Monument Valley area, Apache and Navajo Counties, Arizona, with a section on serpentine at Garnet Ridge by E. E. Malde and R. E. Thaden: U.S. Geol. Surv. Bull. 1103, 171 p.
21. Thaden, R. E., *et al.*, 1964, Geology and ore deposits of the White Canyon area, San Juan and Garfield Counties, Utah: U.S. Geol. Surv. Bull. 1125, 166 p.
22. Witkind, I. J., 1964, Age of the grabens in southeastern Utah: Geol. Soc. Amer. Bull., v. 75, p. 99–106.
23. Young, R. G., 1964, Distribution of uranium deposits in the White Canyon-Monument Valley districts, Utah-Arizona: Econ. Geol., v. 59, p. 850–873.
24. Lewis, R. Q., Sr. and Campbell, R. H., 1965, Geology and uranium deposits of Elk Ridge and vicinity, San Juan County, Utah: U.S. Geol. Surv. Prof. Paper 474-B, p. B1–B69.

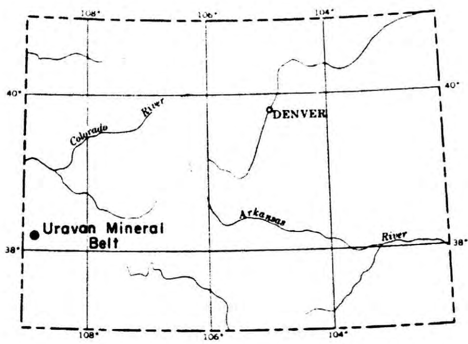
39. Geology and Uranium-Vanadium Deposits in the Uravan Mineral Belt, Southwestern Colorado

J. E. MOTICA*

Contents

Illustrations

* Union Carbide Corporation, Grand Junction, Colo.



ABSTRACT

Ores containing uranium and vanadium minerals have been mined from the Salt Wash Member of the Morrison Formation from many localities in the Colorado Plateau region since about 1900. The most productive deposits are in a relatively small area in Southwestern Colorado referred to as the Uravan mineral belt.

The mineral belt is a narrow elongate area in which uranium-vanadium deposits in the Salt Wash have a closer spacing, larger size, and higher grade than those in adjoining areas. Pre-1948 ore production from the mineral belt was 655,000 tons averaging 1.91 per cent V_2O_5 and 0.28 per cent U_3O_8. Production during the 1948 to 1964 period was 7,900,000 tons of ore averaging 1.46 per cent V_2O_5 and 0.27 per cent U_3O_8.

The ore deposits occur principally in the uppermost sandstone unit of the Salt Wash. This unit consists of sandstone lenses formed by a system of aggrading braided streams flowing in an easterly direction generally normal to the mineral belt. These lenses, referred to as channels, are as much as one mile in width and average about 50 feet in thickness and can be traced for several miles along their courses. Areas favorable for one deposits are recognized principally by the following criteria: (1) a host sandstone thickness of over 30 feet, (2) the presence of carbonaceous material in the host sandstone, and (3) gray mudstones and clays associated with the ore-bearing sandstone. The ore minerals are believed to have been precipitated from laterally migrating solutions; there is no apparent genetic relationship between ore deposits and tectonic structural features.

Exploratory and development drilling from the surface is conducted in three phases: first, wide-spaced drilling to find and outline favorable channels; second, moderate-spaced drilling in favorable ground to locate ore deposits; and third, close-spaced drilling to block-out ore. Long-hole drilling from underground stations is used to find and delineate extensions of ore bodies being mined.

Due to intense production since 1948 from shallow deposits, best potential for new deposits exists in areas where the ore-bearing unit is 600 to 800 feet deep.

INTRODUCTION

Uranium-vanadium deposits in the Salt Wash Member of the Morrison Formation occur at many locations in the Colorado Plateau region. In general, the more productive occurrences are in southwestern Colorado and adjacent portions of southeastern Utah in an area referred to as the Uravan mineral belt.

The mineral belt extends in an arcuate pattern from Polar Mesa in southeastern Utah to the Slick Rock district in southwestern Colorado as indicated by Figure 1. As it is known at present, the Uravan mineral belt is approximately 70 miles long and 2 to 8 miles wide. The boundaries of the belt are indistinct and are subject to personal interpretation.

