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PROGRESS REPORT

GEOLOGIC, MINERALOGIC, AND GEOBOTANICAL GUIDES TO ORE IN THE CARNOTITE DEPOSITS OF THE COLORADO PLATEAU

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CONTENTS

GEOLOGIC GUIDES TO CARNOTITE DEPOSITS

Topic Report No. 1, preliminary

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By R. P. Fischer and Doris Hinckson

U. S. Geological Survey

Grand Junction, Colorado

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PART I

GEOLOGIC GUIDES TO CARNOTITE DEPOSITS

by R. P. Fischer and Doris Hinckman

SUMMARY AND CONCLUSIONS

The carnotite deposits of the Colorado Plateau appear to be genetically related to geologic structures that resulted from sedimentary conditions rather than from regional deformation or from hydrothermal activity. The deposits are thought to have formed from ground-water solutions shortly after the ore-bearing beds accumulated. Information on the ore controls and the exploration guides is summarized here as a preliminary statement of the results of geologic studies being made by the Geological Survey.

Most carnotite deposits are in or near the thicker, central parts of sandstone lenses. Most lenses are broad and vaguely defined but in places some are well defined. The trends of the lenses can be recognized by a study of bedding and the orientation of fossil logs where observations can be made, but these trends cannot be projected for any great distance because the lenses are discontinuous. The sandstone near ore deposits is dominantly yellow-brown, and some of the red mudstone that is associated with the sandstone is altered to gray, whereas away from the deposits some of the sandstone has a reddish cast and the mudstone is unaltered. As a working hypothesis, it is assumed that these color changes resulted from circulating solutions, perhaps the ore-bearing solutions themselves. The abundance of carbonaceous matter or the organic material from which it was derived in and near ore bodies may have affected the chemical conditions that favored precipitation of the ore metals.

Statistical relations between several of these geologic features and the proximity to ore deposits are given. Where enough data are available to express these relations as mathematical averages, some relations appear to show systematic variations; at least these averages seem to confirm the validity of these features as guides to ore. On the other hand, variations at single points of observation are so extreme that these relations must be used with caution. In general the relations are so subtle that knowledge based on experience over a wide area is essential as a guide in exploration.

The geologic studies now in progress and those planned are reviewed briefly.

INTRODUCTION

This report briefly describes the geologic features that are thought to have influenced the localization of the carnotite deposits. It also makes a preliminary appraisal of their value and limitations as guides to ore-finding. In addition, ideas about the origin of the deposits are stated briefly, in order to show their influence on long-range exploration plans and resource appraisals. A brief review of the geologic studies in progress and those planned is also presented.

A more detailed report on this general subject will be prepared later when certain studies now under way have progressed sufficiently to yield significant contributions to the geology of the deposits and to the problem of ore-finding. The present report, which is only a preliminary statement, is prepared now at the request of the Atomic Energy Commission.[1]

1/ Letter of Feb. 8, 1949, from P. L. Merritt to T. B. Nolan, subject: "Study of ore controls."

GEOLOGY

The carnotite-bearing deposits have many interesting geologic features, some of them essentially unique among metallic ores. Practically 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. In most areas or mining districts the deposits are largely, or wholly, confined to a single stratigraphic zone in one of these formations. Most of the deposits are in the Morrison formation, and the following description applies particularly to these.

The ore mainly impregnates sandstone, but some of the fossil plant material in the ore-bearing beds is richly mineralized. Ore bodies range from small irregularly shaped masses only a few feet across, containing a few tons of ore, to large tabular bodies as much as several hundred feet across, containing many thousand tons of ore; most bodies contain less than a thousand tons each. Many of the deposits are clustered in relatively small but poorly defined areas; the larger areas between clusters contain only a few scattered deposits, most of which are small. The tabular bodies are irregular in thickness and plan. Though their long dimensions are nearly parallel to the sandstone bedding, the ore layers do not follow the beds in detail.

The structural environment of the carnotite deposits differs from one place to another. The ore-bearing and associated beds in general dip at low angles, having been tilted by broad folds, but some otherwise typical deposits occur in steeply dipping beds; others are in horizontal beds several miles away from areas of deformation. High-angle faults with displacements ranging from a few inches to a hundred feet or more are common in places. All faults displace the ore. Although the ore-bearing strata have been intruded in some places by igneous masses, the deposits as a whole seem to be distributed without regard to these intrusions and many are miles from any known igneous activity. Furthermore, the mineral composition of the deposits is not that of hydrothermal ores.

The distribution of the deposits and the habits of the ore show a relationship to lithologic features that would influence the movement and chemical composition of ground waters in the ore-bearing beds, at least before regional deformation disrupted the continuity of the beds. Most deposits are in or near the thicker, central parts of sandstone lenses. In some places the deposits are alined parallel to the trend of the sandstone lenses. Ore bodies are commonly elongate parallel to this trend, and the rolls of ore within the bodies trend in the same direction. Many deposits also are associated with carbonaceous matter derived from fossil plant material. This material may have played a part, if only indirectly, in the precipitation of the metals from solution.

