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By DORIS BLACKMAN WEIR

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GEOLOGIC GUIDES TO PROSPECTING FOR CARNOTITE DEPOSITS ON COLORADO PLATEAU

By Doris Blackman Weir

ABSTRACT

This report describes the geologic features that can be used to appraise the favorableness of ground in guiding diamond-drill exploration for carnotite deposits in the Upper Jurassic Morrison formation on the Colorado Plateau. It is based on a statistical study of the geologic logs of about 2,500 holes drilled by the Geological Survey. The most useful features consist of the thickness and color of the ore-bearing sandstone, the altered mudstone associated with the ore-bearing sandstone, and the abundance of carbonaceous material in the sandstone. Although each feature can be used alone to appraise the favorableness of the ground, an appraisal based on all of them together is more useful. A method of expressing this in numerical values is suggested.

The results obtained by the Geological Survey using these geologic guides appear to be at least twice as favorable as the drilling results obtained with little or no geologic guidance.

INTRODUCTION

The relations of certain geologic features to carnotite deposits in the Colorado Plateau region have long been recognized by miners and geologists. Not until 1947, however, when the Geological Survey began a large-scale program of diamond-drill exploration on behalf of the Atomic Energy Commission, were these features used extensively as guides in prospecting for carnotite. This report summarizes the results of a study of geologic logs of about 2,500 holes drilled by the Geological Survey in several areas in southwestern Colorado. All geologic features observable in drill core, which might be of value in guiding exploration, were recorded systematically and appraised as guides. It is hoped that the geologic relations discussed here will be of practical value to private industry in prospecting for carnotite ore, and that the recognition and study of these guides will result in the development of more useful application and perhaps additional guides.

The geologic guides to be described in this paper—those that appear to be most valuable in recognizing ground favorable for ore—are the thickness and color of the ore-bearing sandstone, the altered mudstone associated with the sandstone, and the presence of abundant carbonaceous material within the ore-bearing sandstone.

The writer wishes to express her appreciation to R. P. Fischer, L. S. Hilpert, and L. B. Riley, of the Geological Survey, for guidance in the study.

GEOLOGY OF ORE DEPOSITS

The carnotite deposits have a wide distribution in southwestern Colorado and the adjoining parts of Utah, Arizona, and New Mexico, where they extend over an area of at least 40,000 sq mi (fig. 6). Nearly

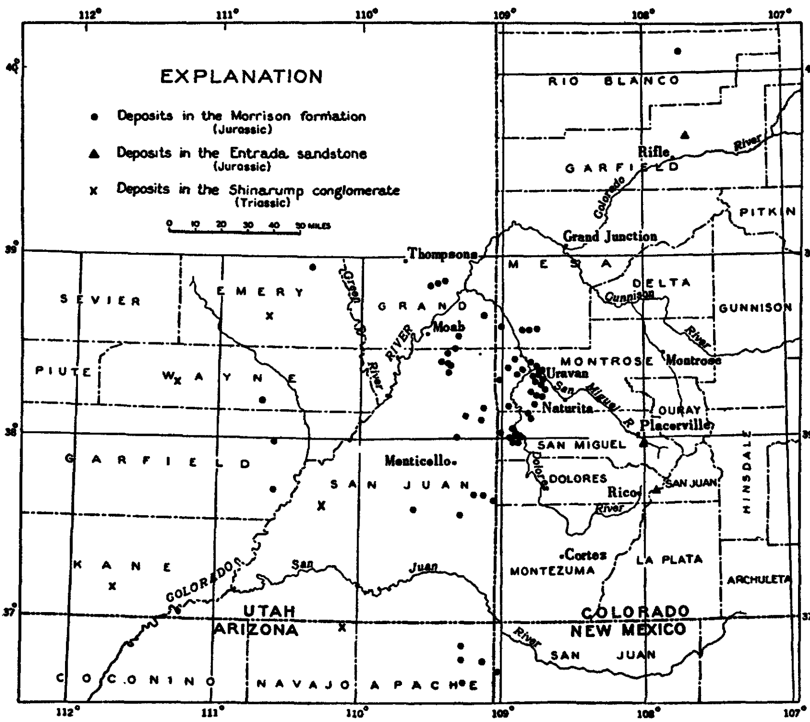

FIGURE 6.—Index map of part of Colorado, Utah, Arizona, and New Mexico showing the general distribution of carnotite-bearing deposits.