The idea of a mineral belt was first conceived in 1943 by R. P. Fischer (1) of the U.S. Geological Survey, who defined it as a narrow elongate area in which the uranium-vanadium deposits in the Salt Wash generally have closer spacing, larger size, and higher grade than those in adjoining areas and the region as a whole. Exploration work within and adjacent to the area postulated by Fischer to be a mineral belt has verified Fischer's original concepts of it.

Even though total uranium ore production from other uranium districts may exceed that from the Uravan mineral belt, the area of this belt has special significance in the uranium industry due to its long and colorful history and to the nature of the hundreds of ore occurrences in it. Some of the world's earliest recorded production of uranium minerals came from outcrops in the Uravan mineral belt. The belt also has the distinction of being the world's leading producer of vanadium from 1948 to the present, as a result of coproduction with uranium.

Due to the strategic importance of the ore deposits within the mineral belt, the geology has been intensely studied and results reported in publications issued by the U.S. Geological Survey, the U.S. Atomic Energy Commission, and geologists working with private concerns. Much has been learned about the geology of the ore deposits in the Salt Wash; however, important questions remain unanswered. The purpose of this paper is to summarize known pertinent geologic features relative to the uranium-vanadium ore deposits in the Uravan mineral belt as well as to outline exploration techniques in common use throughout the area.