ORIGIN

Because of the unique character of the carnotite deposits, they are not comparable to other metallic deposits about which more is known regarding origin. Perhaps it is for this reason that conclusive evidence of the origin of carnotite deposits seems to be lacking.

Earlier theories

Theories of the origin of the carnotite deposits have run the gamut of possibilities. It is worthy of note, however, that most geologists and groups of geologists who have made a detailed study of these deposits seem to favor the theory that the deposits were formed by deposition from solutions at the time the ore-bearing sands accumulated or shortly afterward. These workers include Hess _/, Coffin _/, Fischer _/, and Webber _/.

_/ Hess, F. L., A hypothesis for the origin of the carnotites of Colorado and Utah: Econ. Geology, vol. 9, pp. 686-687, 1914.

_/ Coffin, R. C., Radium, uranium, and vanadium deposits of southwestern Colorado: Colo. Geol. Survey Bull. 16, p. 159, 1921.

_/ Fischer, R. P., Sedimentary deposits of copper, vanadium-uranium and silver in southwestern United States: Econ. Geology, vol. 32, No. 7, pp. 943-949, 1937.

_______________, Vanadium deposits of Colorado and Utah: U. S. Geol. Survey Bull. 936-P, p. 389, 1942.

_/ Webber, B. N., Geology and ore resources of the uranium-vanadium depositional province of the Colorado Plateau region: Union Mines Develop. Corp., pp. 231 and 232, 1947.

Lindgren _/ has suggested that the deposits were formed by circulating

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_/ Lindgren, W., Mineral deposits, p. 404, 1933.

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ground waters, and Butler ✓ concurs, but further suggests that the circu-

✓ Butler, B. S., et al, The ore deposits of Utah: U. S. Geol. Survey Prof. Paper 111, pp. 154-158, 1920.

lation and deposition followed regional deformation.

Some geologists are reluctant to abandon the possibility of a hydrothermal origin for these deposits, but no one has published strong support of this theory.

Significance of origin

From the practical standpoint of exploration in a given area, the local habits and association of ore deposits must be known, but it is not essential to know the origin of these deposits. Knowledge regarding the origin is helpful, however, particularly in recognizing and in accurately interpreting the observed characteristics of ore occurrence. In order to appraise the total reserves in a large area, and to make long-range plans for exploration, it is essential to have as much knowledge as possible regarding the origin of the deposits.

If the carnotite deposits had a hydrothermal origin, the deposits should have a distribution related to the sources of thermal solutions and to channels of migration across beds, in addition to channels of migration along beds. The deposits, therefore, would presumably have a restricted geologic and geographic distribution. Similarly, if the deposits were formed from ground water after regional deformation, they would also have a restricted distribution related to regional structure and the physiographic history of the region. However, if the deposits were formed from early ground waters, their localization would have been controlled by sedimentary conditions that would have no relation to regional deformation or recent physiographic history.

Present working hypothesis

The Geological Survey has planned its exploration on the assumption that the deposits were formed from early ground-water solutions, and that sedimentary structures and chemical conditions within the beds controlled localization.

If the assumed origin is essentially correct, it is reasonable to expect that the deposits exposed at the present surface are a random sample, and therefore are representative of those that are concealed. Exploration of large areas in which sedimentary structures are favorable, regardless of regional deformation and the proximity of hydrothermal and igneous activity, is therefore justifiable. A statistical appraisal of the total resources of the entire carnotite region or large parts of it, based on a study of the distribution of deposits at the present outcrop and in explored ground, is also justifiable and may be significant. Nevertheless, because conclusive evidence of origin is admittedly lacking, the present ideas of origin, the broad exploration plans, and the appraisals of total resources eventually may have to be modified.

GUIDES TO ORE

Some of the geologic features with which ore is commonly associated, and which therefore are presumed to have been favorable for ore deposit[illegible], are useful guides in ore-finding or at least in recognizing ground fa[illegible] for ore and in eliminating unfavorable ground. These features as [illegible] some of the habits of the ore are described briefly, because th[illegible] by the Geological Survey in guiding exploration. The prospe[illegible] tory to use these guides should be cautioned that most of [illegible] subtle, and they must be evaluated together in apprais[illegible] prospecting, that no single one is well defined or can be used alone, and that some can be observed only at the outcrop or in mine workings whereas others can also be observed in diamond-drill cores.

