Zoning of the Bitter Creek Vanadium-Uranium Deposit Near Uravan Colorado

GEOLOGICAL SURVEY BULLETIN 1042-F

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ZONING OF THE BITTER CREEK VANADIUM-URANIUM DEPOSIT NEAR URAVAN, COLORADO

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ABSTRACT

The vanadium and uranium deposit of the Bitter Creek mine south of Uravan, Colo., is in the upper part of the Salt Wash sandstone member of the Morrison formation. The deposit is divided into three zones, each having distinctive geologic features. The zones merge, the first into the second and the second into the third, as the thickness of cover on the ore bodies increases. The deepest zone contains nodular and concretionary masses of vanadium–uranium oxides associated with pyrite and chalcopyrite. These masses grade into disseminated deposits of vanadiferous clays and carnotite nearer the outcrop. Similar but less distinctive zones are exposed in many other mines in the Uravan district. The zones represent progressive oxidation of older primary (?) concretionary vanadium-uranium oxide deposits that contained iron and copper sulfides.

INTRODUCTION

The Bitter Creek vanadium and uranium mine (fig. 28) is in the eastern part of the carnotite-producing "Uravan mineral belt" (Fischer and Hilpert, 1952, pl. 1) in Mesa, Montrose, and San Miguel Counties, Colo., and adjacent parts of Utah. The mine is about 6 miles south of Uravan, Colo., in the SW¼SW¼ sec. 1, T. 46 N., R. 17 W., Montrose County (Fischer, 1944). It is reached by an unpaved road from Uravan that leads through Long Park and by a similar road from Colorado Route 90 in Paradox Valley. The mine, which is owned by the Vanadium Corp. of America, was operated by Mr. Vard Beckman, a lessee, in 1952.

The deposit is in a group of large ore bodies in the Morrison formation in western Colorado, eastern Utah (Fischer, 1944), and northern Arizona. Concretionary masses of vanadium–uranium oxides occur in the deepest parts of the mine. The oxide ores grade up dip toward the outcrop into vanadiferous clays and carnotite (Fischer, 1942;

Weir, 1952). Similar but less conspicuous gradations are discernible in many of the other mines (particularly those beneath thick covers of rock) in the "Uravan mineral belt."

FIELD WORK AND ACKNOWLEDGMENTS

Studies of the Bitter Creek vanadium and uranium deposit were begun in the summer of 1952 as part of a program of detailed geologic mapping by the U. S. Geological Survey on behalf of the U. S. Atomic Energy Commission. R. L. Boardman, W. D. Carter, M. D. Okerlund, and other geologists of the U. S. Geological Survey assisted in the work.

Acknowledgment is made to the Vanadium Corp. of America, owner of the Bitter Creek mine, and Mr. Vard Beckman, lessee, for permitting access to their property and providing maps of the mine. Acknowledgment is also made to the U. S. Vanadium Co. for similar assistance during our visits to its properties.

GENERAL GEOLOGY

The Bitter Creek ore bodies of vanadium- and uranium-bearing sandstone are in the Morrison formation of Late Jurassic age (Fischer, 1942, p. 368). The ore bodies are in the lower part of the upper sandstone beds of the Salt Wash sandstone member (fig. 28). Most of the rock of these upper beds is light brown and buff, but some (the unoxidized part) is white and gray. The sandstone is medium to coarse grained, massive-bedded to lenticular and irregular bedded, and crossbedded. The Salt Wash member forms an erosion-resistant cliff and bench about 60 feet high. Lenses, thin beds, and pebbles of red shale have been altered to pale green in and near the ore body (Weir, 1952). Locally, fragments of fossil plants and trees are abundant; saurian bones are fairly common.

