PROGRESS REPORT

GEOLOCIC, MINERALOGIC, AND MICROPALYNA-LOGICAL STUDIES TO DATE

IN THE GARGASITE DEPOSITS OF THE COLORADO PLATEAU

July 1949
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PART I

GEOLITICAL GUIDES TO CARBONITE DEPOSITS
by R. P. Fischer and Doris Madison

SUMMARY AND CONCLUSIONS

The carbonite 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 carbonite deposits are in or near the thickest, 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 legs 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 sandstone that is associated with the sandstone is altered to grey, whereas away from the deposits some of the sandstone has a reddish cast and the sandstone 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, such 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 copper 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.
GEOLOGY

The cerussite-bearing deposits have many interesting geologic features, some of them essentially unique among metallic ores. Practically all the known deposits of cerussite importance are restricted to the Shimney formation of Triassic age and the Utica 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 sediments, 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 clearly 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 cerussite deposits differs from one place to another. The ore-bearing and associated beds in general dip at
ice augen, 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 may be miles from any known igneous activity. Furthermore, the mineral composition of the deposits is not that of hydrothermal ore.

The distribution of the deposits and the habits of the ore show a relationship to lithologic features that could 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 thickest, central parts of sandstone lenses. In some places the deposits are aligned parallel to the trend of the sandstone lenses. Ore bodies are commonly elongate parallel to this trend, and the veins 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.

SUMMARY

Because of the unique character of the covellite 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 covellite 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.


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


Lindgren has suggested that the deposits were formed by circulating

Lindgren, W., Mineral deposits, p. 404, 1933.
ground waters, and Butler 
concurs, but further suggests that the cir-


ulation and deposition followed regional deformation.

Some geologists are reluctant to abandon the possibility of a hydro-
thermal 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 carnocite 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 writing hypothesis

The Geological Survey has planned its exploration on the assumption that the deposits were formed from early groundwater 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 carbonate 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 appraisal of total resources eventually may have to be modified.

GUIDE TO ORE

Some of the geologic features with which ore is commonly associated, and which therefore are presumed to have been favorable for ore deposition, are useful guides in ore-finding or at least in recognizing ground favorable for ore and in eliminating unfavorable ground. These features as well as some of the habits of the ore are described briefly, because they are used by the Geological Survey in guiding exploration. The prospector who would try to use these guides should be cautioned that most of them are subtle, and they must be evaluated together in appraising the ground.
presumed, 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 70 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 conglomerate 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 were broad and vaguely defined. The trend of the channel sands generally 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 are 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 sandstone 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 sandstones are 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 sands, it is assumed that most of the ground water that moved along the beds could 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 could 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 sandstone 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. Yellow to pale yellow-brown or reddish-brown sandstone contains a few deposits but most of them are small. The sandstone that is interbedded with this sandstone, as well as the grains, pebbles, and lenses of sandstone within the sandstone, is dominantly red, which is believed to have been its original color. Near ore deposits, however, the sandstone within the ore-bearing sandstone and the upper few inches to few feet of the sandstone 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 sandstone 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 mineral**—the intensity, or amount, of alteration that has resulted in the color change in the sandstone 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 sandstone 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 622 holes drilled by the Geological Survey on the Calumet group of claims. It shows in a somewhat generalized manner the variations in thickness of the altered sandstone at the base of the ore-bearing sandstone, as related to the location and approximate size of the copperite deposits found by this drilling.

Although the lack of close relationship between the thickest areas of altered sandstone 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 sandstone 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 sulphite at the base of the ore-bearing sandstone and the deposit seems to be well defined. Table 1 gives the average thickness of the altered sulphite beneath ore deposits and those in 100-foot wide zones that extend outward from drill holes in the margins of the deposits on the salinity group of claims. It is compiled from the geologic logs of 500 holes drilled in the zones specified.
Areas of altered mudstone 2 feet or more thick.
Areas of altered mudstone 1 to 2 feet thick.
Areas of altered mudstone less than 1 foot thick.