General relations

The Morrison sandstone beds that contain the ore deposits are lenticular and in places as much as 50 feet or more thick. They are interbedded with mudstone. The sands were deposited in channels and on flood plains of streams that meandered broadly across a surface of low relief and grade. Most of the carnotite deposits seem to occur in or near the thicker, central parts of the lenses; the portions of the channel sands that occupy meander bends seem to be particularly favorable for deposits in some areas. In places the channel sands form well defined lenses, some only a few hundred feet across, and these can be recognized at the outcrop or in cross sections through drill holes. Other channels are broad and vaguely defined. The trend of the channel sands commonly can be determined by observations of bedding, and in places by the orientation of the fossil logs. Some channels can be projected and followed, though caution must be used in projection for some of the channel sands seem to fray out along their course and others were cut off by later channels trending in other directions. Furthermore, overlying beds and even the upper part of the ore-bearing bed might not have accumulated in a stream that flowed in the same direction as the stream in which the lower, more favorable part of the ore-bearing bed was formed. Therefore, observations at the surface commonly do not reveal the trend of underlying beds. The sandstone in the central parts of the channels is dominantly medium-grained, medium- to thick-bedded or irregularly bedded, and moderately clean though some mudstone in the form of grains, pebbles, and small lenses is common. Beds of sandstone lean than about 20 feet thick, which might have been deposited in small or short-lived channels or on flood plains bordering the main channels, rarely contain sizeable ore deposits. Such sandstone is dominantly fine-grained, thin-bedded, and either clean or argillaceous.

As a working hypothesis to explain the observed associations of the deposits to the channel axis, it is assumed that most of the ground water that moved along the beds would follow the central parts of the sandstone lenses due to the effect of greater thickness and greater permeability. Even so, the route of ground waters through discontinuous lenses would be devious and in some lenses might be controlled by other factors that might not be recognizable. The deposits are thought to have been localized where chemical conditions favored the precipitation of metals, perhaps in the environment of decaying organic matter (fossil plant material).

The sandstone beds and the associated mudstone have characteristic colors in the vicinity of ore deposits, and these colors probably express the effect of circulating solutions. The color of the ore-bearing sandstone is dominantly pale to light yellow-brown and the sandstone is speckled with small spots of limonite stain. Whitish to pale yellow-brown or reddish-brown sandstone contains a few deposits but most of them are small. The mudstone that is interbedded with this sandstone, as well as the grains, pebbles, and lenses of mudstone within the sandstone, is dominantly red, which is believed to have been its original color. Near ore deposits, however, the mudstone within the ore-bearing sandstone and the upper few inches to few feet of the mudstone beneath the ore-bearing sandstone is altered to gray (the so-called "blue clay" of the miners). Though the character and cause of this color change are not understood clearly, the presence of considerable altered mudstone in the ore-bearing sandstone and immediately below it is probably the most useful guide in recognizing ground favorable for ore deposits.

Appraisal of specific guides

The several guides to ore are being studied systematically now in order to appraise their value and establish their limitations. The incomplete results and tentative conclusions of this study and of earlier studies are summarized briefly below.

Altered mudstone.—The intensity, or extent, of alteration that has resulted in the color change in the mudstone decreases outward from ore deposits, as shown by the average thickness of the altered zone at the base of the ore-bearing sandstone and by the proportion of altered to unaltered mudstone within the sandstone. However, variations in the intensity of alteration at single points of observation, such as individual drill holes, are so extreme that the relationship of alteration to ore must be used with caution.

Figure 1 is a map compiled from the geologic logs of 522 holes drilled by the Geological Survey on the Calamity group of claims. It shows in a somewhat generalized manner the variations in thickness of the altered mudstone at the base of the ore-bearing sandstone, as related to the location and approximate size of the carnotite deposits found by this drilling.

Although the lack of a close relationship between the thicker areas of altered mudstone and the deposits is obvious, some of the discrepancies may result from lack of information, such as the partial or complete core loss of the altered mudstone in some drill holes, for which no compensation can be made. Even so, a general relationship between alteration and the ore deposits is apparent.

On the other hand, where enough data are available to obtain a statistical approach to the problem, the relationship between the average thickness of the altered mudstone at the base of the ore-bearing sandstone and the deposits seems to be well defined. Table 1 gives the average thickness of the altered mudstone beneath ore deposits and also in 100-foot wide zones that extend outward from drill holes in the margins of the deposits on the Calamity group of claims. It is compiled from the geologic logs of 504 holes drilled in the zones specified.

Figure 1.-- Variations in thickness of altered mudstone at base of ore-bearing sandstone as related to location of carnotite deposits found by Geological Survey drilling, Calamity group, Mesa County, Colorado.

Table 1

Comparative average thickness of altered sandstone at base of ore-bearing sandstone, Calamity group, Mesa County, Colorado

Number of drill holes	Zones beneath and outward from ore deposits	Average thickness in feet	
177	Beneath	3.30	
225	0-100 feet outward	1.85	wt'd. av. 1.30 ft.
79	100-200 feet outward	1.31	
48	200-300 " "	0.81	
35	300-400 " "	0.61	
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Based on the geologic logs of 107 holes drilled on the Maverick group of claims, the altered sandstone at the base of the ore-bearing sandstone averages 5.8 feet thick in all holes that cut mineralized sandstone and only 3.7 feet thick in all barren holes.

Table 2 shows the percentage of holes that cut altered, mottled (partly altered), and unaltered sandstone immediately below the ore-bearing sandstone beneath deposits and in zones outward from the known deposits on the Lower group of claims. The table is based on the 91 holes drilled by the Geological Survey in that area.

