Criteria for Outlining Areas Favorable for Uranium Deposits in Parts of Colorado and Utah

GEOLOGICAL SURVEY BULLETIN 1009-J

This report concerns work done on behalf of the U. S. Atomic Energy Commission and is published with permission of the Commission

Criteria for Outlining Areas Favorable for Uranium Deposits in Parts of Colorado and Utah

By E. J. McKAY

A CONTRIBUTION TO THE GEOLOGY OF URANIUM

GEOLOGICAL SURVEY BULLETIN 1009-J

Investigations in the Uravan and Gateway districts, Montrose and Mesa Counties, Colo., and Grand County, Utah. This report concerns work done on behalf of the U. S. Atomic Energy Commission and is published with permission of the Commission

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1955

UNITED STATES DEPARTMENT OF THE INTERIOR

Douglas McKay, *Secretary*

GEOLOGICAL SURVEY

W. E. Wrather, *Director*

For sale by the Superintendent of Documents, U. S. Government Printing Office
Washington 25, D. C. - Price 55 cents (paper cover)

CONTENTS

ILLUSTRATIONS

A CONTRIBUTION TO THE GEOLOGY OF URANIUM

CRITERIA FOR OUTLINING AREAS FAVORABLE FOR URANIUM DEPOSITS IN PARTS OF COLORADO AND UTAH

By E. J. McKay

ABSTRACT

Most of the uranium deposits in the Uravan and Gateway mining districts are in the persistent upper sandstone stratum of the Salt Wash member of the Morrison formation.

Areas in which this stratum is predominantly lenticular have been differentiated from areas in which the stratum is predominantly nonlenticular. The most favorable ground for uranium deposits is in areas of lenticular sandstone where the stratum is underlain by continuous altered greenish-gray mudstone. Ore is localized in scour-and-fill sandstone beds within favorable areas of lenticular sandstone.

Regional control of the movement of ore-bearing solutions in the principal ore-bearing sandstone zone is indicated by belts of discontinuously altered mudstone transitional in a northerly and southerly direction from an area of unaltered mudstone to areas of continuously altered mudstone; and an area of unaltered mudstone in which no ore deposits are found and an increase in size, number, and grade of ore deposits from areas of discontinuously altered to continuously altered mudstone.

Discrete regional patterns of ore deposits and altered mudstone are associated with Tertiary structures; where these structures and favorable host rocks occur in juxtaposition, regional controls appear to have localized ore deposits.

INTRODUCTION

Uranium deposits in sandstone beds of the Morrison formation have a wide and scattered distribution on the Colorado Plateau. Some of the most productive areas in Colorado have been studied and drilled intensively by the Geological Survey to obtain guides in prospecting for ore and to aid in the development of mineral resources. This work has resulted in the recognition that several lithologic features of the ore-bearing beds can be useful in guiding exploration and in appraising the favorableness for ore deposits. Those features that can be readily observed in drill core, and their application in exploration, have been described by Weir (1952), and they are summarized in this

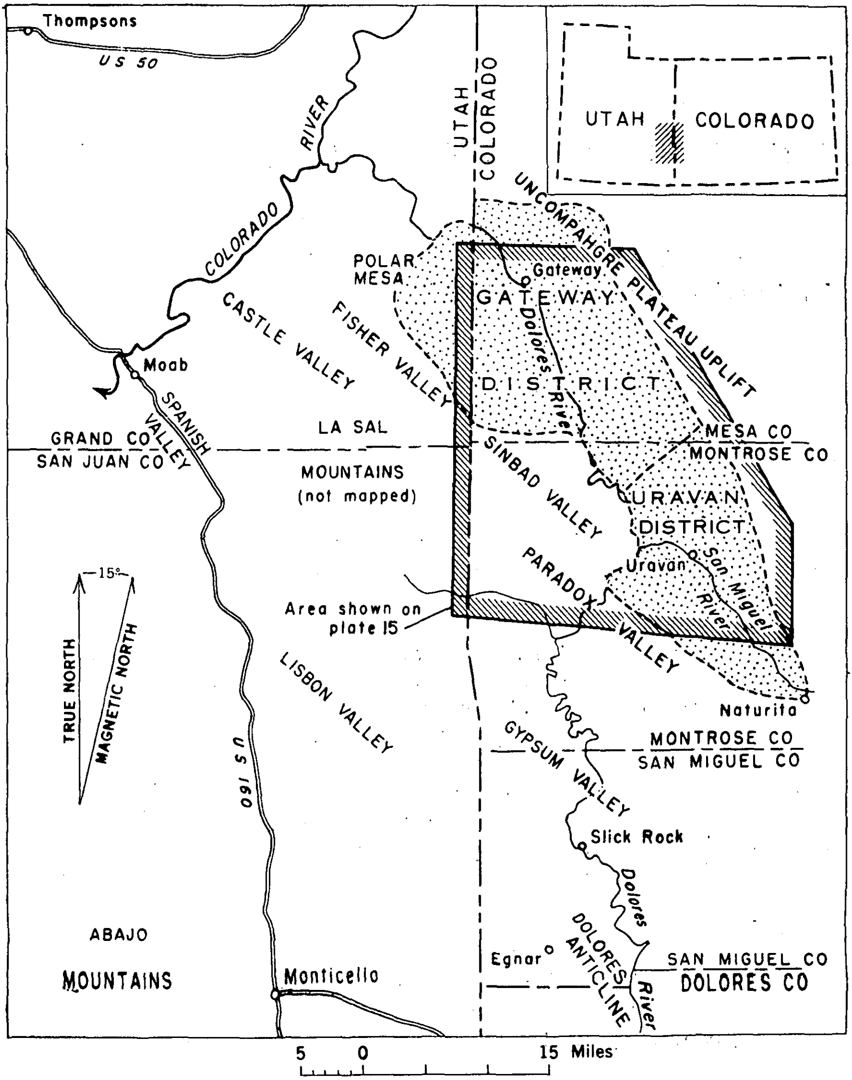


FIGURE 43.—Index map of part of the Colorado Plateau showing Uravan and Gateway mining districts.

report. They are particularly useful in guiding diamond drilling, as they have limited areal distribution and offer relatively small-scale targets. Other features can be observed better at the outcrop and can be used as large-scale guides.