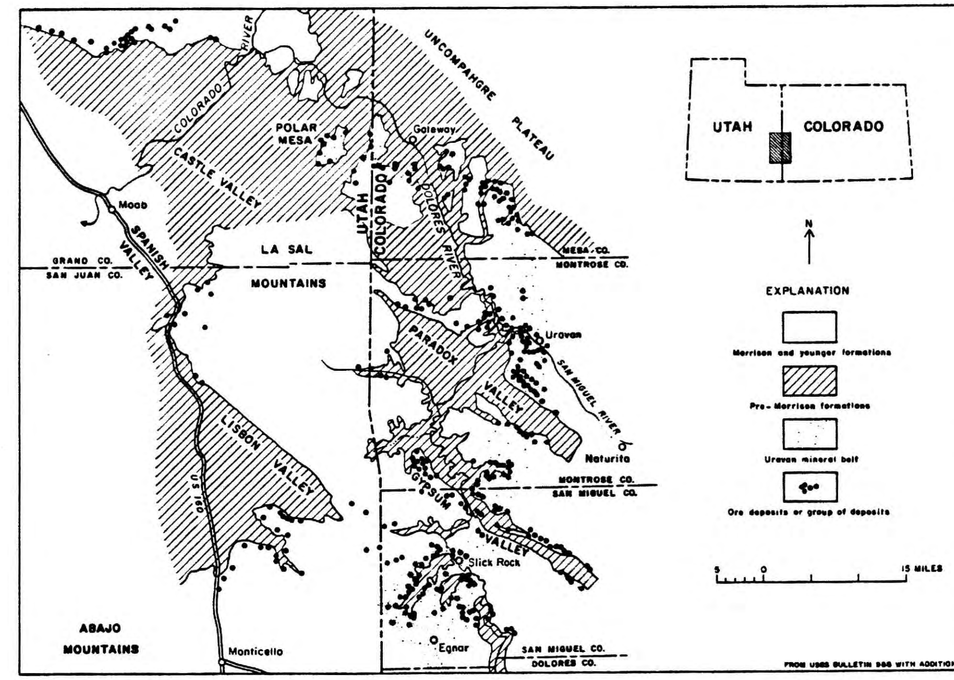


FIG. 1. *Map, showing the location of the Uravan Mineral Belt.*

History and Production

Interest in the deposits in the Uravan mineral belt varied from the time of discovery in 1898 to the present, depending on the demand for a particular metal. Initial interest in the deposits was by the French who recovered radium from the ores in the early 1900's. Domestic recovery of radium from these ores prevailed from 1910 to 1923, when the uranium deposits in the Belgian Congo were brought into production and this source supplied the demand for radium. From 1915 to 1923, however, some by-product vanadium and a little by-product uranium were recovered from the radium ore of the mineral belt ores. There was virtually no production from the mineral belt from 1923 until 1937, when the mines were reactivated in response to increased demands for vanadium. Mining for vanadium continued to 1944, but some uranium was recovered as a by-product under the Manhattan Project during World War II years. Most mines were inactive from 1945 to 1948, when the Atomic Energy Commission initiated the domestic uranium procurement program. Production was greatly expanded under this program and has been intensive from 1948 to the present, vanadium being recovered from the ores as well as uranium. Some of the operators in the mineral belt are participating in the AEC's uranium stretch-out program and production is assured through 1970.

Most of the ore mined in the Uravan mineral belt has been from underground mines. Production records furnished by the U.S. Atomic Energy Commission show the following for the mineral belt:

Period	Tons of Ore	Grade	
		V_2O_5	U_3O_8
Pre-1948	655,000	1.91%	0.28%
1948–thru 1964	7,900,000	1.46%	0.27%

Principal operators with milling facilities under the AEC program include Union Carbide Corporation, Vanadium Corporation of America, and Climax Uranium Company. In addition to ores processed from properties controlled by these milling companies, significant quantities of ore are treated from properties operated by independents.

GEOLOGY

Stratigraphy of the Salt Wash

The Salt Wash Member of the Morrison Formation has been studied extensively by Craig (3), who concluded that the member was formed as a large alluvial fan by an aggrading system of braided streams diverging to the north and east from an apex in south-central Utah. The entire Salt Wash in the Uravan mineral belt area averages about 250 feet thick and is composed of interbedded units of sandstone and mudstone.

The sandstone units within the Salt Wash range in color from red to brown to light gray. The mudstone units vary from red-brown to gray-green. The colors of the units within the Salt Wash will be further discussed under the section of this paper which describes guides to ore deposits.

The Salt Wash conformably overlies the Summerville Formation, which consists of approximately 100 feet of marine shale, mudstone, and thin-bedded sandstone. Overlying the Salt Wash is the Brushy Basin Member of the Morrison Formation; it is composed predominately of variegated mudstone, with lenses of siltstone, sandstone, and conglomerate, principally in the lower portion of the member. The Brushy Basin varies in thickness from 400 to 500 feet throughout the mineral belt. The contact between the Salt Wash and the Brushy Basin is not a distinct boundary but rather one that is picked somewhat arbitrarily. Some geologists place the contact at the top of the uppermost prominent sandstone in the Salt Wash. Craig (3) describes the contact as at the base of a widespread chert pebble conglomerate in the lower portion of the Brushy Basin.

Commonly the Salt Wash consists of three prominent stratigraphic units of sandstone separated by layers of mudstone and thin sandstone lenses. The three sandstone units are similar in lithology and thickness. Occasionally a unit will split to give more than three sandstone layers or a unit may be entirely missing and only two prominent sandstone layers will be present. The uppermost unit is by far the most important from the standpoint of ore production and reserves, but some ore has been mined from deposits in the other two Salt Wash units as well as from sandstone beds in the lower part of the Brushy Basin.

The uppermost sandstone unit in the Salt Wash represents several separate sandstone deposits formed by several separate aggrading braided stream systems at the same stratigraphic level. Many geologists working with the Salt Wash refer to these fluvial sandstone deposits as channels.

The character of the individual ore-bearing sandstone channels is remarkably similar throughout the Uravan mineral belt. The channels are as much as one mile or more in width and can be traced for several miles along their courses. The depositional direction is easterly, generally normal to the Uravan mineral belt. The edges of the sandstone channels are indistinct and are usually represented by a gradual thinning of sandstone and lateral gradation to mudstone. The sandstone thickness within a channel ranges from 25 feet to 100 feet with an average of about 50 feet. The abnormally thick portions of a channel occur randomly and generally represent local conditions which are not continuous over large areas.

Lithology of the Salt Wash

The ore-bearing sandstone is fine to medium grained and is composed predominately of quartz with minor amounts of accessory minerals consisting of feldspar, chert, zircon, tourmaline, garnet, staurolite, rutile, apatite, and magnetite-ilmenite. In light brown and light gray portions of the host rock, iron occurs as limonite in the oxidized zones and as pyrite and marcasite in the unoxidized zone. Nondetrital components are mainly silica, calcite, dolomite, and gypsum.