Table 2

Percentage of holes cutting altered, mottled (partly altered), and unaltered mudstone at base of ore-bearing sandstone, lower group, San Miguel County, Colorado

Zones	Percentage of holes cutting altered mudstone,	mottled mudstone,	unaltered mudstone
Beneath deposits	86	none	14
0-100 ft from deposits	54	24	22
100-300 ft from deposits	33	17	50
Beyond 300 ft from deposits	22	12	66

The ratio of altered to unaltered mudstone within the ore-bearing sandstone decreases outward from the deposits, as shown in the last column in table 3. Although the average total thickness of mudstone in sandstone increases outward, it is doubtful that any significance can be placed on this relationship or in the average thickness of the altered and unaltered mudstone.

Table 3

Ratio of altered to unaltered mudstone within ore-bearing sandstone, Calamity group, Mesa County, Colorado

Zones beneath and outward from ore deposits	Number of holes	Average thickness of mudstone in feet: Total	Altered	Unaltered	Ratio of altered to unaltered mudstone
Beneath	177	1.70	1.19	0.51	2.33
0-100 feet outward	225	1.99	1.03	0.96	1.06
100-200 feet outward	79	3.39	1.27	2.12	0.59
200-300 feet outward	48	3.45	1.12	2.33	0.48
300-400 feet outward	35	4.59	1.86	2.73	0.68

Color of sandstone.--Observations based on regional mapping and detailed studies near deposits suggest that most of the ore is in yellow-brown sandstone; drilling experience confirms this association. Some deposits, however, are in reddish-brown sandstone, but most of them are too small to justify subsurface exploration; for that reason reddish sandstone has been classed as generally unfavorable. Even though this suggested difference in favorability between yellow-brown and reddish-brown sandstone has not yet been confirmed by statistical studies, these differences probably are useful in appraising the ore possibilities of broad areas, particularly in eliminating areas of reddish sandstone from close-spaced drilling. On the other hand, in areas where the sandstone is dominantly yellow-brown, color differences are apt to be so slight or locally erratic that they have little or no value.

Carbonaceous matter.--Carbonaceous matter, which was probably derived from plant material, now fossilized, in the ore-bearing sandstone is more abundant in and near ore deposits than away from deposits (see table 4). Just what relationship, if any, the carbonaceous matter had to ore localization is not yet clear. Perhaps the metals were precipitated in the environment of the decaying plant remains; almost certainly the carbonaceous matter did not directly precipitate the ore minerals, for much of the plant remains near ore is barren. At any rate, the presence of plant remains is useful in appraising the favorability of ground and therefore a helpful though indirect guide to ore.

Table 4

Percentages of drill holes that cut abundant carbonaceous matter, in ore deposits and away from deposits, Calamity group, Mesa County, Colo.

	Total number of drill holes	Holes cutting abundant carbonaceous matter	
		Number	Percentage
Holes in ore deposits	177	69	38.9
Holes 0-400 feet outward from ore deposits	387	49	12.7

Thickness of sandstone.—Regional observations show that most of the deposits are in sandstone that is more than 20 feet thick. This generalization, however, can be applied only very broadly. The average thickness of sandstone in the 177 holes that cut mineralized sandstone on the Calamity group of claims is 43.2 feet, whereas this sandstone averages 42.5 feet thick in the 35 holes in the zone 300 to 400 feet from known deposits. However, a local, small increase in thickness of the sandstone may indicate an old stream channel. This can be used in exploration by projecting a favorable zone for a short distance.[1] In other places structure contours on the base of the

[1] Stager, H. K., Carnotite deposits on Government-owned claims, Calamity Mesa, Mesa County, Colorado: U. S. Geol. Survey Colorado Plateau project Prelim. Report No. 2, p. 8, March 1949.

ore-bearing sandstone have the configuration of slight depressions in the vicinity of the deposits. Most of these depressions are so shallow and small, however, that they offer a target almost as small as the associated deposits, and close-spaced drilling would be required to find them. As any ore present would be found by this close-spaced drilling, the borings themselves have proved of little value in guiding exploration.

Relations of ore rolls to fossil logs and bedding.—Rolls of ore are peculiar masses bounded by one or two well defined surfaces which cross the bedding in a smooth curve. Some of these masses are nearly cylindrical and others are crescent-shaped in cross section. Nearly all are elongate, ranging from 10 to 100 feet or more in length. Most rolls in a single ore body, and in neighboring bodies as well, trend in about the same direction. As ore bodies are elongate in the same direction, and as nearby ore bodies may be alined in this direction, the trend of the rolls in a mine is a useful guide in prospecting near mine workings. 1/

1/ Fischer, R. P., Vanadium deposits of Colorado and Utah: U. S. Geol. Survey Bull. 936-P, p. 390, 1942.

It is clearly established by observations at many places that locally the rolls are closely parallel in trend to the direction of orientation of the fossil logs in the ore-bearing sandstone. As the logs were rafted into place, their orientation had to be controlled by the currents in the stream in which the enclosing sands were deposited. The rolls and the logs commonly parallel the trend of the sandstone lenses or channel-fills and the direction of current bedding.

