINE WORKINGS

CAUSES OF INACCURACY

Both the original and the revised reserve estimates are subject to error. In general, the causes of error differ for the type of estimate, but one major cause of error is common to both—the restricted number of points of observation (sample points) on which the estimates are based.

Original reserve estimates

The density of sampling is the most important factor controlling the amount of error in the original reserve estimates. In general, the drilling is sufficient to indicate the approximate outline and extent of the ore deposit, but in specific cases, the ore bodies may extend between barren or weakly mineralized drill holes for a significant distance (fig. 8 and 11). The drill holes may not adequately sample or may not even penetrate the parts of the deposit that constitute the ore bodies (fig. 8).

The drill core samples, in addition, may not be representative of the average thickness of the ore body or of its average grade. Core loss in drilling may result in significant misinterpretations of the thickness of the mineralized rock. Also the more richly mineralized rock is generally softer and more friable and hence is more subject to grinding and disintegration. Core loss, therefore, is frequently concentrated in the more richly mineralized rock, so that the apparent grade of the sample is less than the true grade.

In most cases, the assumption that the deposits (and ore bodies) are uniformly tapering tabular layers, essentially parallel to the bedding of the host sandstone, is used in calculating the reserve (fig. 9). Other limiting conditions are also assumed; for example the edge of the deposit is assumed to be midway between a sample point in barren rock and a sample point in mineralized rock. Deviations in form, shape, and habit from these idealized conditions introduce errors in the reserve estimate (figs. 8 and 10).

Revised reserve estimates

The revised reserve estimates also have their basic source of error in the restricted number of points of observation. The influence of this distribution is less pronounced than in the case of the original estimate, as the prerequisite to the revised estimate is additional information. Additional drilling by the operator frequently outlines both the deposit and the ore bodies far better (fig. 11). The mine workings permit a more accurate assessment of the habits of the deposit, and the concentration and size of the ore bodies (fig. 9 and 10). In many cases, however, the thickness and grade data available from the operator's drilling are less reliable than data from the Geological Survey's drilling, because of difference in objectives, technique, and the usual lack of chemical assay data.

Major use is made of the production data in revising the estimate of tonnage and grade given in the original reserve estimate. Several opportunities for error in the revised estimate may result from the character of the production data. In many cases the production record cannot be broken down with sufficient reliability to permit the accurate assignment of production to individual deposits. In such cases, the production must be estimated for each deposit, or the deposits must be grouped and a combined depletion estimate for the group must be made. It is obvious that additional uncertainties are introduced in either case, both for tonnage and for grade. Such uncertainties, however, are thought to be small generally and certainly do not invalidate the overall picture presented here.

Nearly all the mine operators attempt to hold to a shipping grade above 0.20 percent U_3O_8. Although the grade cutoff used by the Geological Survey in its estimates is 0.10 percent U_3O_8 (the lowest grade that is being purchased by the AEC), the average grade of the reserves at this cutoff are generally above 0.20 percent U_3O_8. Thus the material mined and that for which reserves are estimated are comparable. In some mines this unofficial cutoff is 0.30 percent U_3O_8 grade of the mined rock, therefore, may be somewhat higher than the grade of the ore body figured at the 0.10 percent U_3O_8 cutoff. This fact has been taken into account in the revised grade estimate for the few deposits concerned.

One other factor affects the use of the production data--the dilution of ore by waste. The effect of this source of error is relatively minor, as the methods of reserve estimation used by the Geological Survey make allowance for a certain amount of dilution.

CONCLUSIONS AND RECOMMENDATIONS

The accuracy of the Geological Survey's estimates of total indicated and inferred reserves, for the 30 cases studies in the Uravan mineral belt, fall well within the defined limits of error for indicated reserve alone, and indeed fall almost entirely within the defined limits of error (20 percent) for measured reserves. The limits of error and the range in error are greatest for reserves on individual deposits, less for reserves on groups of deposits, and still less for reserves of districts. It is obvious that the inaccuracies involved are largely compensating, to the point of very little error if a sufficient number of deposits are considered.

The 30 cases considered in this study represent a fair sample of all deposits on which the Geological Survey has made reserve estimates. They include: 1) deposits ranging from slightly less than 1,000 tons of reserves to more than 50,000 tons; 2) deposits where all the information comes from drill-hole samples and deposits where a larger part of the information comes from extensive mine workings; and 3) deposits where the drill-hole samples come from close-spaced, medium-spaced, and relatively wide-spaced holes, or any combination of these. As such, the realization ratios determined for the total group of cases studied can be applied with reasonable confidence as correction factors to the total of the indicated and inferred reserves estimated for all the deposits discovered or explored by the Geological Survey. These realization ratios are about 1.15 for the tonnage of ore, 1.15 for the amount of contained U_3O_8, and 1.20 for the amount of contained V_2O_5. The original grade estimates are 0.35 percent U_3O_8 and 1.80 percent V_2O_5; the revised estimates are 0.35 percent U_3O_8 and 1.87 percent V_2O_5.