all the known deposits of economic importance are restricted to the Shinarump formation of Triassic age and the Entrada and Morrison formations of Jurassic age. Most of the deposits occur in the Salt Wash sandstone member of the Morrison formation, and in many mining districts the deposits are found in one stratigraphic zone within the Salt Wash. This zone consists of sandstone lenses interbedded with some mudstone. The sandstone in this zone ranges in thickness from slightly less than 20 ft to slightly more than 80 ft, averaging about 50 ft. This sandstone is referred to in this report as the "ore-bearing sandstone."

The ore mainly impregnates sandstone, averaging about 0.25 percent U_3O_8 and 2 percent V_2O_5, but some of the fossil plant material in the ore-bearing beds is richly mineralized. The ore bodies are irregular tabular layers, at most only a few feet thick, and generally lie parallel to the sandstone bedding, but do not follow the beds in detail. They range in size from those containing only a few tons of ore to those containing many thousand tons; most of the deposits contain only a few hundred tons or less. Although the deposits have a spotty distribution, most of them are clustered in relatively small, vaguely defined areas. The larger areas between these clusters contain only a few scattered deposits, most of which are small.

The ultimate source, or sources, of the metals in the ore have not been determined. The distribution of the deposits and the habits of the ore, however, suggest an origin that is due to precipitation from ground-water solutions shortly after accumulation of the sands. Localization probably resulted from slight changes in the chemical composition of the solutions, perhaps in the environment of decaying organic material.

Readers desiring a more complete description of the geology of these deposits are referred to Coffin (1921), Fischer (1942, 1950), and Fischer and others (1951).

GEOLOGICAL SURVEY EXPLORATION

The exploration work of the Geological Survey is done in three general stages. During the first stage, holes are drilled at a wide spacing, usually about 1,000 ft apart, for geologic information. From this drilling, it is possible to recognize favorable ground that may contain one or more clusters of deposits. During the second stage, the favorable ground is drilled with holes at a moderate spacing, usually 100 to 300 ft apart, to find ore deposits. In the third stage, holes are drilled at a close spacing, about 50 to 100 ft apart, to extend and outline any deposits discovered in the earlier drilling. The geologic features that serve as guides are particularly useful during the first and second stages, as these features provide larger targets for drilling than do the ore deposits themselves.

GUIDES TO PROSPECTING

The geologic guides described below are now being used by the Geological Survey in its exploratory drilling program. They are discussed in terms of their application to subsurface exploration, though all of them are useful in surface prospecting. These guides vary in importance according to the size of the drilling target that they provide, and are described in that order of importance, beginning with the one that provides the largest target.

Accompanying the description of each geologic guide is a graph showing the relation of that guide to ore. In order that enough measurements may be included for the graphs to have statistical meaning, each graph is a composite of several of the larger areas drilled by the Survey. These graphs show the average amount (arithmetic mean) of each feature cut by holes in all of the areas studied. The drill holes are grouped into five zones according to their position relative to ore deposits. The first zone includes all holes that cut mineralized rock, and the remaining four include, respectively, the holes in the zone 0 to 100 ft outward, 100 to 200 ft outward, 200 to 300 ft outward, and 300 to 400 ft outward from mineralized rock. A limit of 400 ft outward is used because drill-hole information beyond 400 ft from the ore deposits is generally insufficient for statistical purposes. It is believed that if a larger number of holes had been drilled in zones farther from mineralized rock, and if data from these zones had been added to the graphs, they would continue to show a decrease in favorableness as distance from mineralized rock increases. It is not the averages themselves on these graphs that are significant, as they may vary from one drilling area to another, but rather the relations between the averages. Likewise, minor deviations from the general slope of these graphs probably represent incomplete statistical data rather than geologically significant variations.