Figure 2 shows statistically the relation of roll trends to the orientation of fossil logs and to the average gradient direction (direction of current-bedding) in the Club mine, Montrose County, Colorado. As only two quadrants are necessary to show either the trend of the rolls or the orientation of the logs, the east half of the compass diagram (fig. 2a)

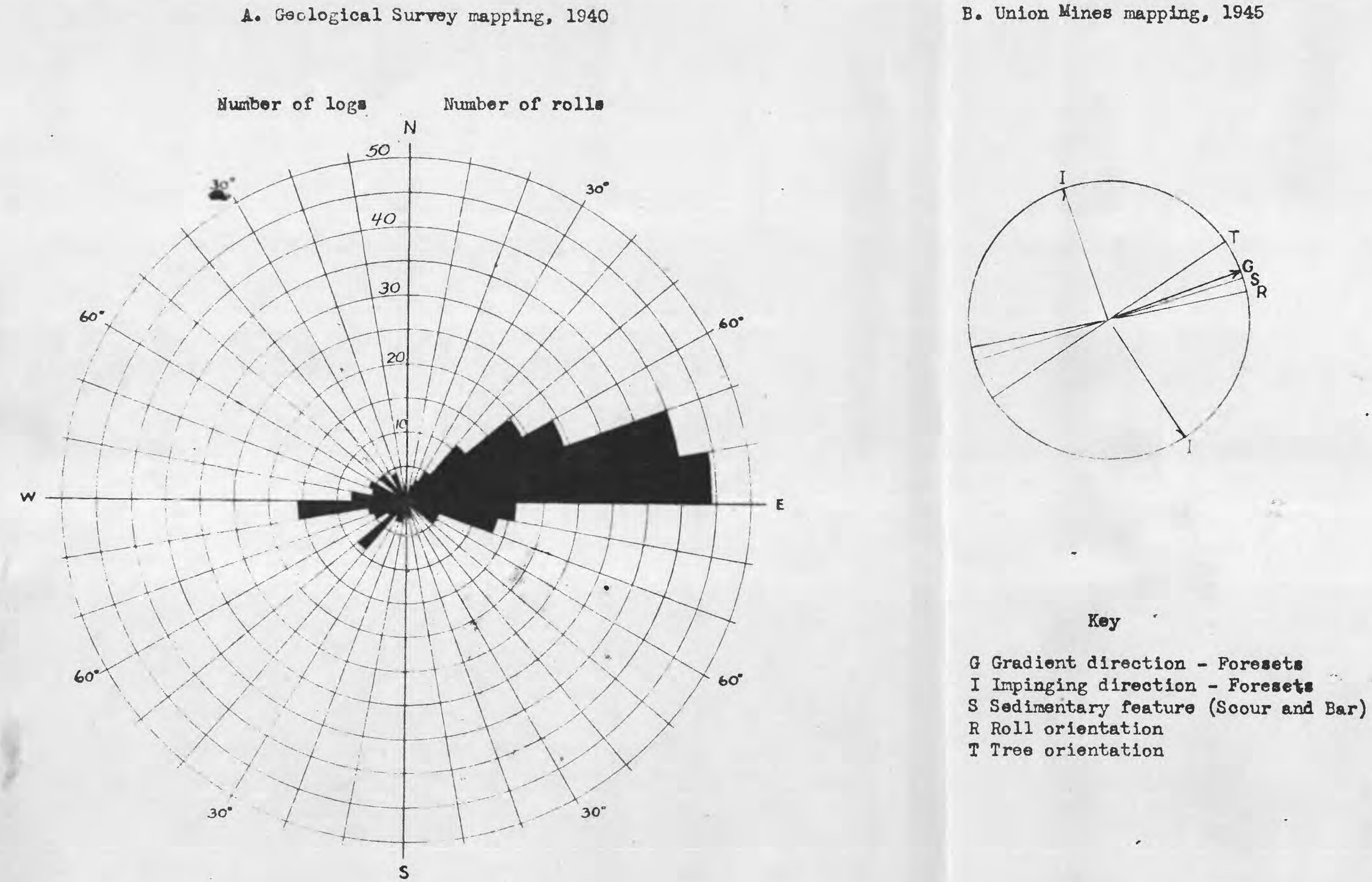

Figure 2.-- Relation of roll trends to orientation of fossil logs and the average gradient direction, Club mine, Montrose County, Colorado.

shows the number of rolls lying in any 10° arc, and the west half shows the number of logs in any 10° arc. A glance shows the dominant trends correspond. Figure 2B shows the average gradient direction (current-bedding), as mapped by Union Mines in 1945.√ This direction corresponds closely to

√ Webber, B. N., Geology and ore resources of the uranium-vanadium depositional province of the Colorado Plateau region: Union Mines Develop. Corp., fig. 70, 1947.

the dominant trend of rolls and orientation of fossil logs.

Figure 5 shows the corresponding relation of roll trends to the direction of current-bedding (festoon- and foreset-bedding) in an area of about 1 square mile in the vicinity of the Yellow Cat group, Grand County, Utah.√ The

√ Stokes, W. L., Vanadium deposits of the Thompsons area, Grand County, Utah: U. S. Geol. Survey unpublished manuscript, 1943.

total <u>footage</u> of rolls in any 10° arc, rather than the <u>number</u> of rolls, is plotted on half the compass (fig. 5A). The number of <u>observations</u> of direction of current-bedding in any 10° arc is shown in figure 5B.