The rocks of the area have been moderately folded into several large northwest-trending folds. The Bitter Creek ore bodies are in the northeast flank of the collapsed Paradox anticline, which trends N. 50° W. for at least 35 miles. The crest of the anticline has been dropped along steeply dipping normal faults on both flanks of the axis (Fischer, 1944). Many vertical joints that strike northwestward, parallel to the faults and the anticlinal axis, occur in the competent sandstone beds. The beds near the mine strike N. 30°–50° W. and dip 10°–25° NE. (fig. 28).

Carnotite ores of milling grade from the Uravan district contain from about 1 to 5 percent of V_2O_5; most of them contain less than 1 percent of U_3O_8 (Fischer, 1942, p. 366–376). The ore from the Bitter Creek mine has a relatively high ratio of vanadium to uranium compared with many of the other deposits in the "Uravan mineral belt."

GENERAL FEATURES OF THE BITTER CREEK MINE

The Bitter Creek mine (fig. 28) is on the northeast rim of Paradox Valley and is near the center of a semicircular bench about half a mile in radius bounded by hills on the east and north sides. The bench is about 800 feet above the valley floor, and its surface marks about the top of the Salt Wash sandstone member of the Morrison formation. A southwest-facing cliff has formed in the resistant Salt Wash immediately below the bench. The small valley of Bitter Creek cuts westward into the bench a few hundred feet north of the mine and exposes

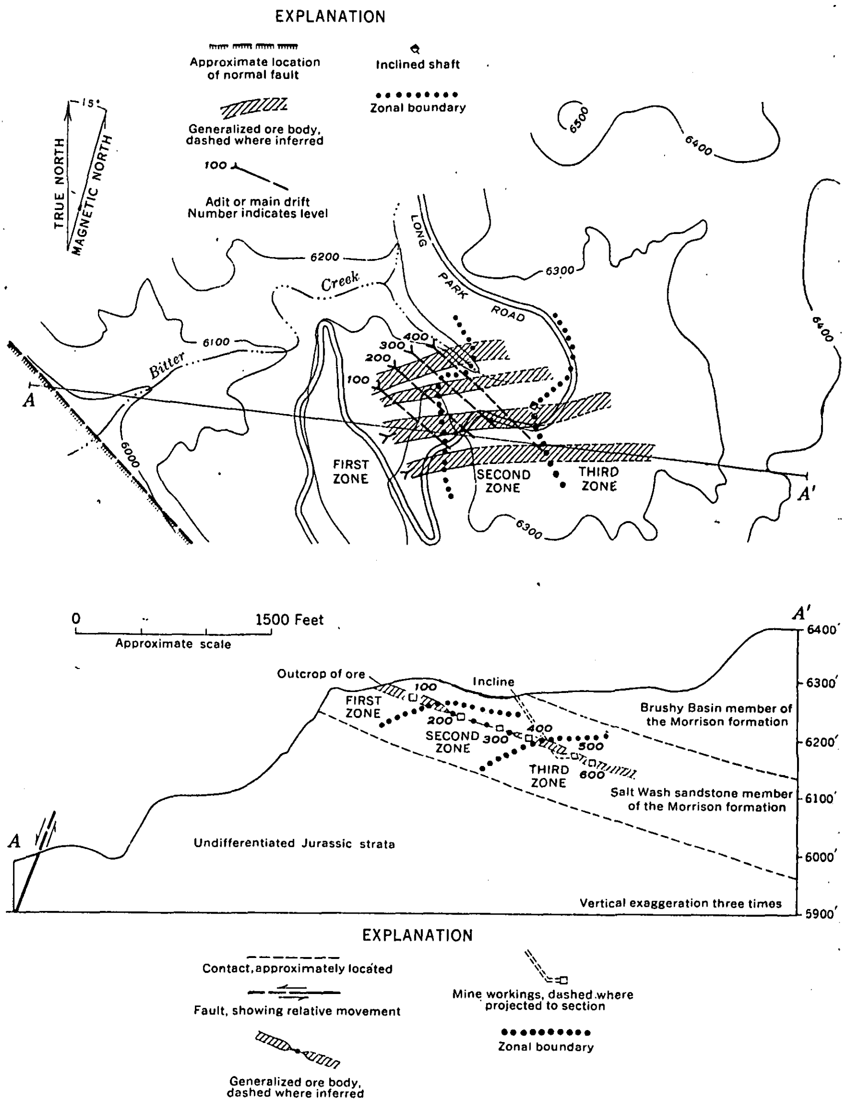

FIGURE 28.—Generalized map and section of the Bitter Creek mine, showing ore bodies and zones.