THICKNESS OF THE ORE-BEARING SANDSTONE

In the Morrison formation the sandstone beds containing the carnotite deposits are lenticular, ranging in thickness from slightly less than 20 ft to slightly more than 80 ft. In southwestern Colorado, no large ore deposit has been found, by Survey drilling, in sandstone that had an original thickness (prior to recent erosion) of less than about 40 ft. This minimum thickness figure is a reliable guide in wide-spaced drilling. In addition, most of the ore bodies are in or near the thicker, central parts of the sandstone lenses; these thicker parts can be recognized in cross-sections through diamond-drill holes. Not all thick sandstone is favorable, however. The spatial relations of ore deposits to differences in sandstone thickness are apparent in figure 7.

COLOR OF THE ORE-BEARING SANDSTONE

The sandstone enclosing most of the ore bodies is dominantly pale to light yellow brown and speckled with limonite stain. Generally this favorable color and staining extend several hundred feet beyond ore deposits. Farther away from deposits, the sandstone in many places is reddish brown. Sandstone with a reddish cast may contain a few ore deposits, but most of them are small, and generally a pronounced red color is indicative of unfavorable ground. These relations are illustrated by figure 8, which shows that the average percentage of ore-bearing sandstone with a reddish cast increases outward from the ore.

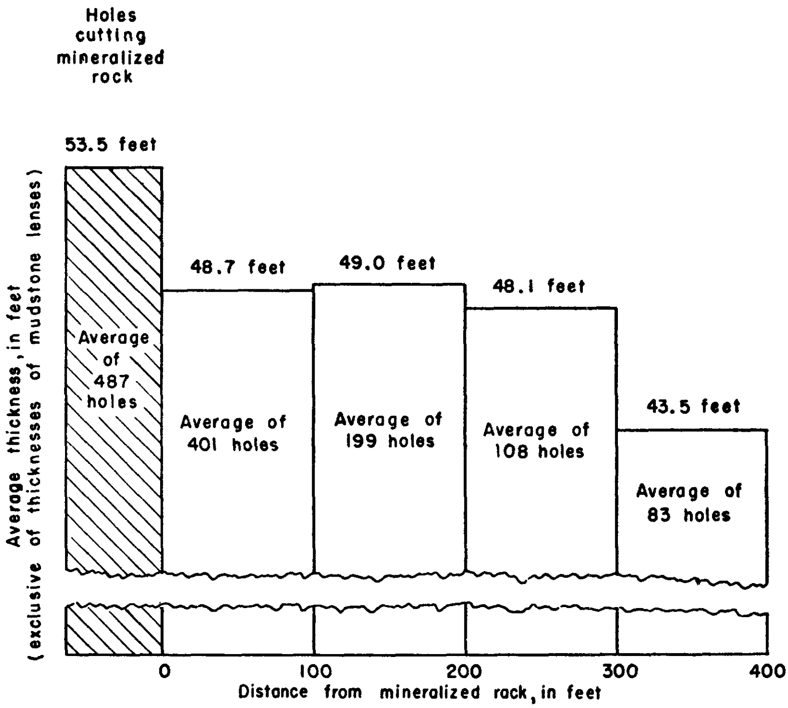

FIGURE 7.—Average thickness of ore-bearing sandstone, in zones coextensive with and outward from ore deposits (composite of five drilled areas).