A. Footage of rolls

B. Number of observations of direction of current bedding

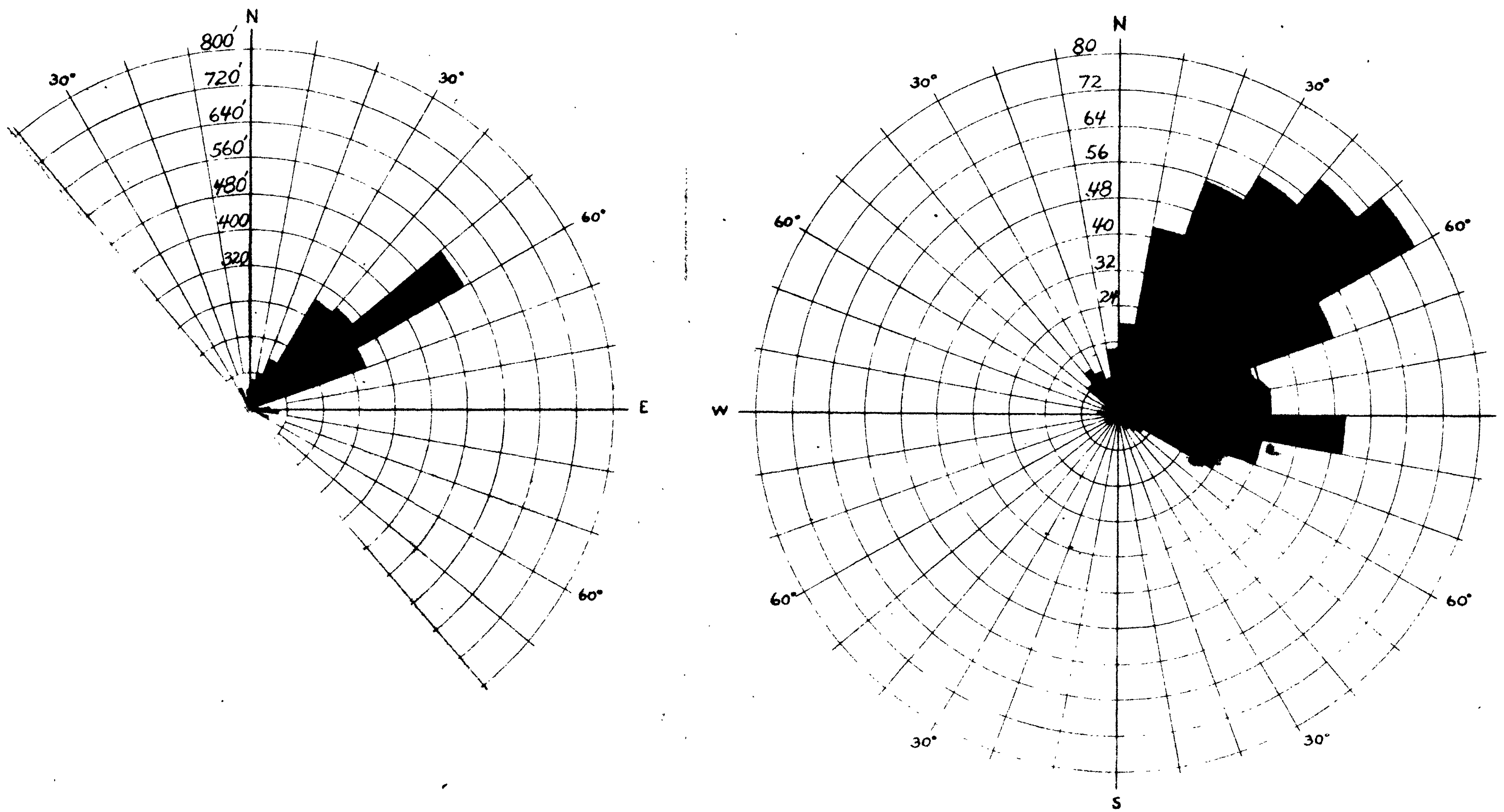

Figure 3.-- Relation of roll trends to the direction of current-bedding, Yellowcat group, Grand County, Utah.

GEOLOGIC STUDIES

The broad phases of the geologic studies are aimed at long-range results--to aid in determining the possible source of the metals in the carnotite deposits, the mode and route of transportation of these metals, and the conditions favorable for the localization of the ore deposits, as a guide to ore-finding and as an aid in evaluating the resources of the region. As a direct service to the exploration work, however, the timing and emphasis of these studies and the daily activities of the geologists undertaking them are modified by the requirements of the geologists who guide exploration, and by the problems encountered in drilling. To serve effectively in such a consulting capacity, and because of overlap among these studies, the geologists work in close coordination for exchange of information and mutual gain.