A special detailed study was made of the ore-bearing sandstone zones in the Uravan and Gateway districts, Montrose and Mesa Counties, Colo., and the adjoining part of Grand County, Utah (fig. 43). Individual sandstone units of the Salt Wash member were mapped and examined in detail and compilation was made on topographic base maps (scale 1:24,000) in the Uravan district; elsewhere the ore-bearing zone was examined and mapped and most of the mines in this mapped area were inspected.

Mapping technique involved drawing the outline of individual sandstone units as they appeared from adjacent canyon walls; the relation in space of these units and mudstone lenses to one another was shown and where mines occur, the position of ore bodies within individual sandstone units or the relation of ore bodies to several sandstone units was also shown. Next, the mapped strip, commonly a quarter of a mile to half a mile long, was "rim walked" to determine details of lithology and bedding, the thickness of altered greenish-gray mudstone beneath the ore-bearing sandstone zone as well as the alteration thickness in mudstone lenses separating the sandstone units, and the orientation of the thicker portion of the individual sandstone lenses.

The purpose of the work was to determine the gross lithologic characteristics of these beds, both in the vicinity of and away from uranium deposits, in order to evaluate certain geologic features as ore guides, and to aid in planning exploration and appraising large areas from the standpoint of favorableness for ore deposits. The pertinent results of this work, prediction of favorable and unfavorable ground for ore deposits, have been supported by drilling done subsequently by the Atomic Energy Commission and the Geological Survey.

In the Uravan and Gateway districts, the general character of the bedding in the ore zone and the amount of alteration in the underlying mudstone, and the relation of these to one another, are the features most useful as large-scale ore guides. These features and their distribution, as well as regional geologic structures, are either associated with deposits or have influenced ore deposition. Observed relations indicate that ore deposits in the main ore-bearing zone are localized by scour-and-fill sandstone bedding in a persistent, dominantly lenticular upper sandstone stratum of the Salt Wash member that is underlain by continuously altered greenish-gray mudstone.

The patterns of alteration and ore deposits probably reflect regional control of ore deposition by Tertiary structure. If this is true, the use of regional structure guides in conjunction with small- and large-scale guides to ore should aid the search for future ore reserves. This study suggests that there are at least two discrete northwest-trending belts instead of a single belt as outlined by Fischer and Hilpert (1952).

ACKNOWLEDGMENTS

This report concerns work done in 1950 by the U. S. Geological Survey on behalf of the Division of Raw Materials of the U. S. Atomic Energy Commission. It is impossible to give individual recognition to the many persons who contributed time and knowledge to this study, but special thanks are given R. P. Fischer, F. W. Cater, L. B. Riley, E. M. Shoemaker, and R. L. Boardman for their many suggestions.

GEOLOGY

GEOLOGIC SETTING

The Uravan and Gateway mining districts are in a broad, shallow syncline between the northwestward-trending Uncompahgre Plateau on the northeast and the northwestward-trending Paradox Valley and Sinbad Valley anticlines on the southwest. The area is a deeply dissected, rugged highland ranging from 5,000 to 7,000 feet in altitude. Rocks ranging in age from Permian to Cretaceous are exposed. The Morrison formation of Late Jurassic age is about 700 feet thick and is composed of two members, the upper Brushy Basin member and the lower Salt Wash member. Uranium-bearing deposits are found mostly in the Salt Wash member (pl. 12A).

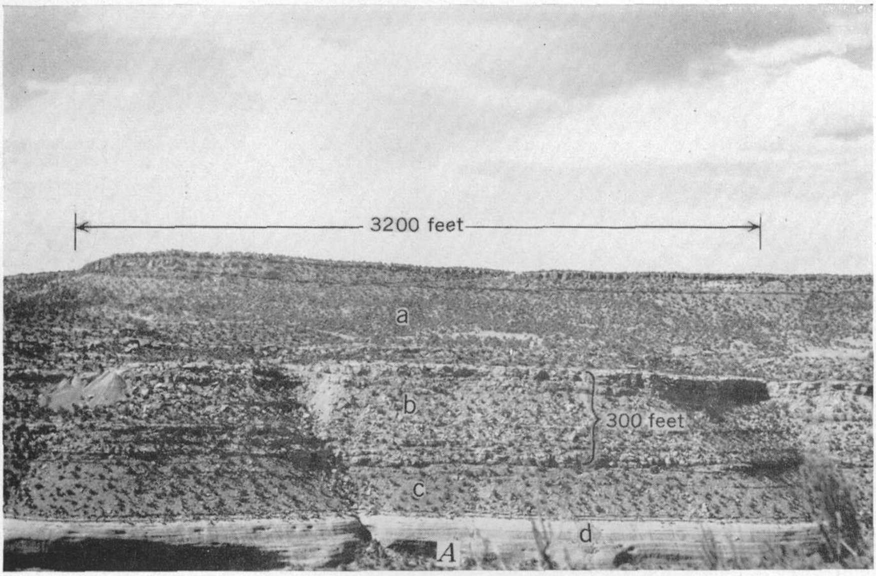
SALT WASH MEMBER

GENERAL FEATURES

The Salt Wash member ranges from 240 to 400 feet in thickness and is composed of about equal parts of sandstone and mudstone strata. On fresh exposures, the color of sandstone ranges from white to gray, yellow, and reddish brown. Limonite occurs in places as specks in the sandstone, and limonite diffusion bands are prominent in some exposures of the sandstone. The sandstone is composed dominantly of fine- to medium-grained clear quartz with minor amounts of white and pink chert, clear feldspar, and interstitial clay. The quartz grains are subrounded to rounded and are well sorted, though in a few places, the textural range is from fine to coarse. Chert grains are angular and their modal diameter is larger than the modal diameter of the quartz grains. Calcite is the principal cementing material. Fossil logs occur in places and are composed of one or more of the following substances: Carbon, silica, limonite, calcite, dolomite, gypsum, and carnotite.