Correction factors cannot be applied to the individual reserve estimates. On a numerical basis, in about two out of every three cases the tonnage of reserves was underestimated; the range of the realization ratios is from about 1.0 to 8.0. However, in two-thirds of the cases where the tonnage of reserves was underestimated, the range of the realization ratios is from 1.0 to only 2.0. The range of the realization ratios for overestimated reserves is from 0.6 to nearly 1.0. Thus any single correction factor designed to reduce the error of underestimate will increase the error of overestimate in one of every three cases. The range and distribution of error for the estimates of grade and amount of U_3O_8 and V_2O_5 are similar to those for total tonnage of ore, and these errors, as well, cannot be remedied by applying single correction factors to the individual deposits.

The realization ratios for each group of deposits studied can be applied with a measure of certainty to the total indicated and inferred reserves of all the deposits in that group. The reliability of the ratios increases with the number of cases used in determining the ratios. Thus for the Charles T., Legin, and Calamity claim groups the ratios are more reliable than those for the other claim groups (table 1 and figs. 2, 3, and 4). Still more reliance can be placed on the realization ratio for the reserves compiled by districts. The Uravan district is represented by only three deposits at the Club group, and is, therefore, an exception to this generalization.

One of the Geological Survey's major objectives in the exploration work is the appraisal of the uranium-vanadium resources of the Morrison formation on the Colorado Plateau. The study indicates that the accuracy of the appraisal of the total known reserves is good. As such, the methods of exploration and estimation being used are adequate to achieve the desired objectives.

Within the framework of the exploration done by the Geological Survey, increased accuracy in the estimates can only be obtained by increased knowledge of the geologic habits of the deposits, and this is largely dependent on an increase in the amount of information available at the individual deposit level--supplied by additional and more closely spaced drilling. So long as the major interest is in the overall appraisal, the present methods are adequate. Increased accuracy on individual deposits will increase the accuracy for each succeeding grouping of deposits, but the significance of this increased accuracy decreases for each succeeding grouping as the amount of error involved under the present methods also decreases markedly.

One recommendation can be made, however. The last two paragraphs of the section on reserves in the appendix describe the method of calculation used where thin layers of waste or low-grade mineralized rock are interbedded with layers of ore. Such layers of nonore rock have been excluded from the calculation if they are 1 foot or more thick. In actual mining practice at the present time, these layers of waste or weakly mineralized rock, as much as 2 feet thick, are blasted and shipped with the ore, if the ore layers are at least 6 inches thick, and the overall average grade of the rock is at least 0.20 percent U_3O_8. If the individual ore layers are 2 feet or more thick, the ore and nonore rock are blasted separately, and the nonore rock goes to the dump.

Therefore, it is recommended that the calculations be amended. The present practice should be continued for nonore layers less than 1 foot thick, and in addition, nonore layers less than 2 feet thick should be included if both the enclosing ore layers are from 6 inches to 2 feet thick, and the overall weighted average grade of the three units is more than 0.20 percent U_3O_8 and/or 2.0 percent V_2O_5. This will tend to increase the tonnage of reserves, and to decrease slightly the average grade. The effect on the accuracy of the reserve estimate is dependent on the individual deposit, but the type of material considered to be a reserve will more closely approach the type of material shipped to the mill.

APPENDIX--RESERVE DEFINITIONS AND METHODS OF CALCULATION

Reserves

The general philosophy and the rules for calculation of reserves have been described by Stager (1949), Bush (1950), and others. (See Unpublished reports.) Much of the following discussion is quoted from these sources.

The terms "indicated" and "inferred" reserves are applied to the uranium- and vanadium-bearing material in the deposits that are known from exposures in natural outcrops, mine workings, or drill holes. These reserves are subdivided by thickness and grade cutoffs and the methods used in calculating them is explained below.

Although reserves are not classified according to their availability for mining, consideration is given to current mining and milling practices in selecting the higher grade and thickness cutoffs. This is done to obtain figures for a category of reserves that will express as nearly as possible the tonnage and grade of the material that actually might be mined from these deposits under current conditions.

Both chemical data from assay of drill cores and gamma-ray data from probing of drill holes are used in classification of the ore-bearing rock as to thickness and grade.

Definitions

Known reserves are classed as indicated and inferred. Owing to the erratic variations in thickness and grade of carnotite ore within short distances, and the general lack of abundant sample data for individual reserve blocks, the amount of reserves that can be calculated within a small limit of error, and thus can be classed as "measured", is so small as to be nearly negligible. Therefore, reserves that might be classed as measured are included with indicated reserves.