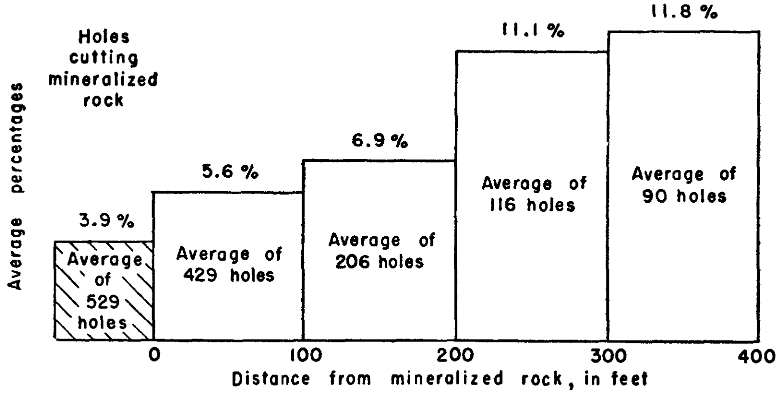

FIGURE 8.—Average percentage of ore-bearing sandstone with a reddish cast, in zones coextensive with and outward from ore deposits (composite of six drilled areas).

ALTERED MUDSTONE ASSOCIATED WITH THE ORE-BEARING SANDSTONE

The ore-bearing sandstone is interbedded with mudstone, and it also contains thin lenses of mudstone and mudstone-pebble conglomerate. This mudstone is normally red, but near ore deposits the mudstone within the sandstone and the mudstone immediately beneath the ore-bearing sandstone have been altered to gray. A preliminary study of the red and gray mudstone has been made by Weeks (1951).

Figure 9 shows the character of a typical ore body and its relationship to the enclosing sandstone and associated mudstone. Near ore, the gray mudstone beneath the ore-bearing sandstone commonly is as much as several feet thick, as shown in this cross section. The thickness of gray mudstone decreases laterally, but some of it usually

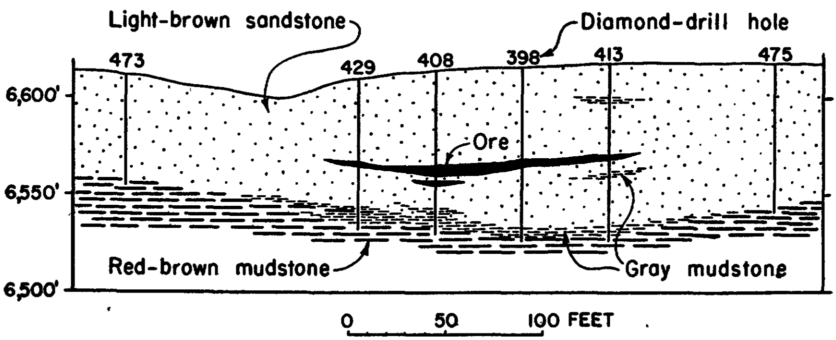

FIGURE 9.—Geologic section through diamond-drill holes, Calamity group of claims, Mesa County, Colo.

extends a few hundred feet outward from the deposits. Figure 10 shows the average thicknesses of gray mudstone immediately beneath the ore-bearing sandstone, in zones coextensive with and outward from ore deposits.

The percentage of gray mudstone relative to the total amount of mudstone within the ore-bearing sandstone is also a useful guide, though it is more difficult to measure quantitatively. In the present study, because of the necessity for a numerical comparison of geologic guides, only measurable units of mudstone within the sandstone (units 0.1 ft or more thick) have been considered. Because units of this thickness are not cut by every drill hole in a given area, some holes have been excluded from the calculations of average percentage of gray mudstone relative to the total mudstone, as shown in figure 11. A sufficient number of holes remains, however, to illustrate clearly the relation of color of mudstone to ore.