The several phases of the geologic studies are treated separately below. The general objectives, work done in fiscal 1949 and before, and future plans for each are summarized below.

Special study

A special, systematic study of the information on the geologic logs of drill holes is in progress, in order to establish more clearly the guides to ore and to appraise their value, limitations, and regional variations. This study should directly aid exploration, and it might point out where changes should be made in geologic logging and drilling plans. It should also contribute information concerning the habits and origin of the deposits. The work will be continued as long as profitable.

Geologic mapping (regional)

The principal objectives of the regional geologic mapping are to determine the geographic and geologic distribution of the carnotite deposits, the broad geologic controls, and the relations to regional stratigraphic changes and regional deformation, as well as to delimit areas favorable for detailed studies and exploration, to which special attention is given.

Southwestern Colorado.--Regional geologic mapping in the main carnotite producing area of southwestern Colorado was begun in 1941 and was continued in 1945, 1947, and 1948. Field work during the summer of 1949 will complete the mapping of this area.

Southeastern Utah.--Geologic mapping will be started in the unmapped part of southeastern Utah in the summer of 1950, and it is hoped to complete the field work that year.

Northeastern Arizona.--In cooperation with the Fuels Branch of the Geological Survey, geologic mapping in the Carrizo Mountain area will be started in 1949 and should be completed in 1950.

No more geologic mapping is planned at present, although work in other areas might be recommended later.

Stratigraphic studies

The stratigraphic studies are planned primarily to obtain needed additional information regarding distribution, the local and regional variations in lithology, the source of the material, the conditions of deposition, and the post-depositional history of the ore-bearing strata and associated formations. Field studies in progress in the main ore-producing part of southwestern Colorado and southeastern Utah will be extended into the surrounding region in decreasing intensity. The field work is to check, standardize, and supplement stratigraphic information available in published and unpublished sources. Special studies are planned to determine the relation of ore deposits to sedimentary and lithologic features. Problems of sedimentary petrology are being investigated in a laboratory.

General stratigraphic studies of the Morrison formation and associated strata began late in the summer of 1947. The work at first consisted of reviewing broad relations and establishing standards. Detailed stratigraphic and lithofacies studies were undertaken in southwestern Colorado during the summer of 1948. Considerable time during the field work has been spent directly aiding the exploration geologists in the problems they encounter, such as standardizing nomenclature and classification of lithologic types, local problems of sedimentary structure, etc. A sedimentary laboratory has been established in Grand Junction to study samples collected during the field work and from drill-cores.

General stratigraphic and lithofacies studies will be continued in southwestern Colorado and the adjoining parts of Utah, Arizona and New Mexico in 1949, and this work should be completed in 1950.

Studies of sedimentary structures and their relations to the carnotite deposits are much needed as an aid to exploration. The apparent spacial relation of ore deposits to the stream channels in which part of the Salt Wash sandstone accumulated, as shown by lensing, foreset-bedding, and festoon-bedding, has already been demonstrated by the Geological Survey and the Union Mines in a few places (see pp. 20-24). These relations must be more firmly established, the more critical features defined, and the techniques for applying pertinent observations better developed. Studies will be made in 1949 in selected areas to obtain these general objectives and in other places as a direct aid to exploration; these studies will also yield general information useful in establishing the paleogeography of the Morrison formation.

Sedimentologic studies of samples collected during stratigraphic work in the field and of core samples will continue in the sedimentary laboratory which is also available to and used by other geologists for making simple qualitative chemical tests and rock studies. It will be of considerable value for the proposed mineralogic studies.

Similar but far less detailed stratigraphic studies of the Entrada formation are planned, in order to obtain additional information regarding the vanadium-uranium deposits in this formation. This work will probably be started in fiscal 1951 and should be concluded in fiscal 1952.

Similar studies will be made of the Shinarump conglomerate, unless this work is undertaken by the Atomic Energy Commission. If this work is done by the Geological Survey, it will probably be started in fiscal 1952.

Geochemical prospecting

Preliminary work during the summer of 1947 indicated that certain plants that grow on outcrops of ore-bearing sandstone might concentrate minor but detectable amounts of metals from the deposits. If this is true, sampling of the plants might be a direct guide to ore deposits in places where the ore-bearing sandstone lies at shallow depth, as, for example, in the Yellow Cat area near Thompsons, Utah, and in the Carrizo Mountains area. Studies are planned during the 1949 field season to establish relations, define limitations, and develop techniques. It is hoped that definite results, either positive or negative, will be obtained by a few months' work, and that the sampling techniques developed, if any, can then be applied by the exploration geologists.

Mineralogic studies

The mineralogic studies are undertaken to determine the composition, distribution, habits, and the age and paragenesis of the ore minerals; their mode of formation and relation to the enclosing rocks; the character of the ore-bearing solutions; and the conditions of migration and localization of the deposits. Information derived from the study will be of aid in developing metallurgical techniques for blending, milling, and beneficiation of the ores, and will be useful in interpreting the ratios between equivalent uranium and uranium in the radiometric laboratory, in addition to probable field use in guiding exploration.