Carnotite deposits of commercial grade and thickness
Carnotite deposits of sub-commercial grade and thickness

Approximate base of ore-bearing sandstone

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

Comparative average thickness of altered mudstone at base of ore-bearing mudstone, Colossus group, Mesa County, Colorado

<table>
<thead>
<tr>
<th>Number of drill holes</th>
<th>Cuts beneath and 100 feet outward from ore deposit</th>
<th>Average thickness in feet</th>
</tr>
</thead>
<tbody>
<tr>
<td>177</td>
<td>Smooth</td>
<td>1.20</td>
</tr>
<tr>
<td>225</td>
<td>0-100 feet outward</td>
<td>1.00</td>
</tr>
<tr>
<td>79</td>
<td>100-200 feet outward</td>
<td>1.25</td>
</tr>
<tr>
<td>17</td>
<td>200-300 feet outward</td>
<td>0.61</td>
</tr>
<tr>
<td>35</td>
<td>300-400 feet outward</td>
<td>0.61</td>
</tr>
</tbody>
</table>

Based on the geologic logs of 107 holes drilled on the Colossus group of claims, the altered mudstone at the base of the ore-bearing mudstone averaged 1.2 feet thick in all holes that cut mineralized mudstone and only 0.7 feet thick in all barren holes.

Table 2 shows the percentage of holes that cut altered, unaltered (partly altered), and unaltered mudstone immediately below the ore-bearing mudstone beneath deposits and in some outward from the limestones 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, metated (partly altered), and unaltered muscovite at base of ore-bearing sandstone, lower group, San Miguel County, Colorado.

<table>
<thead>
<tr>
<th>Zones</th>
<th>Percentage of holes cutting altered muscovite, metated muscovite, unaltered muscovite</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beneath deposit</td>
<td>65</td>
</tr>
<tr>
<td>0-100 ft from deposit</td>
<td>96 97 22</td>
</tr>
<tr>
<td>100-300 ft from deposit</td>
<td>33 17 50</td>
</tr>
<tr>
<td>Beyond 300 ft from deposit</td>
<td>22 12 66</td>
</tr>
</tbody>
</table>

The ratio of altered to unaltered muscovite within the ore-bearing sandstone decreases outward from the deposit, as shown in the last column in Table 3. Although the average total thickness of muscovite 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 muscovite.

Table 3

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

<table>
<thead>
<tr>
<th>Zones beneath and outward from ore deposit</th>
<th>Number of Halves</th>
<th>Average thickness of muscovite in feet</th>
<th>Ratio of altered to unaltered muscovite</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beneath</td>
<td>177</td>
<td>1.79 1.29 0.31</td>
<td>5.33</td>
</tr>
<tr>
<td>0-100 feet outward</td>
<td>225</td>
<td>1.99 1.03 0.96</td>
<td>1.06</td>
</tr>
<tr>
<td>100-300 feet outward</td>
<td>79</td>
<td>3.29 1.27 2.12</td>
<td>0.99</td>
</tr>
<tr>
<td>200-300 feet outward</td>
<td>16</td>
<td>3.65 1.12 2.53</td>
<td>0.48</td>
</tr>
<tr>
<td>300-400 feet outward</td>
<td>35</td>
<td>4.99 1.95 3.04</td>
<td>0.68</td>
</tr>
</tbody>
</table>
**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 redish-brown sandstone, but most of these are too small to justify subsurface exploration; for that reason redish sandstone has been closed as generally unfavorable. Even though this suggested difference in favorability between yellow-brown and redish-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 redish sandstone from selective drilling. On the other hand, in areas where the sandstone is predominantly 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 are probably derived from plant material, are 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 has 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 each 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 3

Percentages of drill holes that cut elemental concentrations matter in ore deposits and away from deposits, Salinity group, Baca County, Colo.

<table>
<thead>
<tr>
<th>Total number of drill holes</th>
<th>Holes cutting elemental matter</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>177</td>
<td>69</td>
<td>37.9</td>
</tr>
<tr>
<td>20 to 400 feet, outside from ore deposits</td>
<td>97</td>
<td>12.7</td>
</tr>
</tbody>
</table>

Thickness of sandstone.—Regional observations show that most of the deposits are in sandstone that is more than 30 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 Salinity group of claims is 92.2 feet, whereas this sandstone averages 92.5 feet thick in the 71 holes in the same 300 to 500 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. In other places structure contours on the base of the


ore-bearing sandstones have the configuration of slight depressions in the vicinity of the deposit. Most of these depressions are so shallow and small, however, that they offer a target almost as well 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 bores themselves have proved of little value in guiding exploration.

Relation 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 nearly ore bodies may be aligned in this direction, the trend of the rolls in a mine is a useful guide in prospecting near mine workings.