Clay minerals are important constituents of the Salt Wash ore-bearing sandstones, occurring as films coating the sand grains, as galls and pebbles, and as lenses of claystone and mudstone. The dominant clay minerals as reported by Keller (7) are illite and chlorite with subordinate amounts of kaolin.

Carbonaceous materials occur in restricted portions of the ore-bearing sandstone. The carbonaceous occurrences represent the coalified remains of vegetal matter enclosed within the sandstone at the time of formation. The carbonized plant remains vary from minute flakes to entire trees and occur in amounts ranging from sparse to abundant, generally in portions of sandstone containing abundant clay. The carbon-bearing section of the sandstone averages only a few feet in thickness.

Sedimentary structures in the ore-bearing sandstone include crossbedding, current lineation, festoons, ripple marks, and scour and fill features. Typically, these structures are present principally in the middle or lower portion of the ore sandstone and the upper portion is generally horizontally bedded or structureless. The sandstone is typically a hard competent rock that stands well during mining.

Structural Features

The most conspicuous tectonic structural features in the Uravan mineral belt area are two northwest-trending salt anticlines which are traversed by the belt. The sedimetary beds along the flanks of these salt anticlines dip at angles ranging from about 5° to 15°. The sediments throughout the balance of the mineral belt are essentially flat-lying or dip at low angles.

The only significant faulting in the mineral belt area is that associated with collapse of portions of the salt anticlines. Faults parallel to the anticlinal axes were developed along the margins of the collapsed areas. Ore deposits in the host sandstone have been displaced by some of these faults, indicating that the faults are post-mineral.

ORE DEPOSITS

Principal metals recovered from the Uravan mineral belt ores are uranium and vanadium. Radium was recovered early in the 1900's but no substantial amounts have been recovered since about 1923. Trace amounts of other metals have been detected in the ores, but none of these occurs in quantities sufficient to warrant recovery. Metals detected other than those found in common rock forming minerals include molybdenum, copper, silver, selenium, chromium, nickel, cobalt, rare earths, and manganese.

Principal uranium minerals in the unoxidized ores are uraninite and coffinite while the main uranium mineral in the oxidized ores is carnotite with minor amount of tyuyamunite. Vanadium-bearing clays, consisting of chlorite and hydromica, are the main vanadium minerals in both the oxidized and unoxidized ores. Montroseite, a low-valent vanadium oxide, occurs in significant amounts in the unoxidized ores. The vanadium in the vanadiferous clays is firmly fixed and is relatively unaffected during oxidation; however, montroseite oxidizes readily first to an intermediate mineral, corvusite, which imparts a blue-black color to the ore. Upon further oxidation the vanadium forms a series of vanadates consisting of carnotite, hewettite, metahewettite, pascoite, rauvite, fervanite, and hummerite. These secondary vanadates do not account for a large proportion of total vanadium in the ores. The mineralogy of the Salt Wash ores is well summarized in a paper by Weeks *et al.* (6).

The uranium-vanadium mineralization imparts a distinct coloration to the host rock, and grades can often be estimated relatively closely on the basis of color. The vanadiferous clays vary in color from a light gray to almost black, depending on the vanadium content. The reduced uranium and vanadium oxide minerals are black, and carnotite is a bright yellow.

Studies show that there has been very little, if any, migration of uranium and vanadium during oxidation. A thin film of carnotite will occasionally be found along fractures, particularly in the fault zone bordering the salt anticlines, but the amount of mineralization found under these conditions rarely is sufficient to make ore.

The uranium and vanadium minerals almost always occur intimately mixed together regardless of the environment containing the mineralization or type of mineral association. Occurrences of one metal without the other in large amounts are virtually unknown in the Uravan mineral belt area. Generally the amount of vanadium exceeds the uranium in ratios ranging from 3:1 to 10:1 for large quantities. This ratio will tend to vary throughout individual deposits as well as between channels. Controls affecting the vanadium-uranium ratio are not known at this time.