ore for about 900 feet down the dip of the strata on the northeast side of the creek. Ore is similarly exposed southeastward from the canyon near the top of the cliff for about 1,000 feet along the strike of the Salt Wash.

The Bitter Creek ore bodies have been opened along the northwest-trending outcrop by adits, shallow trenches, pits, and opencuts. Four adits and the drifts extending from them, called the "100," "200," "300," and "400" levels, provide access to the ore bodies from Bitter Creek valley (fig. 28). The levels are spaced about 300 feet apart down the northeasterly dip of the beds. The drifts extend southeastward and are within the ore-bearing beds along the strike. Each drift cuts the several parallel tabular ore bodies at vertical intervals of from 15 to 30 feet. Stopes along the ore bodies connect the several haulage drifts to form a rhombic pattern. In the northeast part of the mined area a steeply inclined shaft provides access to the deeper "500" and "600" levels, which are also connected to the upper workings by stopes. The difference in altitude between the ore outcrop and the deepest workings in 1952 was about 180 feet. Above the deepest workings the cover of rocks was about 180 feet thick.

The ore deposit is larger than most in the Colorado Plateau and consists of several parallel tabular ore bodies that extend from the outcrop eastward down the dip of the beds more than 2,000 feet. The ore bodies are about parallel to the sandstone beds and at the same horizon, but parts of the ore bodies cut abruptly across the beds for several feet. Such bodies in the Uravan area have irregular outlines and range from a few to several hundred feet in width and from a few inches to 15 feet in thickness (Fischer, 1942, p. 382–383). The mineralized parts of the ore bodies are very irregular in shape. Masses of unmineralized sandstone within the bodies are abundant and of many sizes.

Fossil tree trunks, branches, and leaves are common in the ore-bearing sandstone. The vanadium and uranium minerals show a marked affinity for plant and animal remains that were not silicified before the ore was deposited. Almost all unsilicified fossil material that lies within the vanadium- and uranium-bearing ore bodies is mineralized.

Very few faults are exposed in the Bitter Creek mine, even though the outcrop of the ore bodies is only about 1,000 feet northeast of the nearest of the Paradox anticline collapse faults. The faults exposed in the mine were formed after ore was deposited. They are either reverse faults or bedding-plane faults along shaly bands, along which only a few inches of displacement has occurred. Some bands of ore follow or end abruptly against the bedding-plane faults. Well-defined joints that are apparently related to the regional structures are abundant, but they have not visibly controlled the ore deposition.

ZONING OF THE BITTER CREEK DEPOSIT

Three zones in the vanadium-uranium ore bodies are exposed in the Bitter Creek mine as the thickness of cover increases (fig. 28). The ore in the first zone consists of vanadiferous clay impregnated by a little carnotite in disseminations, bands, and along curved surfaces called rolls (Fischer, 1942, p. 383) (fig. 29). The ore in the second zone is richer than that of the first and contains blue-black vanadium and probably uranium oxides in similar rolls (fig. 29). The third and deepest zone exposed in the mine (figs. 29 and 30) contains rich nodules and concretions, bands and incipient irregular rolls of black vanadium oxides, and iron and copper sulfides. The change between the first and second zones is completely gradational, but the change between the second and third zones appears to be more abrupt. However, the average grade of the ore mined is about the same in all three zones (Mr. Vard Beckman, lessee, Bitter Creek mine, personal communication, 1952). The broad diffuse ores of the top zone contain about the same total quantities of uranium and vanadium per cubic yard mined as the higher grade, but more widely spaced, rolls of the second zone, and the rich small nodules of the third zone, which are scattered through nearly barren rock.