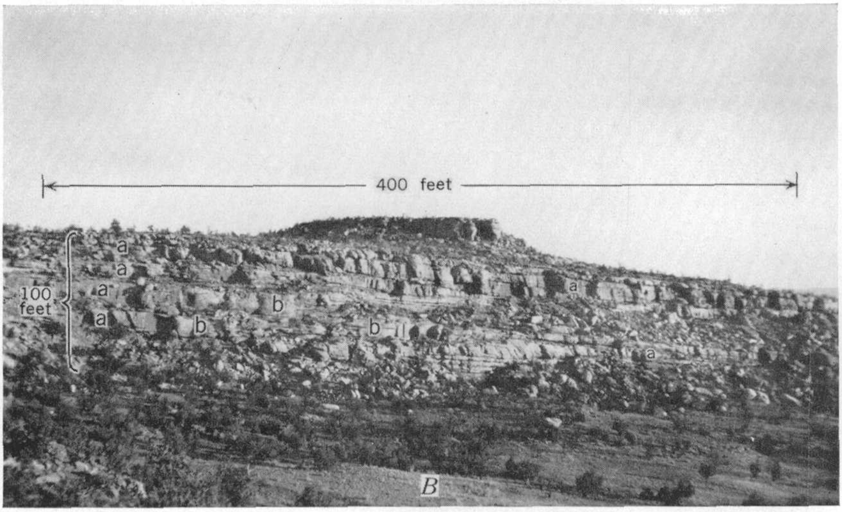
The sandstones of the Salt Wash member are broadly lenticular. Lenses are numerous, forming fairly continuous sandstone strata, and are generally thicker near the top and base than near the middle of the member (pl. 12A). Scour-and-fill bedding is present in places (pl. 12B).

A mudstone sequence with interbedded sandstone lenses occurs between the upper and lower sandstone units. Mudstone also occurs in the sandstone as thin lenses, films, and reworked fragments ranging in size from pebble to cobble. The mudstones are dominantly



A. VIEW LOOKING TOWARD DOLORES GROUP OF MINES

Salt Wash member of Morrison formation (*b*) overlain by Brushy Basin member (*a*), underlain by Summerville formation (*c*) and Entrada sandstone (*d*). Caprock of mesa is Burro Canyon formation of Early Cretaceous age.



B. VIEW LOOKING TOWARD EAST SIDE OF CLUB MESA

Lenticular upper sandstone stratum of the Salt Wash member composed of scour-and-fill sandstone beds (*a*) that interfinger with mudstone at (*b*).

PHOTODIAGRAMS OF THE SALT WASH MEMBER OF MORRISON FORMATION

red and are composed largely of argillaceous material in which minor amounts of fine- to medium-sized quartz grains and other minerals of silt size or slightly larger are mixed. Fossil logs and remnants of vegetal material are almost absent in mudstone.

Over wide areas red mudstone has been altered to a greenish-gray color within and immediately beneath the upper sandstone stratum of the Salt Wash. Altered greenish-gray mudstone is also found locally beneath the lower sandstone stratum of the Salt Wash and beneath individual sandstone lenses in the mudstone stratum. Although the phenomenon of alteration of the clay from red to greenish gray has been established by field evidence the chemical nature of this change and its significance in relation to ore deposition is only partly understood. Results of clay studies by Weeks (written communication, 1952) show that the total iron and ferric-ferrous iron ratio is higher in the red than in the greenish-gray clay and suggest that the change was effected under reducing conditions.

PRINCIPAL ORE-BEARING SANDSTONE ZONE

The upper sandstone stratum, the principal ore-bearing zone, ranges from 15 to 80 feet in thickness. In places this stratum is rather thinly and evenly bedded; the beds range from a few feet to 60 feet in thickness and from several hundred to several thousand feet in horizontal extent (pl. 12A). Sandstone lenses are separated in many places by mudstone lenses that range from a fraction of an inch to 20 feet in thickness. As used in this report, areas of dominantly lenticular sandstones refer to the predominance of channel-type sandstone over sandstone of the flood-plain type. Conversely, areas of dominantly nonlenticular sandstone refers to the predominance of flood-plain sandstone.

Scour-and-fill bedding is common in areas of dominantly lenticular sandstone but is rare in areas of dominantly nonlenticular sandstone. The scour-and-fill bedding consists of truncated segments of sandstone lenses interbedded with thin discontinuous mudstone lenses and conglomerate consisting of mudstone, pebbles, and cobbles. Fragments and masses of fossil wood are abundant in many of these scour-and-fill beds and the sandstone is generally poorly sorted. Scour-and-fill sandstone bedding of the channel-fill type in some places occupies the entire stratigraphic interval of the upper sandstone zone of the Salt Wash but in most places only part of the interval is so occupied.

In places, sandstone lenses in the upper sandstone stratum have filled channels cut in the underlying mudstone, but the depth of these channels rarely exceeds 10 feet. The sandstone filling these channels generally contains more reworked interstitial and conglomeratic mudstone and fossil wood material than sandstone in scour-and-fill bedding at higher levels within the sandstone stratum.

The relatively slight scouring indicated at the contact between the upper sandstone stratum of the Salt Wash and the underlying mudstone over most of the area, together with relatively little redeposited pebble and cobble aggregates of mudstone in the sandstone, indicate a terrain of low relief and gradient upon which the upper sandstone stratum was deposited. Relatively clean claystone and thin limestone lenses near or at the top of the mudstone stratum suggest local ponding prior to or simultaneous with initial stages of deposition of the upper sandstone. In places, the lower 2 or 3 feet of the sandstone lens contains much reworked fragments of claystone and limestone. The individual sandstone lenses within the sandstone stratum were deposited by many aggrading northeastward-flowing streams, which appear to have formed a braided rather than a dendritic pattern. Levee structures have not been recognized; conditions of intermittent flooding and aggradation were probably such that levees, if present, were low lying and continually broken and destroyed by shifting stream channels. Fossil plant material was not seen in place of growth; although stumps with roots in place of growth have been reported in some mines, most of the plant fragments were probably rafted into the positions they now occupy.