The studies, both mineralogic and petrographic, will be comprehensive and detailed in character, embodying many specialized fields of laboratory investigation as well as more routine methods. Emphasis will be placed on the investigation of the mineralogy of features which are presently considered to be guides to ore. There appears to be a relationship between the presence of mineralization within the ore-bearing sandstone and the amount of alteration of the mudstone underlying the sandstone. A detailed study will be made of the character of the alteration, in order to determine the composition of the altering solutions, and thus aid in the evaluation of this guide to ore. Other features will be similarly investigated and evaluated. Information obtained in the course of detailed field investigations in 1939, 1940, and 1941 will be collated with the mineralogic program, as will information derived from the present exploration drilling program, and associated geologic studies.

A memorandum from L. R. Stieff to J. C. Rabbitt, dated March 24, 1949, outlines additional special laboratory investigations of carnotite mineralogy, equilibrium relations, and associated studies, as well as the necessary supporting field work. A copy of this memorandum has been furnished to the AEC.

Ground-water studies

Because the habits of the deposits suggest the ore was formed from ground waters circulating along the ore-bearing beds, probably before regional deformation, a study of past and present ground-water conditions has been recommended. It should aid in determining the age and origin of the deposits and the factors that localized them, as well as supplementing the information that will be obtained from the other geologic studies and the exploration work. These studies are proposed for fiscal 1951.

GEOBOTANICAL PROGRAM FOR COLORADO PLATEAU

Topic Report No. 3, preliminary

July 1949

By H. E. Hawkes

U. S. Geological Survey

Grand Junction, Colorado

PART III—GEOBOTANICAL PROGRAM FOR COLORADO PLATEAU

by H. E. Hawkes

In 1947 the Geological Survey made a preliminary study of the relation of plants to the uranium deposits of the Colorado Plateau. The object of this study was to determine whether geobotanical studies held any promise as a method of prospecting for carnotite ore, and to bring the general problem of geobotanical prospecting in that area into sharper focus as a guide to further experimental research. Although the results of this cursory study were not conclusive, they did show sufficient promise to warrant additional and more intensive investigation.

Specifically, it was shown that certain indigenous species of plants are associated with uranium ore bodies in the Thompsons area of Utah. These are some of the same species that have been widely studies by Agricultural scientists as specific indicators of soils containing relatively large amounts of selenium. Under favorable conditions, systematic mapping of the distribution of these and possibly other diagnostic plant species may indicate the presence of underlying ore.

It was further found that certain plants, notably pinon and juniper, both of which put down deep tap roots in search of water, tend to concentrate in their green parts traces of uranium and associated elements derived from underlying ore bodies. Such plants with deep tap roots may serve as sampling agents for relatively deeply buried ore and that gives no other surface clue of its presence. The following table presents the scanty data collected to date on the amounts of uranium, vanadium, lead, and molybdenum contained in vegetation over ore as compared with similar vegetation in non-mineralized areas. It will be noted that a fair correlation exists for uranium and molybdenum, but apparently no correlation for lead and vanadium; much larger scale and more systematic sampling will be needed to confirm this conclusion.

Plant	Locality	Ore	Parts per million, dry weight U	V	Pb	Mo
juniper	Prescott, Ariz.	No	<0.4	<2	-	-
"	Dakota sandstone	No	1	-	3	1.0
"	Rifle Mine	Very low grade	<0.3	2	-	-
"	Charles T ore zone	Yes	1	-	4	2.4
"	Lower group ore	Yes	2	-	5	5.5
"	" " "	Yes	1	3	-	-
pine	Prescott, Ariz.	No	<0.3	<1	-	-
pinon	Dakota sandstone	No	1	-	8	0.9
"	Rifle Mine	Very low grade	0.2	4	-	-
"	Charles T ore zone	Yes	1	-	5	0.3
"	Lower group ore	Yes	4	-	10	14.5
"	" " "	Yes	0.7	4	-	-
Russian thistle	Rifle Mine	Very low grade	0.0	<5	-	-
"	Ore pile, club group		1	10	-	-
sage brush	Garfield Mine	Yes	6	<2	-	-
Indian millet	Lower group ore	Yes	16	50	-	-

Further research proposed for fiscal year 1950 includes:

1) Ecological studies of the distribution of all plants in the Colorado Plateau area, to determine the relationship between vegetation and the geology and ore deposits.

2) Large scale sampling and analysis of vegetation for traces of all elements associated with the carnotite ore, particularly uranium, vanadium, lead, molybdenum, copper, zinc, and barium, to determine which plants are the best accumulators of ore metals from underlying carnotite deposits.

3) Development and field application of rapid, semi-quantitative methods of chemical analysis of vegetation and soil for uranium, vanadium, molybdenum, and lead, to serve as a day-to-day guide in prospecting.

4) Investigation of any other geobotanical or geochemical surface indication of buried ore that appears to show promise. This may include studies of color variations of plants due to chemical factors, disease symptoms of plants resulting from toxic quantities of ore metals in the nutrient solution, sampling and analysis of ground and surface water, soils and alluvium for traces of the ore metals.