The nature of the uranium-vanadium mineralization suggests that the ore minerals were precipitated from laterally migrating solutions inasmuch as the minerals are not related to fractures or through-going feeders. The ore minerals impregnate the host sandstone and occur principally as interstitial cement with lesser amounts occurring as replacement of vegetal material and with clay galls and thin clay seams.

The Salt Wash ore deposits in the Uravan mineral belt area are relatively small, tabular or podlike bodies, the long dimensions of which are parallel to the bedding. The deposits are irregularly shaped, both in section and in plan, and generally consist of a single ore layer which may split into two or more tongues. In places, more than one ore layer may be present in the principal ore-bearing sandstone, and the ore layers are separated by unmineralized rock. Commonly the ore deposits are elongate in a direction parallel to the long axis of the channel. The deposits can be almost anywhere within the boundaries of the sandstone channel but they are generally in areas with average or greater sandstone thickness. The ore deposits favor the portion of the sandstone containing carbonaceous material although not all carbon-bearing portions are mineralized.

Typically the ore deposits are nearly concordant to the bedding of the host rock but frequently the ore layers cut sharply across the bedding for no obvious reason, forming deposits known as rolls. Shawe (4) describes roll ore bodies as layered deposits that cut across sandstone bedding in sharply curving forms. The roll ore bodies are typically C or S shaped in cross-section (Figure 2) and may be elongated for several hundred feet generally parallel to the long axis of the sandstone channel. The rolls are a few feet wide at their widest portion and up to 10 feet in height with an average of about 5 feet. A significant feature of the roll ore bodies is the sharp boundary along the edges between mineralized and barren rock. Roll ore deposits are found in both oxidized and unoxidized portions of of the host sandstone. Shawe (4) postulates that the roll ore bodies were formed by precipitation of minerals at the interface between solutions of different composition and density. Ore production from roll deposits is relatively small compared to the total production from other Salt Wash deposits.

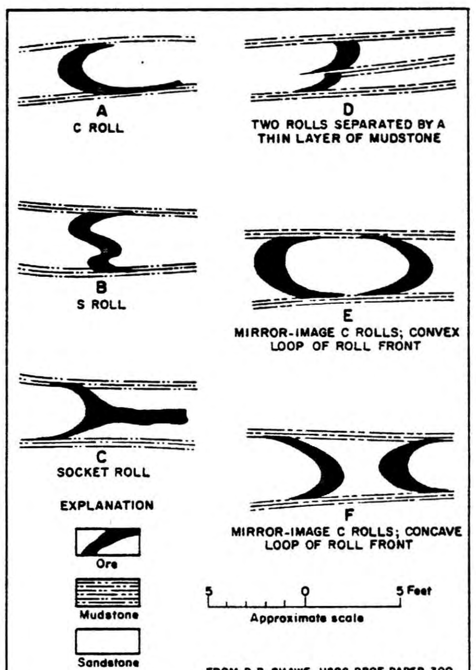


FIG. 2. *Cross-sectional Forms of Roll Ore Bodies.*

The ore deposits vary considerably in size, ranging from deposits consisting of a single mineralized fossil log containing a few tons of ore to those that may be continuous for several hundred feet containing many thousand tons of ore. Wood and Lekas (5) studied 666 typical Salt Wash ore deposits that ranged in size from a few hundred to 150,000 tons. Results of the study showed that 70 per cent of the deposits contained less than 3000 tons each. The ore thickness ranges from a few inches to about 25 feet, but the average is only 3 to 4 feet. Sub-ore grade mineralization is associated with the ore deposits, but large halos of low grade mineralization are not common. The edges of the ore deposits are very irregular and are defined by either abrupt or gradual changes in grade or thickness.

The intensity of uranium-vanadium mineralization varies considerably throughout a typical deposit ranging from weakly mineralized rock to ore containing several per cent U_3O_8 and V_2O_5. Average shipping grades of typical mines are 0.2 to 0.3 per cent U_3O_8 and 1 to 2 per cent V_2O_5.