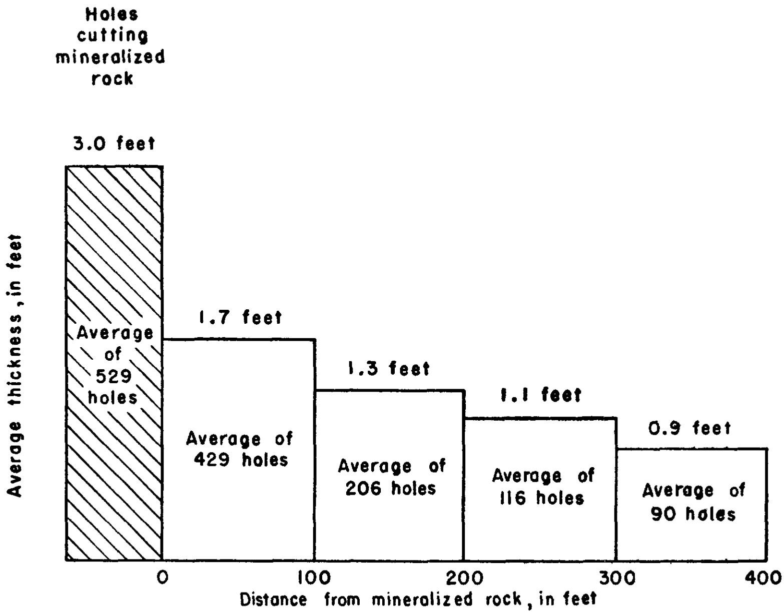

FIGURE 10.—Average thickness of gray mudstone immediately beneath the ore-bearing sandstone, in zones coextensive with and outward from ore deposits (composite of six drilled areas).

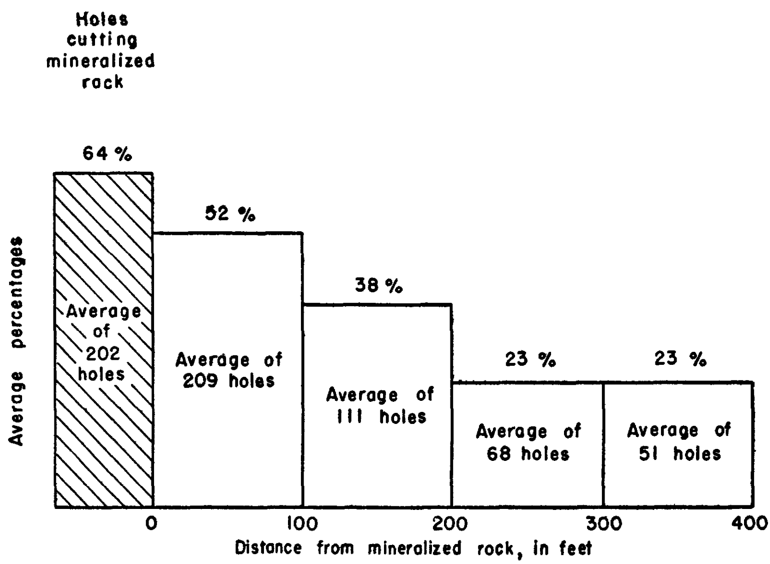

FIGURE 11.—Average percentage of gray mudstone relative to the total mudstone within the ore-bearing sandstone, in zones coextensive with and outward from ore deposits (composite of six drilled areas).

ABUNDANCE OF CARBONACEOUS MATERIAL WITHIN THE ORE-BEARING SANDSTONE

Carbonized plant remains, consisting of fossil logs, branches, leaf-like material, and unidentifiable fragments, are common in the ore-bearing sandstone. A close relationship between carnotite ore and these remains has long been recognized, for some of the remains have been richly replaced by ore minerals. As not all of the remains have