The sedimentary-structure trend of a sandstone lens is generally parallel to the long axis of the lens and represents the direction in which the stream that transported and deposited the sand was moving. The direction of movement is indicated by orientation of the thick channel-filled portion of the sandstone, crossbedding, current lineation, and ripple marks. Orientation readings of these sedimentary features have different values and are variable, but where readings of similar value are given equal weight the average of the readings are within 20° of the long axis of the sandstone lens. Orientation of several sandstone lenses in a sandstone stratum are generally confined to a 90° arc. Scour-and-fill bedding structures within a sandstone lens or between two or more sandstone lenses have more erratic trend directions than a single lens or two or more adjacent but discrete sandstone lenses. Dominantly nonlenticular sandstones have relatively consistent trends.

GEOLOGIC GUIDES TO ORE

SMALL-SCALE GUIDES

Geologic features observed in drill cores have been analyzed statistically and have been shown by Weir (1952) to be useful small-scale guides in diamond-drill exploration for uranium ore in the Morrison formation in southwestern Colorado. These geologic features are as follows:

1. The ore-bearing sandstone is 40 feet thick or more in the vicinity of large ore deposits.
2. Sandstone near ore deposits is dominantly light brown, whereas away from ore deposits the sandstone has a reddish cast.
3. The mudstone in and immediately below the ore-bearing sandstone is altered from red to greenish gray in the vicinity of ore deposits, whereas away from ore the amount of altered mudstone decreases.
4. Carbonized woody material is more abundant in the sandstone near ore deposits than away from deposits.

In addition to these features which can be observed in diamond-drill core, geologists have observed that the ore deposits occur mainly in association with mudstone lenses in crossbedded, massive sandstones.

During this study of the Salt Wash member in the vicinity of Uravan the following geologic relations were observed:

1. The sandstones are dominantly lenticular and lithologically similar in the Salt Wash member. Sedimentary structures have a dominant east-northeasterly trend, though locally the trend diverges from the average as much as 45° (pl. 13).
2. Scour-and-fill bedding, fossil wood material, and greenish-gray mudstone occur together in the middle and lower sandstones of the Salt Wash member, but only in the upper sandstone stratum of the Salt Wash are these features associated with ore deposits.
3. Greenish-gray mudstone is continuous beneath lower and upper sandstone strata of the Salt Wash, ranges from 6 to 18 inches in thickness beneath lenticular sandstone strata, and is as much as 5 feet thick beneath channel-fill sandstone of the upper sandstone stratum.
4. The size of the ore bodies is proportional to the thickness of sandstone lenses in the ore-bearing sandstone stratum. Sandstone strata 15 to 35 feet thick contain small deposits of ore, whereas the thicker strata contain both small and large deposits.

The most obvious examples of the association of ore deposits with scour-and-fill sandstone bedding can be seen in the Red Fox, Fortyfive Ninty, and Tramp mines, the Cue Ball and J. B. No. 1 mines in the Julian Group, the Grass Roots mine in the Wright Group, and the Little Dick and Ophir mines in the Dolores Group (pl. 13). Although the structure of the sandstone is not entirely exposed at any one of these mines, a composite section of exposed rocks suggests that the ore zone is composed of several sandstone lenses with relatively flat tops, thin margins, and thick, relatively narrow sections in the center. The long axes of these relict lenses are generally oriented within 45° of one another. Some of the sandstone units are tilted slightly from one another so that underlying and adjacent lenses are beveled, scoured, and in some places, destroyed. Large-scale scour-and-fill bedding structures occur where the thicker part of these units have filled scours in the underlying sand lens or in the underlying mudstone stratum. Projection of these thicker sedimentary structures behind the outcrop is uncertain because of the unpredictable extent and varied trend of superimposed lenses within the ore-bearing sandstone stratum. Field observations suggest, however, that the various scour-and-fill beds are genetically related to one another and reflect the shifting of the braided streams that deposited the sands; therefore, scour-and-fill bedding structures are stratigraphically dispersed in the ore-bearing sandstone stratum, and clusters of these structures are elongated in the direction of depositional trend.

LARGE-SCALE GUIDES

The coincidence of two geologic features in favorable ground became apparent as the areal scope of field work increased away from the vicinity of Uravan. These features or guides are the character of the sandstone bedding, and the thickness and areal extent of altered greenish-gray mudstone immediately beneath the upper sandstone stratum of the Salt Wash. Other guides such as thickness and color of sandstone or presence of carbonaceous material were found to be related but mostly incidental to bedding and altered mudstone. (See plate 13.)

DISTRIBUTION OF LARGE-SCALE GUIDES TO ORE DEPOSITS

SOUTHEAST OF RED FOX MINE AREA

Southeast of the Red Fox mine (pl. 13) sandstones composing the principal ore zone become dominantly nonlenticular, the altered mudstone beneath the zone is continuous but thin, and few ore deposits are found. The sandstones in the Salt Wash member as a whole become dominantly nonlenticular and thin bedded in a distance of a few miles. These sandstone layers are light brown or gray, in a few places reddish brown, uniformly fine grained, hard, and conspicuously limy.

The upper sandstone stratum of the Salt Wash is composed of several thin, relatively persistent sandstone lenses from 1 to 10 feet thick. Total thickness of the stratum ranges from 15 to 25 feet in most places and only in a few places exceeds 30 feet. Scour-and-fill bedding structures in the upper sandstone stratum occur only in a few places and are generally small and poorly developed. Sedimentary-structure trends of different sandstone lenses deviate no more than an average of 20° from a northeasterly direction. Greenish-gray mudstone beneath the upper sandstone stratum is continuous, but only in the vicinity of seeps and springs and near small areas of scour-and-fill bedding is it more than 6 inches thick. Fossil wood is not as abundant as in the Uravan area.