A typical mine area (Figure 3) generally consists of one or more clusters of individual ore bodies which may or may not be connected by low grade mineralization. Economics of mining generally determine the lateral extent of mine workings from a given mine opening. Production from individual mines ranges from a few hundred to a few hundred thousand tons.

GUIDES TO ORE

Principal criteria used in exploring for uranium-vanadium deposits in the Salt Wash throughout the Uravan mineral belt are: (1) thickness of the host sandstone, (2) quantity of carbonaceous matter within the ore-bearing sandstone, (3) color of the host sandstone and associated clays and mudstones, (4) lithology and sedimentary structure of the host sandstone, and (5) radioactivity. Weir (2) describes a statistical study of some of these features as seen in drill core and suggests a scheme of numerical rating to appraise the favorableness of the rock penetrated by a drill hole.

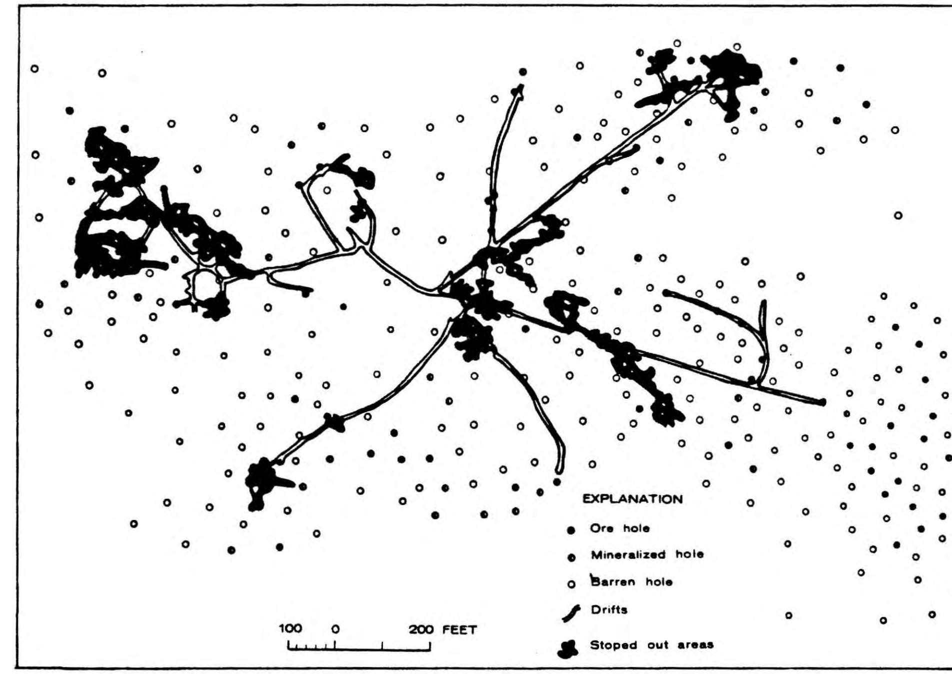


FIG 3. *Plan Map, showing a Typical Salt Wash mine.*

Although ore deposits are known to occur almost anywhere within the channels, regardless of sandstone thickness, the deposits favor the thicker portions of the sandstone unit. Generally the minimum favorable sandstone thickness is about 30 to 35 feet and the most favorable thickness is from 50 to 90 feet. In areas where the sandstone unit splits into more than one layer, ore deposits frequently occur in each layer.

Organic matter appears to have greatly influenced the emplacement of the ore minerals since, although not all carbon-bearing zones are mineralized, almost all ore deposits are associated either directly with or are adjacent to carbonaceous materials. Rich concentrations of ore minerals frequently occur with local accumulations of coalified plant remains, sometimes referred to as "trash piles," and fossil logs almost completely replaced by ore minerals are common throughout the mineral belt. However, the size and grade of an ore deposit is not always governed by the amount of carbonaceous material present. Large ore deposits are known to occur with only moderate amounts of carbon and unmineralized carbon-bearing zones commonly occur adjacent to ore deposits. The permeability of the host sandstone does not seem to be a key factor in determining whether or not a carbonaceous zone will be mineralized. The association of ore deposits with coalified plant remains is not fully understood.