FIRST ZONE

The first zone (figs. 28 and 29) contains dark-gray vanadiferous clay, yellow carnotite, and tyuyamunite deposited in lean disseminations, broad bands along bedding planes, and well-formed rolls. These ores are the only ones observed at the outcrops near the mine, in the shallow open pits along the strike, and at the outcrops down the dip of the beds along the Bitter Creek valley at the north edge of the deposit (fig. 28). They are typical of the stopes wherever the cover is less than 80 feet thick.

The only abundant vanadium mineral in the first zone is a gray vanadium hydromica, a clay mineral that has not been fully identified. It forms aggregates of minute flakes that coat the sand grains or fill the interstices of the sandstone. Its composition is approximately $(Al,V)_2(AlSi_3)(K,Na)O_{10}(OH,F)_2$. Some rauvite, $CaA \cdot 2UO_3 \cdot 5V_2O_5 \cdot 16H_2O$, is found in the upper levels of the mine (A. D. Weeks, personal communication, March 1953). Small areas and pockets of less oxidized ores are found, commonly in moist areas beneath shale lenses.

The principal uranium minerals are yellow carnotite minerals—carnotite, $K_2(UO_2)_2(VO_4)_2 \cdot 3H_2O$; tyuyamunite, $Ca(UO_2)(VO_4)_2 \cdot nH_2O$ (Frondel and Fleischer, 1952); and metatyuyamunite, $Ca(UO_2)_2(VO_4)_2 \cdot 4\text{–}6H_2O$. Much of the yellow color of the minerals