NORTHWEST OF URAVAN

Northwest of Uravan sandstone lenses in the upper sandstone zone of the Salt Wash are thick and dominantly lenticular, but continuously altered greenish-gray mudstone beneath the zone changes gradually to discontinuously altered mudstone where ore deposits are small and few. Discontinuously altered mudstone changes gradually to unaltered mudstone where no ore deposits are found.

Greenish-gray mudstone within, as well as beneath, the upper sandstone zone decreases in thickness northwestward from the Dolores Group of mines to Mesa Creek (pl. 13). Beneath lenticular sandstones at the Dolores Group the greenish-gray mudstone is generally from 6 to 18 inches thick, whereas beneath scour-and-fill sandstones it is from 1 to 5 feet thick. Along the outcrop between the Dolores Group of mines and Mesa Creek the mudstone is discontinuously altered and ranges from a thin film to 6 inches thick beneath lenticular sandstone and from 1 to 3 feet thick beneath scour-and-fill bedded sandstones. This partly altered mudstone commonly has a mottled appearance or consists of alternately banded red and greenish-gray mudstone. Likewise, a transition from discontinuous greenish-gray to unaltered red mudstone occurs in the northwest end of Atkinson Mesa. On the north side of Mesa Creek and the southwest side of Blue Mesa the mudstone at the base of the upper sandstone stratum of the Salt Wash is dominantly red, and only in a few places are found thin discontinuous streaks and films of greenish-gray mudstone.

The transition in color of mudstone is accompanied by changes in color of the overlying sandstone. In the Dolores Group area, lenticular as well as scour-and-fill sandstones are predominantly light brown. In the transition area, an increasing proportion of lenticular sandstone is reddish brown whereas scour-and-fill sandstone is light brown. In the area of unaltered red mudstone, both lenticular and scour-and-fill sandstones are reddish brown.

NORTHEAST OF DOLORES GROUP

Northeast of the Dolores Group in the Blue Basin area the sandstones in the upper sandstone stratum of the Salt Wash are dominantly lenticular, but the underlying altered greenish-gray mudstone is discontinuous and ore deposits are small and few in number.

The Salt Wash is not exposed between the Uravan area and Blue Basin. Between Blue Basin and Mesa Creek the upper sandstone stratum of the Salt Wash is dominantly lenticular, but appears to have a greater range in thickness and probably has less continuity than the sandstone stratum on the west side of Atkinson Mesa and Blue Mesa. Discontinuously altered mudstone underlies exposures of the upper sandstone stratum in the area between Blue Basin and Mesa Creek. On the basis of amount of altered mudstone, this area was recognized as transitional, probably to more favorable ground to the east, and to unfavorable ground to the west. However, the Salt Wash has been lost to erosion east of the transition area and to the west it is covered.

A comparison of sedimentary features in the upper sandstone stratum of the Salt Wash between the unfavorable Blue Mesa and the favorable Uravan areas suggests the need for careful evaluation of ore guides. The sedimentary-structure trends of the lenticular sandstones are alike in the two areas. Fossil vegetal material is more abundant in scour-and-fill bedded sandstone than in surrounding sandstone in both areas. Light-colored sandstone underlain by altered greenish-gray mudstone in the Uravan area contain some carnotite-impregnated logs, but none of the reddish-brown sandstone underlain by red mudstone on Blue Mesa contains carnotite-impregnated logs. Limonite-speck stain occurs in the upper sandstone stratum in both areas, but limonite diffusion bands were observed only in the Uravan area.

The significance of locally thick altered mudstone zones can be misinterpreted because in some places altered mudstone is not associated with favorable ground. Greenish-gray mudstone is locally thicker in the vicinity of water seeps in the Uravan area. A water seep near the base of the upper sandstone stratum of the Salt Wash in a cutbank above the North Fork of Mesa Creek has effected a color change in the sandstone from reddish brown to gray and has changed the color of the underlying mudstone from red to greenish gray in a zone about 3 feet thick and about 30 feet wide.

On the other hand, a locally thick altered mudstone zone may be related to favorable ground in a stratigraphically lower ore-bearing zone. An altered mudstone and sandstone zone about 200 feet wide occurs in the upper sandstone stratum of the Salt Wash on the southwest side of Blue Mesa, where it is associated with a fault belonging to the Roc Creek fault system. The alteration normal to and along this fault may be due to present-day water seepage or to older solutions, perhaps the same solutions responsible for ore deposition in the lower sandstone stratum of the Salt Wash.

NORTH AND EAST OF BLUE MESA

The sandstones composing the upper stratum of the Salt Wash are dominantly lenticular north and east of Blue Mesa; unaltered mudstone beneath the stratum at Blue Mesa undergoes a change in a northward and eastward direction first to discontinuously altered mudstone where ore deposits are small and few in number, then to continuously altered mudstone where ore deposits are large and numerous.

The amount of altered greenish-gray mudstone increases to the northeast along the periphery of Blue Mesa and increases both north and south of Blue Mesa. The northeastern part of Blue Mesa and a belt through the central parts of Outlaw Mesa and Calamity Mesa are areas of discontinuously altered mudstone that are transitional in a northeasterly and northerly direction from an area of unaltered to an area of continuously altered mudstone. The area of continuously altered mudstone includes the northeast corner of Blue Mesa, the northern half of Outlaw Mesa and Calamity Mesa, and all of Tenderfoot Mesa.

Greenish-gray mudstone, from 1 to 5 feet thick, underlies the ore-bearing sandstone zone in the northern part of Outlaw Mesa and on the north-central part of Calamity Mesa. Greenish-gray mudstone is continuous on the northern part of Calamity Mesa and all of Tenderfoot Mesa but in few places is it as much as 1 foot thick.