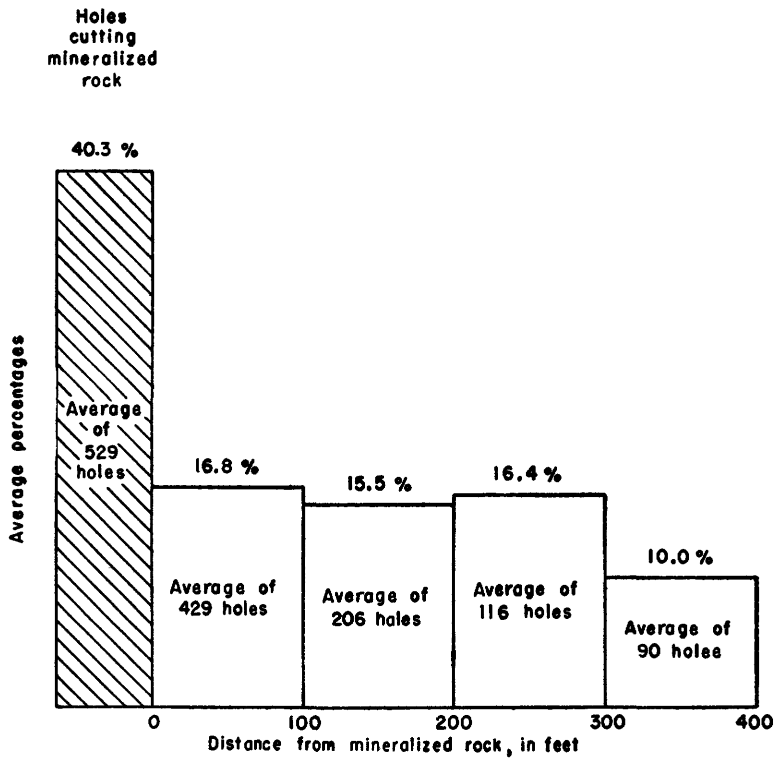

FIGURE 12.—Average percentage of drill holes cutting abundant carbonaceous material, in zones coextensive with and outward from ore deposits (composite of six drilled areas).

been mineralized, however, and as the plant materials—particularly the logs—are not uniformly distributed through the sandstone, either horizontally or vertically, the significance of the observed relationship between carnotite ore and plant remains is difficult to evaluate. This relationship, therefore, has limited application in exploration. Figure 12 shows, however, that abundant carbonized material is more common in holes cutting mineralized rock, and in holes near ore deposits, than in holes several hundred feet away from ore deposits. Possible traces of carbonized material have been ignored in this study, because of the limitations of observation in drill core and the possibility of misidentification of minute amounts of material.

Field relations suggest that ore deposits have been localized in the vicinity of abundant carbonaceous material, and the relations shown in figure 12 can be interpreted to mean the same thing. In diamond-drill exploration, abundant carbonaceous material can be interpreted to indicate favorable ground, but because of the erratic distribution of plant remains, the lack of abundant carbonaceous material in a single drill hole does not in itself mean unfavorable ground.

NUMERICAL EVALUATION OF GEOLOGIC GUIDES

Each of the geologic guides described above is useful individually, but an appraisal based on all of them, expressed in numerical terms, is more valuable than is the use of any one alone. In order to test the reliability of such an appraisal, the following method was applied to one area (Calamity group) after drilling by the Geological Survey was completed. Modifications of this method are now being applied in the appraisal of other areas.

Each drill hole in the area was rated numerically according to the following scheme:

Thickness of ore-bearing sandstone (exclusive of mudstone lenses)

Rating:	Thickness (feet)	Rating:	Thickness (feet)
8	41 or more	2	11–20
6	31–40	0	10 or less
4	21–30		

Color of ore-bearing sandstone

Rating:	Percentage of sandstone with a reddish cast	Rating:	Percentage of sandstone with a reddish cast
8	0	2	31–60
6	1–15	0	More than 60
4	16–30		

Thickness of gray mudstone at base of ore-bearing sandstone

Rating:	Thickness (feet)	Rating:	Thickness (feet)
8	More than 4.0	2	1.1–2.0
6	3.1–4.0	0	1.0 or less
4	2.1–3.0		

Color of mudstone (units 0.1 ft or more thick) within the ore-bearing sandstone

Rating:	Percentage of total mudstone that is gray	Rating:	Percentage of total mudstone that is gray
8	100–85	2	39–10
6	84–70	0	Less than 10
4	69–40		

Carbonaceous material within the ore-bearing sandstone

Rating:

4 .... Abundant.

0 .... Sparse or absent.

It will be noted from the above table that a maximum rating of 8 is assigned to each of the first four features, but that a maximum rating of 4 is assigned to carbonaceous material, owing to its erratic distribution and the fact that a quantitative measurement of this feature is more difficult than for the other features.