The color of the ore-bearing sandstone and associated clays and mudstones differs between areas favorable and unfavorable for ore deposits in the Salt Wash. In the favorable areas, the host sandstone is light brown in the oxidized zone and a light gray where unoxidized, and the clays and mudstones are some shade of gray in both the oxidized and unoxidized zones. In unfavorable areas, the sandstone and associated clays and mudstones are principally red colored in both the oxidized and unoxidized zones. There appears to be a close spatial relationship between the distribution of gray clays and mudstones with carbonaceous matter, indicating that the red ferric oxide has either been reduced to the ferrous state or has been removed by solvents originating from the decay of vegetal matter.

Lithology and sedimentary structures within the host sandstone serve to indicate potential carbon-bearing zones. The carbonaceous material generally is located in lithologic zones containing abundant clay galls or seams and in thin bedded sandstone.

Radioactivity is helpful in defining areas favorable for ore deposits. Only a small proportion of the carbon-bearing areas contain ore deposits, and a significant amount of the carbonaceous material is not even weakly mineralized. All drill holes are generally probed for radioactivity, and carbonaceous zones showing weak radioactivity are considered to be more favorable than those that are completely barren.

There is no apparent genetic relationship between regional structures and ore deposits in the Salt Wash in the Uravan mineral belt, although the salt anticlines may have influenced the Salt Wash drainage pattern. Ore deposits are found in sandstone channels located in synclines as well as those associated with anticlines. The major portion of the mineral belt is free of faults, and the only significant faulting is that associated with collapse features in the salt anticlines. Where faults intersect ore deposits, the deposits are displaced, indicating that the particular faults are post-mineral.

Typically an upper Salt Wash sandstone channel within the Uravan mineral belt exhibits favorable characteristics in varying degrees over a large area; however, estimates are that less than 10 per cent of the favorable area actually contains ore deposits. Studies to date have failed to reveal the specific features that localized the ore deposits.

EXPLORATION METHODS

Exploration procedures generally in use are based on the favorable criteria outlined above. Initially, efforts are made to outline the boundaries of the sandstone channels containing the ore deposits. This information is compiled from outcrop studies and from drilling data. In unexplored areas, wide-spaced core drilling is used for the first drilling phase. Holes are placed on about 1000 foot centers in fences approximately normal to the projected direction of stream deposition. Information from this phase of exploration not only delineates the channels but serves to outline broad areas of favorability.

The second drilling stage is conducted within the favorable areas indicated by phase I and the purpose is to attempt to obtain ore intersections. Core drills are generally used during this phase and holes are placed at random on 200 to 600 foot centers or as offsets to any mineralized holes drilled during phase I.

The third drilling phase is the ore-blocking-out phase which is designed to outline the ore deposits. Normally, ore or mineralized holes from stage II are offset on a square grid. Due to the erratic nature of the Salt Wash ore bodies, holes should be drilled on about 25 foot centers if the deposits are to be outlined with a high degree of accuracy. Since this is impractical because of the high cost of sufficient drilling, drill hole centers are expanded to different distances depending on the depth to the ore horizon. At shallow depths of 150 feet or less, drill holes are on about 50 foot centers. Block-out centers are expanded as depths increase to where holes are drilled on about 200 foot centers where the ore-bearing sandstone is 600 to 800 feet below the surface. Only a small proportion of the total ore reserves is intersected by holes on these centers, but sufficient data are collected to compute reserves over relatively large areas. The ratio of ore holes to total holes drilled serves as a basis for computing ore reserves, and the computations are greatly influenced by the favorability of the ore-bearing sandstone.

Core drills are used generally for phases I and II, and for block-out drilling in deep areas, but in all of these only the ore-bearing sandstone is cored. Wagon drills and rotary plug drills are used for blocking out ore in relatively shallow areas. Generally all holes are probed for radioactivity which gives a reliable estimate of uranium grade since the uranium and decay products are in good equilibrium in both the oxidized and unoxidized zones.

Underground long-hole drilling, employing diamond drills or percussion drills, is used extensively to supplement surface drilling, principally in deep mines where final block-out surface drill holes are on centers of 100 feet or greater. Stations for drill sites to be located in haulage drifts are generally predetermined and are included in the primary mine development plans. In planning the location of the underground drill sites, efforts are made to position the stations so as to obtain a large angle of intersection with the target zone; however, where this is difficult, raises are driven

for the drill position, thus increasing the angle of intersection.