Sedimentary structures and lithology of the ore-bearing sandstone zone on Outlaw Mesa and the central part of Calamity Mesa are similar to those in the Uravan area, whereas on the northern part of Calamity Mesa and on Tenderfoot Mesa the upper sandstone stratum of the Salt Wash is persistent, dominantly nonlenticular, and is rarely more than 30 feet thick. This sandstone is light brown, fine grained to medium grained, and friable. Sedimentary-structure trends change from east on the northeastern end of Blue Mesa to northeast on the northern part of Outlaw Mesa to north on the central and northern parts of Calamity Mesa and on Flattop Mesa (pl. 13.) On Tenderfoot Mesa trends are dominantly to the east though locally they deviate 20°.

NORTHWEST OF BLUE MESA

On Flattop Mesa the upper sandstone stratum is reddish brown, persistent, lenticular, and more than 50 feet thick. It is underlain by red mudstone except in the vicinity of ore deposits along the northwestern side of the mesa where the upper 3 feet of the mudstone is greenish gray and the sandstone is light brown. The change from red to greenish-gray mudstone occurs in an interval of about 300 feet along the outcrop where greenish-gray mudstone underlies an outcrop of scour-and-fill sandstone; but, red mudstone underlies similiar sandstone structures exposed at other places on the mesa.

On Beaver Mesa the principal ore-bearing sandstone zone is not persistent but where present the sandstone beds are highly lenticular and, in places, unusually thick. The sandstone is generally reddish brown, friable, and seems to contain more fossil wood material than the upper sandstone stratum of the Salt Wash studied elsewhere. Limonite and manganese oxide diffusion banding also seems to be more abundant and occurs in both reddish-brown and light-colored sandstone. The top of the mudstone underlying the upper sandstone zone on Beaver Mesa is red except in the immediate vicinity of ore deposits. On outcrop, no transition between areas of unaltered and altered mudstone is apparent and the change is similar to that on Flattop Mesa.

DISTRIBUTION OF OTHER ORE-BEARING ZONES

Most of the other ore-bearing zones in the Uravan and Gateway districts occur in the Tenderfoot Mesa–Beaver Mesa area. These zones are scattered stratigraphically in conglomeratic sandstones lenses in the lower part of the Brushy Basin member, sandstone lenses between the upper and lower sandstone strata, and in the lower sandstone stratum of the Salt Wash. Altered greenish-gray mudstone underlying these zones is limited to the vicinity of the ore deposits.

An anomalous type of ore-bearing zone in the Roc Creek–Mesa Creek area is localized in the lower stratum of the Salt Wash by faults, fractures, and joints belonging to the Roc Creek fault system. The fault system is due to collapse of an intruded salt plug in Roc Creek, southeast of the Sinbad Valley salt anticline. The ore belongs to the copper-uranium-vanadium type and upriver from Mesa Creek the deposits show a decrease in copper content in a southeastward direction.

LOCALIZATION AND CONTROL OF ORE DEPOSITS

The largest and richest known deposits in the Uravan and Gateway districts are in the vicinity of Long Park, Club Mesa, and the south part of Atkinson Mesa near Uravan; the northern part of Outlaw Mesa, and the central part of Calamity Mesa near Gateway (pl. 13). These deposits are restricted stratigraphically to the upper sandstone stratum of the Salt Wash. The sandstones composing this stratum in these areas are dominantly lenticular and the top of the underlying mudstone is continuously altered. The occurrence of stratigraphically scattered deposits in the Tenderfoot Mesa and Beaver Mesa areas probably reflects a lack of favorable sedimentary structure, the predominance of mudstone, or a lack of continuity of sandstone lenses in the upper stratum of the Salt Wash. However, it must be assumed that definite regional controls were active for ore deposition in the Gateway district, in spite of stratigraphic dispersion of deposits in certain areas. Similarly, the deposits localized by faults in the Roc Creek area and by favorable sedimentary structures in the Uravan district were subject to the same regional controls.

Drilling in the principal ore-bearing sandstone zone has shown that ore bodies occur in elongate clusters, whose long axes are generally normal to the Uravan mineral belt and parallel to the sedimentary-structure trend (Fischer and Hilpert, 1952, pl. 2). Individual ore bodies, however, may or may not be elongate parallel to the sedimentary-structure trend. No consistent interval between deposits could be seen in outcrop or on maps of deposits compiled from drilling data. Also, no consistent pattern of size, number, or spacing of ore bodies is apparent from one cluster to another. Ore deposits are erratically grouped in an elongated pattern probably because complex scour-and-fill sandstone structures localized ore deposition; consequently the pattern of ore deposits reflects the complex distribution of the scour-and-fill structures.

It has been generally conceded that carnotite or its unoxidized parent minerals were deposited by laterally migrating solutions. The present water-carrying capacity of the upper sandstone stratum of the Salt Wash indicates that the permeability and transmissibility of the beds are relatively high. Evidence suggests that the upper stratum of the Salt Wash which is overlain by impermeable mudstone of the Brushy Basin member, is limited in its present function as an aquifer by the small volume of water available in recharge areas rather than by physical nature of the sandstone. For example, one of the most favorable recharge areas for the upper sandstone stratum of the Salt Wash is on the flank of the Uncompahgre Plateau between Blue Basin and Mesa Creek. The discharge in seeps and in drill holes in a relatively discontinuous sandstone stratum downdip from this area is much greater than the discharge elsewhere.

Thus, the upper stratum of the Salt Wash can be likened to an aquifer within which are broad and thick lenticular sandstones of simple structure and lithology that allow the passage of a relatively large volume of circulating solutions. In contrast, the scour-and-fill sandstones within the aquifer are composed of interbedded sandstone and mudstone and mixed lithology in a structure which would either tend to inhibit movement of solutions, providing a locus for ore deposition, or control deposition as "rolls" in adjacent well-sorted sandstone. The ore shows a selectivity for only part of scour-and-fill sandstone and well-sorted sandstone in most places. The unpredictable nature of this selectivity is probably due to the concentration, volume, and pH of the ore-bearing solutions and the reaction of the solutions with clay minerals in the sandstone.