Indicated reserves are those for which the grade is computed from drill-hole samples, exposures in mine workings and natural out-crops, gamma-ray logs, and production data, and for which the tonnage is computed by projection for a reasonable distance on geologic evidence from points of exposure (drill holes, mine workings, and natural out-crops). Inferred reserves are those for which quantitative estimates are based largely on broad knowledge of the geologic character of the deposits, and for which there are few, if any, samples or measurements.

Thickness cutoff

Although mining practices vary from place to place in the region as well as with individual operators, under current conditions most ore bodies of average grade are being mined to where they pinch to a layer about 1 foot thick. Reserves, therefore, are calculated with a thickness cutoff of 1 foot. Layers of material less than 1 foot thick are mined in places if the grade is high. The tonnage of minable material less than 1 foot thick is small with respect to the total reserves, and for that reason reserves less than 1 foot thick are not calculated.

Grade cutoffs

The deposits contain two metals of economic value, uranium and vanadium. Within the deposits, the two metals are so erratically distributed that a single sample, such as obtained from a drill hole, is not necessarily representative of the grade or metal ratio of the material near the point sampled. Knowing this by experience, the miner will drive to a drill hole that shows a good value in vanadium even though the uranium content of the sample might be negligible. Thus the material in the vicinity of this sample must be classed as a reserve, even though the sample shows a value for only one metal. Under current price schedules, the vanadium content of the ore represents an appreciable part of the ore's market value. Both metals, therefore, must be considered in reserve appraisals and in selecting grade cutoffs.

Reserves 1 foot or more thick are classified by two grade cutoffs. The higher cutoff used--0.10 percent U_3O_8 or 1.0 percent V_2O_5--corresponds to the Atomic Energy Commission purchase cutoff for uranium and the mill cutoff for vanadium used by the major processing companies. Reserves also are figured on a lower cutoff--0.05 percent U_3O_8 or 0.50 percent V_2O_5--on the possibility that conditions in the future might demand or permit the mills to accept low-grade ore.

Calculation of tonnage

The method used for calculating the volume, and hence the tonnage, of reserve unit 1 foot or more thick differs with the geologic interpretation of the form of the deposit. Some deposits are roughly tabular or lenticular, so that projections can reasonably be made between drill holes, and the average thickness of the drill-hole samples that can be combined within a specified grade class can be assumed to be the average thickness of the reserve unit. Other deposits consist of small bodies of ore of minable thickness, connected by layers of mineralized sandstone that are too thin to mine. Reserves are estimated by assuming that each drill hole in ore indicates a single minable body that is comparable in tonnage to the average size of the ore bodies that have been mined nearby, or that the deposit contains a comparable tonnage per unit area to that of a deposit that has been mined nearby.

The tonnage of indicated reserves is computed by projection for a reasonable distance on geologic evidence. The distance that indicated reserves are projected, both between and beyond drill-holes and other sample points varies with the geologic habits of the deposits. Reserves are classed as inferred rather than indicated if they are projected farther than the limits chosen for the indicated class.

Although a single drill hole in ore obviously permits the designation of some tonnage of indicated reserves, there is no reasonable basis for projecting an indicated reserve block more than a few feet from a single hole. Rather than calculate such an indicated reserve block separately, or assign a small arbitrarily selected amount of indicated reserves to a single hole, the reserve block is projected to its assumed limits and the ore calculated and classed as inferred.

A constant of 14 cubic feet per ton is used to calculate tonnage.

Calculation of grade

The grade of indicated reserves in a single block is calculated by weighting the assay grades by lengths of the samples. If the deposit has been mined in part, the grade of the ore produced is also considered in establishing the grade of the adjoining reserve block. In reserve blocks containing only one or two drill holes, however, if the core assays are appreciably higher than the average grade of the ore mined nearby, it may be assumed that the drill penetrated abnormally high-grade parts of the body, and an estimated grade may be assigned. The grade of the samples in an inferred block is considered but is used in conjunction with the grade of production from nearby mines, or from the area as a whole.

Strict grade cutoffs are used in calculating reserves 1 foot or more thick. Except as noted in the following paragraph, no material belonging to a class with a lower grade cutoff is included with material of a higher cutoff class, even though the weighted average grade of the whole is above the cutoff grade of the higher class.

In mining, layers of waste or of low-grade mineralized material, less than 1 foot thick, would probably be blasted with the enclosing layers of ore. Some of this material might be picked out by hand, but most of it would go to the mill with the ore. If the aggregate thickness of this interbedded ore and waste is 1 foot or less thick, it is included in calculating reserves, thereby increasing the thickness of ore, but decreasing the grade proportionately. This ore is classed according to the grade of the weighted average. If the waste is more than 1 foot thick, it probably would be blasted separately from the ore layers in mining, and thus ore layers more than 1 foot apart, with waste or low-grade material between, are calculated as separate ore bodies.

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