Several holes, in a radiating pattern, are drilled from each drill station to intersect favorable target zones within the ore-bearing sandstone. Maximum effective length of diamond drill holes is about 200 feet and of holes drilled with percussion machines about 75 feet. Holes are drilled with water as a circulating medium, and cores or drill cuttings generally are not saved, but the holes are probed for radioactivity.

Geologic maps showing ore trends and favorability of the host sandstone are constructed for those areas of interest as geologic information becomes available. These maps are used to plan successive drilling programs and also provide information which is useful for planning primary mine development. A common method used in constructing these maps is to assign numerical ratings to each drill hole and then to contour the values. The numerical ratings represent a summation of values assigned individual geologic guides used to evaluate favorability. Data acquired from underground geologic mapping are added to the maps to provide additional information that may indicate favorable trends.

Drilling depths to the ore horizon throughout the Uravan mineral belt vary considerably. The Salt Wash ore sandstone is exposed along numerous drainages within the belt, and where benches have developed on top of the Salt Wash, drilling depths are less than 250 feet. Most of the ore produced to date in the Uravan mineral belt has come from these areas with relatively shallow depths to ore. There are large areas in the mineral belt, however, where the surface is formed by the Dakota Formation and depths to the Salt Wash ore horizon are approximately 700 feet. A considerable amount of exploration for Salt Wash ore deposits has been done in these deeper areas, and a significant amount of production has resulted from successful exploration programs.

OUTLOOK FOR FUTURE DISCOVERY

Most of the lands throughout the Uravan mineral belt area consist of public domain, and mineral rights are held under mining claims. Large areas within the mineral belt were withdrawn from entry during the early years of the AEC uranium procurement program for exclusive exploration by government agencies. Much of the land has been restored to the public domain as unfavorable for ore deposits; however, significant favorable areas are still withdrawn.

The relatively shallow areas in the mineral belt have been intensively explored and resulting ore deposits heavily produced since 1948 under the AEC uranium program. The reserves will continue to be depleted since many of the properties will be produced through 1970 under the AEC stretch-out program.

Best estimates are that most of the ore reserves in the shallow areas in the mineral belt will have been mined by 1971 except those reserves on withdrawn ground, and the remaining significant reserves will be in areas where the ore horizon is 600 to 800 feet deep. There are large areas in the Uravan mineral belt with these depths that remain to be explored.

REFERENCES CITED

1. Fischer, R. P. and Hilpert, L. S., 1952, Geology of the Uravan mineral belt: U.S. Geol. Surv. Bull. 988-A, 13 p.
2. Weir, D. B., 1952, Geologic guides to prospecting for carnotite deposits on Colorado Plateau: U.S. Geol. Surv. Bull. 988-B, p. 15–27.
3. Craig, L. C., *et al.*, 1955, Stratigraphy of the Morrison and related formations, Colorado Plateau region—a preliminary report: U.S. Geol. Surv. Bull. 1009-E, p. 125–168.
4. Shawe, D. R., 1956, Significance of roll ore bodies in genesis of uranium-vanadium deposits on the Colorado Plateau: *in Contributions to the geology of uranium and thorium,* U.S. Geol. Surv. Prof. Paper 300, p. 239–241.
5. Wood, H. B. and Lekas, M. A., 1958, Uranium deposits of the Uravan mineral belt: *in Guidebook to the geology of the Paradox Basin,* Intermountain Assoc. Petrol. Geols. 9th Am. Annual Field Conf., p. 208–215.
6. Weeks, A. D., *et al.*, 1959, Geochemistry and mineralogy of the Colorado Plateau uranium ores; summary of the ore mineralogy: *in Geochemistry and mineralogy of the Colorado Plateau uranium ores,* U.S. Geol. Surv. Prof. Paper 320, p. 65–79.
7. Keller, W. D., 1962, Clay minerals in the Morrison formation of the Colorado Plateau: U.S. Geol. Surv. Bull. 1150, 90 p.