However, the movement of solutions as represented by the regional pattern of altered mudstone (pl. 13) does not correspond to the available regional capacity of the upper Salt Wash sandstones to transmit solutions during Morrison time. Instead, movement of solutions was selective and the resulting pattern of altered mudstone suggests later regional structure control. Alteration effects and primary black uranium and vanadium ore minerals are intimately associated and both are probably the result of laterally migrating reducing solutions that predate oxidation of the metals to carnotite ore.

Ore deposits in or near the Uravan and Gateway districts are composed of carnotite ore, relict uraninite in carnotite ore, and black uranium and vanadium ore minerals in association with pyrite below present ground-water levels. The mineralogy of the black uranium-vanadium ore is largely unknown (Weeks, A. D., written communication, 1952) because the ore has only recently been recognized in deeper workings on Beaver Mesa, Tenderfoot Mesa, and Calamity Mesa, and in deep drill holes in the Uravan district. The occurrence of these ores with one another within the regional pattern of altered mudstone suggests that early ore-bearing solutions and later oxidizing solutions were subject to the same regional control. The associated pattern of altered mudstone and ore deposits also suggests that alteration may have taken place at the time of ore deposition, before or after ore deposition, but before oxidation of the primary black ore to carnotite ore.

The concepts of localization and control of ore deposition have heretofore been based on the hypothesis of a penesyngenetic origin of ore in the ore-bearing sandstone. This has been given tentative support by the development of ore guides (Weir, 1952) which were believed to apply only to the vicinity of ore deposits. Other bases for the penesyngenetic hypothesis rest on local patterns established on the common orientation of ore deposits, trends of ore rolls, fossil logs, and cross beds in favorable ground. A regional pattern that includes parts of the Uravan and Gateway districts, normal to and including favorable ground, based on ore-production data and on closer spacing of deposits and "probably localized by geologic conditions extant during the time the ore-bearing Morrison formation was deposited" (Fischer and Hilpert, 1952, p. 1 and pl. 2) has been named the Uravan mineral belt.

Results of the author's study in the north half of the mineral belt have established that ore deposits are related to one another in a regional pattern of altered greenish-gray mudstone. Sedimentary structures and their trends are incidental to this pattern but within the pattern they are essential controls for localization of ore deposits. In a general way, sandstones are dominantly lenticular northeast of Paradox Valley and Sinbad Valley but only within the pattern of continuously altered mudstone do the ore deposits have a close spacing, large size, and high grade. Ore deposits are small and scattered in the adjoining transitional zone and are absent in the unaltered mudstone zone.

There is no evidence to support projection of the pattern of continuously altered mudstone northeastward from Uravan around the east side of Blue Basin to Outlaw Mesa. The eastern limit of continuously altered mudstone and ore deposits on Spring Creek Mesa, determined by drilling, is from 1 to 1½ miles southwest of the synclinal axis (pl. 13). Projection of the pattern of continuously altered mudstone to the southwest side of Paradox Valley cannot be made because little, if any, work has been done there. However, the position of deposits on both sides of the valley, downdip and roughly parallel to the long axis of the salt anticline, suggests control of ore deposition by that structure.

RELATION OF REGIONAL STRUCTURE TO ORE DEPOSITS

The major structural elements of the area (pl. 13) include a broad northwestward-trending syncline between the Paradox and Sinbad anticlinal valleys on the southwest and the Uncompahgre Plateau uplift on the northeast. The en échelon pattern of these salt anticlines was developed parallel to and contemporaneously with the ancestral Uncompahgre uplift in late Pennsylvanian time. This part of the Uncompahgre was reduced to sea level by Late Triassic time but parts of the salt anticlines remained topographically high until covered by Salt Wash sediments during Late Jurassic time. Deposition continued near sea level during the remainder of Jurassic time and near or below sea level through most of Cretaceous time. Uplift of the Uncompahgre Plateau and compression of the salt anticlines to present regional structure probably began in Late Cretaceous or early Tertiary time. The broad folds or highlands formed by the Uncompahgre uplift and the salt anticlines were eroded to a region of low relief before middle Tertiary time. Broad uplift of the Colorado Plateau, rejuvenation of streams and canyon cutting, and increase in groundwater circulation with breaching of the crests of the salt anticlines followed, probably in middle Tertiary time. The early stage of canyon cutting was interrupted and modified by doming resulting from igneous intrusion of the La Sal Mountains. Renewed folding and uplift of the Uncompahgre Plateau evidenced by the present elevation of Unaweep Canyon probably occurred in late Tertiary or early Pleistocene time (Cater, 1954).

Modification of earlier Tertiary structure by doming of the La Sal Mountains of Utah and renewed late Tertiary uplift of the Uncompahgre Plateau disrupted the early synclinal structure parallel to the Uncompahgre Plateau and produced a high divide of the Beaver Mesa area. Northeast of Calamity Mesa renewed uplift of the Uncompahgre produced faults that have about 1,500 feet of stratigraphic throw and northeast of Uravan faults that have about 500 feet of stratigraphic throw. The same movement probably shifted the synclinal axis to the southwest in the Uravan district. Abstraction of salt and collapse of a salt plug in Roc Creek shifted the synclinal axis locally to the southwest in the lower Mesa Creek area.

Observed relations between the position of ore deposits and the patterns of altered and partly altered mudstone is interpreted as a reflection of fluctuating ground-water conditions in ore-bearing beds in both the Gateway and Uravan districts. However, the position of ore deposits and the related patterns of mudstone alteration show no apparent control by the thickness of the Salt Wash and Brushy Basin members (pl. 13), relative thickness of the members as drawn in a diagrammatic section (pl. 13), or by favorable sedimentary structure in the Blue Mesa area (pl. 13). If the apparent lack of evidence for regional control of ore deposition by geologic conditions extant during the time the Morrison formation was deposited is valid, then it must be assumed that the position of deposits and patterns of alteration were controlled by regional structures resulting from crustal movement in Late Cretaceous or early Tertiary time.