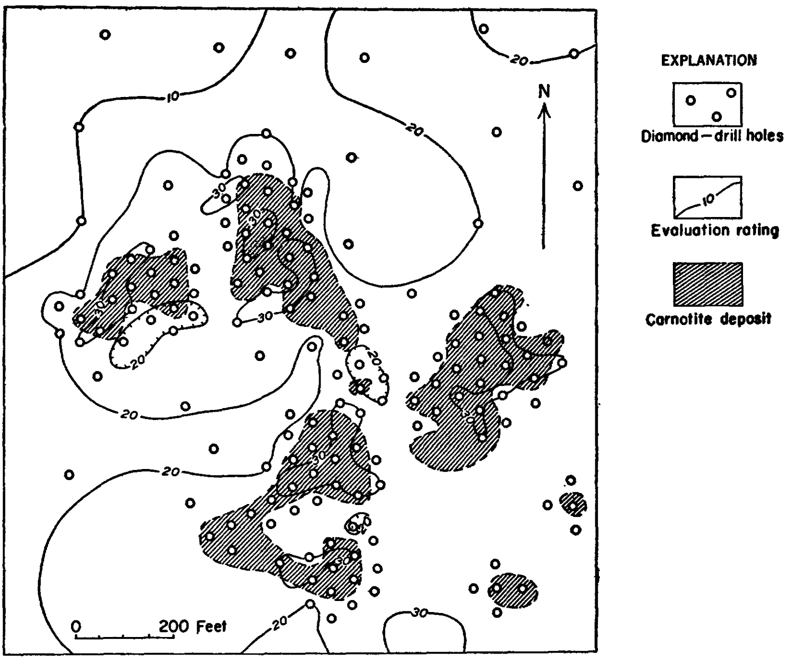

FIGURE 13.—Map showing the relations of numerical evaluation ratings and carnotite deposits on part of Calamity Mesa, Mesa County, Colo.

To determine an evaluation rating for each drill hole, the numerical values given each of the features cut by that hole are totalled. In order to compensate the rating for holes that do not cut mudstone units 0.1 ft or more thick, and thus are assigned ratings for only four features rather than five, the total ratings for these holes are multiplied by 1.29. In this manner, a range of zero to 36 is obtained (or 36.12 for those holes that are rated on the basis of four features).

On the basis of drilling on the Calamity group of claims, Mesa County, Colo., the critical point on this evaluation scale is approximately 20; no large ore deposits occur in ground given a lower rating. Ground that has a rating of less than 15 is essentially barren. Ratings of 30 or more generally occur in the centers of the deposits. Figure 13 shows these relations in part of the area.

Figure 14 shows graphically the relation of numerical values of favorableness to distance from ore deposits in the Calamity group of claims. Forty-two ore bodies, including all those drilled by the Geological Survey in this area, are included. It is believed that no importance should be attached to the slight upward trend of the averages in the zone 300–400 ft outward from ore. The trend of the averages is downward, outward from ore; if more data were available from the 300–400 ft zone, as well as from zones farther