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 rested into place, their orientation had to be controlled by the currents in the stream in which the enclosing sandstone was deposited. The rolls cut 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, Routt 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 $10^3$ arc, and the west half shows the number of logs in any $10^6$ arc. A glance shows the dominant trends correspond. Figure 39 shows the average gradient direction (current-bedding), as mapped by Union Oil in 1945. This direction corresponds closely to

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Sellers, W. E., Geology and ore resources of the uranium-uranium depositional province of the Colorado Plateau region: Union Oil Development Corp., fig. 70, 1947.

---

the dominant trend of rolls and orientation of fossil logs.

Figure 3 shows the corresponding rotation of roll trends to the direction of current-bedding (fossil- and present-bedding) in an area of about 1 square mile in the vicinity of the Yellow Butte group, Grand County, Utah. The

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total number of rolls in any $10^6$ arc, rather than the number of rolls, is plotted on half the compass (fig. 39). The number of observations of direction of current-bedding in any $10^6$ arc is shown in figure 39.
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 sources of the metals in the escarpment deposits, the mode and route of transportation of these metals, and the conditions favorable for the localization of the ore deposits, as a guide in 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 overlapping among these studies, the geologists seek 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 constitute 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 vanadinite deposits, the broad geologic controls, and the relations to regional stratigraphic changes and regional deformation, as well as to delineate areas favorable for detailed studies and exploration, to which special attention is given.

Southwestern Colorado. Regional geologic mapping in the main vanadinite producing area of southwestern Colorado was begun in 1941 and was continued in 1946, 1947, and 1948. Field work during the summer of 1949 will complete the mapping of this area.

Southwestern Utah. Geologic mapping will be started in the unmapped part of southeastern Utah in the summer of 1946, and it is hoped to complete the field work that year.

Southwestern Arizona. In cooperation with the Public Branch of the Geological survey, geologic mapping in the Carman 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 southeastern 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 1937, the work at first consisted of reviewing broad relations and establishing standards. Detailed stratigraphic and lithofacies studies were undertaken in southeastern Colorado during the summer of 1938. 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 lithologic studies will be continued in southeastern Colorado and the adjoining parts of Utah, Arizona and New Mexico in 1959, and this work should be completed in 1960.

Studies of sedimentary structures and their relations to the carbonate deposits are much needed as an aid to exploration. The apparent special relation of ore deposits to the stream channels in which part of the salt such as limestone accumulated, as shown by lashing, forest-holding, and foment-holding, has already been demonstrated by the Geological Survey and the Union Mine in a few places (see pp. 25-26). 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 1959 in selected areas to obtain these general objectives and in other places as a direct aid to exploration whose studies will also yield general information useful in establishing the paleogeography of the Jurassic 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 Jurassic formation are planned, in order to obtain additional information regarding the vanadium-cromium deposits in this formation. This work will probably be started in fiscal 1959 and should be completed in fiscal 1960.
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 Thoempoa, 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 mineralologic 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. Babbitt, dated March 24, 1949, outlines additional special laboratory investigations of carnallite mineralogy, equilibrium relations, and associated studies, as well as the necessary supporting field work. A copy of this memorandum has been furnished to the ARC.

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. Haskes

U. S. Geological Survey

Grand Junction, Colorado
PART III—GEOBOTANICAL PROGRAM FOR COLORADO PLATEAU

by R. E. Haines

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 Thompson area of Utah. These are some of the same species that have been studied 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 pine 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.

<table>
<thead>
<tr>
<th>Plant</th>
<th>Locality</th>
<th>Ore</th>
<th>Parts per million, dry weight</th>
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<tr>
<td></td>
<td></td>
<td></td>
<td>U</td>
</tr>
<tr>
<td>juniper</td>
<td>Prescott, Ariz.</td>
<td>No</td>
<td>&lt;0.4</td>
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<td></td>
<td>Dakota sandstone</td>
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<td></td>
<td>Rifle Mine</td>
<td>Very Low Grade</td>
<td>&lt;0.3</td>
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<td></td>
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<td>1</td>
</tr>
<tr>
<td></td>
<td>Lower group ore</td>
<td>Yes</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>&quot; &quot; &quot; &quot;</td>
<td>Yes</td>
<td>1</td>
</tr>
<tr>
<td>pine</td>
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<td>No</td>
<td>&lt;0.3</td>
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<td>pinion</td>
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<td>sage brush</td>
<td>Garfield Mine</td>
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<td>Indian sallot</td>
<td>Lower group ore</td>
<td>Yes</td>
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</table>
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 carnitite ore, particularly uranium, vanadium, lead, molybdenum, copper, zinc, and barium, to determine which plants are the best accumulators of ore metals from underlying carnitite 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.