Restoration of Tertiary regional structures that may have controlled ore disposition is complicated by episodes in the structural history such as doming of the La Sal Mountains, the extent and magnitude of early Tertiary uplift of the Uncompahgre Plateau, the difference in magnitude of salt folds, and the adjustment of salt anticline structure to abstractions of salt from middle Tertiary time to the present. The occurrence of ore deposits parallel to the long axis of the Dolores anticline and the Gypsum Valley and Paradox Valley salt anticlines and the variable range in elevation of deposits from one anticline to another suggest early Tertiary control of mineralization by these structures. However, the position of deposits in the Gateway district is anomalous in that those on Tenderfoot, Calamity, and Outlaw Mesas have no apparent spatial relation to salt anticlinal structure. If the hypothesis for Tertiary structural control of ore deposition is true it is probable that the early Tertiary Uncompahgre uplift played a role similar to that of salt structures in controlling ore solution movement in part of the Gateway district.

Thus, if the deposits in the Gateway district which now range between 6,400 and 7,000 feet in altitude were restored to the altitude existing before uplift of the La Sal Mountains and the last uplift of the Uncompahgre Plateau there is no assurance that the restored altitude would be that of deposits in the Uravan district which range from 5,300 to 6,500 feet. On the contrary, there is a strong suggestion in associated patterns of alteration and deposits in the Uravan-Gateway districts that ore deposition occurred in discrete ground-water systems localized by individual early Tertiary structural environments.

ORIGIN OF ORE DEPOSITS

Coffin (1921), Hess (1933), and Fischer and Hilpert (1952) have defined mineral belts in southwestern Colorado and from detailed studies concluded that the geologic relations are best interpreted as the result of circulating ground waters leaching and redepositing uranium and vanadium minerals soon after deposition of the Salt Wash member. Butler (1920) and others believed that similar deposits in Utah may have been influenced by circulating ground waters resulting from folding and faulting in Tertiary time.

The geologic history of the Colorado Plateau permits the interpretation of ore deposition either soon after the ore-bearing Morrison formation was deposited, during Cretaceous time, or after an upset of Mesozoic structural conditions near the end of that era or in early Tertiary time. Results of this study in the Uravan and Gateway districts have established that a regional pattern of altered greenish gray mudstone is coincidental with a regional pattern of ore deposits in both of these districts. The patterns of ore deposits and altered mudstone responded to geologic conditions that were active either before or after Late Cretaceous time. This study has shown that the common orientation of sedimentary features such as cross beds, fossil logs, and ore "rolls" reflecting the influence of geologic conditions during Salt Wash time, are incidental to the pattern of altered mudstone but that within the pattern of altered mudstone scour-and-fill bedded sandstone structures are essential controls for localization of ore deposits. Also, the coincidental regional patterns of altered mudstone and ore deposits was probably not controlled by regional geologic structure extant before the end of Cretaceous time (pl. 13, diagrammatic section). On the other hand, the spatial relation of the common pattern of ore deposits and altered mudstone with Tertiary structures in the vicinity of or adjacent to salt anticlines suggests that ore deposition accompanied or followed folding in Late Cretaceous or early Tertiary time. The position of deposits and the pattern of mudstone alteration provide a geologic basis for delineating discrete mineral belts in the Uravan and Gateway districts.

If the suggested control of ore deposition by Tertiary structure is true then a hypogene source must be inferred for the ore-bearing solutions (Cater, 1954). Geochemical relations are necessarily generalized because little detailed geochemical work has been done on ore deposits on the Colorado Plateau and on the relation of salt bodies and ore deposits in particular. The presence of vein copper deposits and fault-controlled copper-uranium-vanadium deposits (pl. 13) in close association with salt structures suggests that uranium-bearing solutions could also move upward in channels provided by salt intrusions to the overlying Salt Wash member. Recent discovery of black uranium and vanadium ore minerals and uraninite in disseminated type ore deposits suggests that carnotite is secondary to these minerals in fault controlled deposits in the Roc Creek area.

The ores in the region of salt anticlines are predominantly potassium-uranyl-vanadates (carnotite) but outside this region, as in Monument Valley in Arizona, the Grants district in the Four Corners area, the Edgemont area near the Black Hills, and the Pumpkin Buttes area in northeastern Wyoming, the dominant minerals are calcium-uranyl-vanadate (tyuyamunite) and hydrous calcium-uranyl-silicate (uranophane). It is reasonable to believe that the association of potassium with uranium and vanadium in the salt anticline region is due to the presence of potassium chloride and high potash shales in salt bodies. Solutions from which primary uranium and vanadium minerals were precipitated, and other later solutions, in following the intrusive path of salt bodies, took potash into solution from contact with black shales. These reducing, primary ore-bearing solutions were probably responsible for the color change of red to greenish-gray mudstone in the vicinity of deposits. Later, aerated ground water oxidized the primary uranium and vanadium minerals to carnotite.

Recent work by Stieff and Stern (written communication, 1951) on age determinations of ore minerals in hypogene hydrothermal veins in the Front Range, in sediments of Triassic and Jurassic age on the Colorado Plateau, and in fault-controlled deposits on the Plateau, indicates a common, probably early Tertiary age for all these deposits.

LITERATURE CITED

Butler, B. S., and others, 1920, Ore deposits of Utah: U. S. Geol. Survey Prof. Paper 111.

Cater, F. W., Jr., 1954, Geology of the Bull Canyon quadrangle, Colorado: U. S. Geol. Survey Geologic Quadrangle Map GQ 33.

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

Fischer, R. P., and Hilpert, L. S., 1952, Geology of the Uravan mineral belt: U. S. Geol. Survey Bull. 988–A.

Hess, F. L., Uranium, vanadium, radium, gold, silver, and molybdenum sedimentary deposits, *in* Ore deposits of the western states (Lindgren volume): Am. Inst. Min. Metall. Eng., p. 467.

Weir, D. B., 1952, Geologic guides to prospecting for carnotite deposits on Colorado Plateau: U. S. Geol. Survey Bull. 988–B.

O