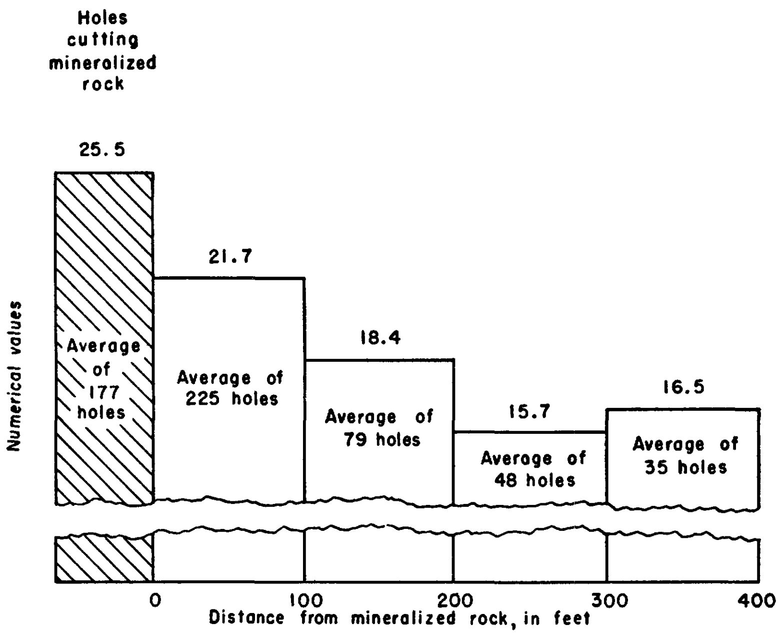

FIGURE 14.—Average numerical values of favorableness, in zones coextensive with and outward from ore deposits, Calamity group of claims, Mesa County, Colo.

outward from ore, they would show a continued downward trend, although less steep.

The significance of these geologic criteria of favorable ground is essentially the same in all the areas drilled by the Geological Survey on the Colorado Plateau. They are being followed in all stages of drilling—wide-spaced as well as moderate- and close-spaced.

COMPARISON OF RESULTS OBTAINED FROM DRILLING WITH AND WITHOUT GEOLOGIC GUIDANCE

Proof of the value of using geologic guides in exploration drilling lies in the results. To demonstrate this value, in order to encourage the practice of using geologic guidance, an attempt has been made to compare the results obtained by the Geological Survey's drilling using geologic features as guides, with the drilling that had been done previously by private interests using little or no geologic guidance. Unfortunately, for two reasons, it is not possible to express these results strictly on a comparable basis—first, security restrictions prevent giving actual figures of results, and second, the two drilling operations differ in character.

Nearly all of the private drilling was near known deposits in ground that would be generally classed as favorable because of the proximity of ore. Thus, there should be a better chance of any single drill hole cutting ore in this type of drilling than in exploration away from known deposits, such as has been done by the Geological Survey. Furthermore, nearly all of the private drilling was in shallow ground, perhaps averaging 50 to 75 ft in depth, whereas the Geological Survey drilling has been in deeper ground averaging approximately 135 ft in depth. On the other hand, the holes drilled by private industry were mostly on a close spacing to develop deposits for mining, and for this reason more holes were put in a single deposit than is normally drilled in a deposit found by the Geological Survey.

If consideration is given to the much greater depth of Survey drilling, and to the higher risk of exploring ground away from known deposits, even though fewer holes are drilled in a single deposit, the results of Survey exploration using geologic guidance systematically are more than twice as favorable as the results obtained by private industry using little or no geologic guidance.

SUMMARY AND CONCLUSIONS

Geologic logs of about 2,500 holes drilled by the Geological Survey in the Morrison formation in southwestern Colorado were studied to appraise the value of certain geologic features as guides to exploration for carnotite deposits. On the basis of this study, the following conclusions are made:

1. Most ore deposits are in or near the thicker, central parts of sandstone lenses, and in general the thickness of the sandstone decreases away from ore deposits. Sandstone that is less than 40 ft thick is generally not favorable for large ore bodies.
2. Sandstone in the vicinity of ore deposits is colored light brown, but an increasing proportion of sandstone away from ore deposits has a reddish color, which is indicative of unfavorable ground.
3. Near ore deposits the mudstone in the ore-bearing sandstone and immediately below it has been altered from red to gray. The amount of altered mudstone decreases outward from ore deposits.
4. Sandstone in the immediate vicinity of ore deposits contains more carbonized plant fossils than do the same beds away from ore deposits, suggesting that ore deposits are localized in the vicinity of abundant carbonaceous material.

Each of these features is useful individually in guiding exploration, but a combination of all of them, expressed in terms of a numerical rating, is even more useful. Exploration that uses these features as guides yields results that are about twice as good as exploration using little or no geologic guidance.

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ILLUSTRATIONS

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