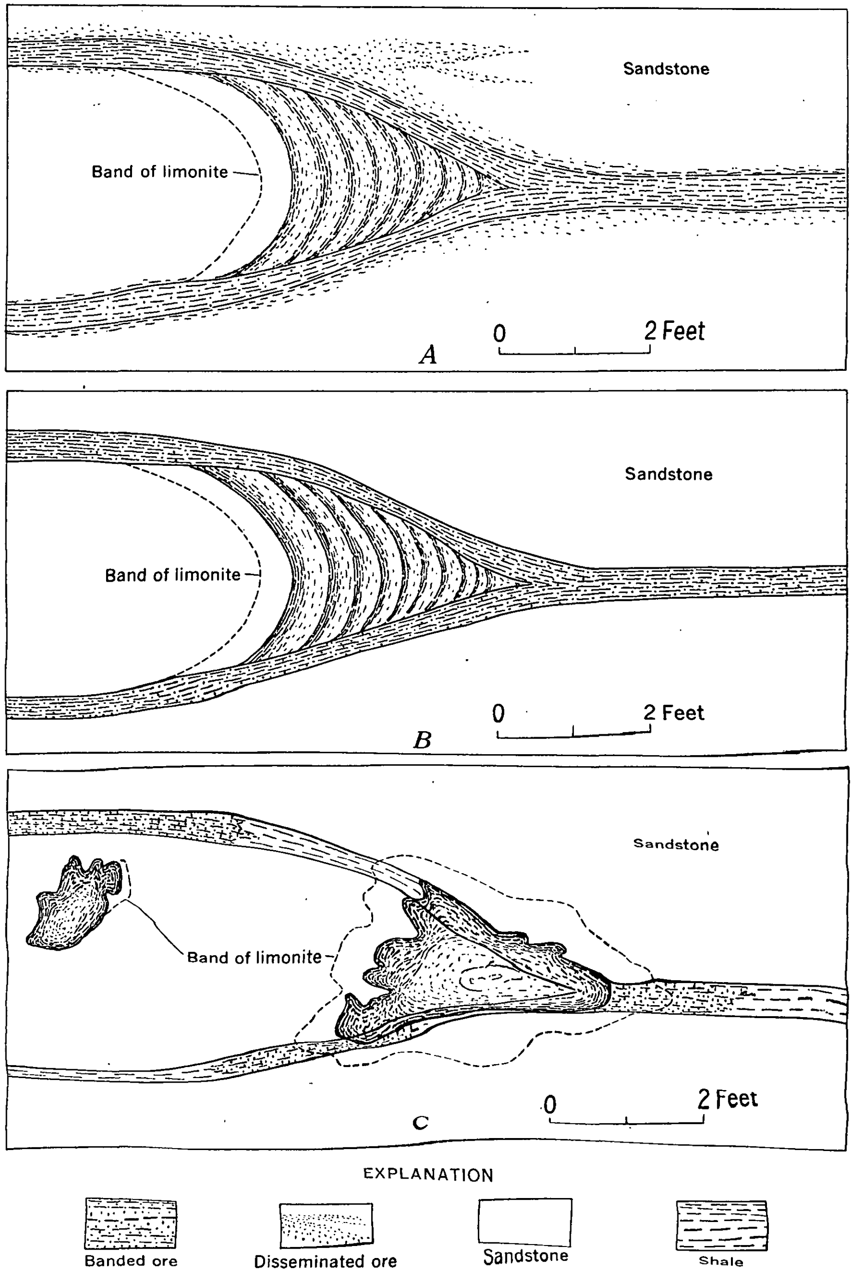

FIGURE 29.—Changes in composition of the vanadium and uranium ores with increasing depth and cover at the Bitter Creek mine. For explanation see facing page.

is masked by the gray vanadiferous clay. (T. W. Stern, U. S. Geological Survey, oral communication, March 1953).

The sandstone is stained yellow and brown by limonite. White veins of fibrous gypsum fill a few fractures. Fossil logs, twigs, and other plant fragments that have been altered to dull black lignite are common. Although a small amount of this lignite is rich in uranium, most of it is barren, especially outside the main ore bodies.

The clay ores are in part disseminated rather uniformly through the sandstone, in part concentrated in bands along the bedding planes, and in part concentrated in curved rolls. Well-developed rolls are characteristic of the first and second zones of the deposit (figs. 29*A* and 29*B*).

Some rolls are localized at the junction points of two shaly bands. In some places these shaly bands appear to be original sedimentary shale layers between sandstone lenses, but in other places the shaly bands may have formed by the dissolving of the quartz grains along bedding planes by the ore solutions.

SECOND ZONE

The second zone extends about 700 feet down the dip of the beds from about the "200" level to a point just above the "500" level. The thickness of cover above the zone ranges between 80 and 120 feet. The

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EXPLANATION OF FIGURE 29

Changes in composition of the vanadium and uranium ores with increasing thickness of cover at the Bitter Creek mine.

A. Vanadiferous clay and carnotite socket roll in the "100" level of the Bitter Creek mine. This ore is typical of the first zone of oxidation, which lies between the surface and a depth of 80 feet. The roll is located at the junction of two shaly layers separating sandstone lenses. The ore contains several percent of V_2O_5, and some of it forms dark-gray rhythmic diffusion bands that curve between the shaly layers. The ore is locally stained by carnotite.

B. Vanadyl vanadate socket roll typical of the "300" and "400" levels at depths of from 80 to 120 feet below the surface. The ore consists primarily of black vanadium vanadates and oxides (corvusite and a small amount of montroseite) and uranium oxide, and it is richer than the vanadiferous clay. Only a small amount of ore is disseminated between the bands.

C. Nodular and banded low-valence vanadium oxide ores on incline between the "500" and "600" levels. Ore in the nodules shown contains from 10 to 20 percent of V_2O_5 (montroseite and a small amount of corvusite). Note the structural similarities of the nodules shown in *C* and the socket rolls shown in *A* and *B*, and note the probable incipient stage of diffusion of the large nodule (compare the large nodule with the small one and with the nodules shown in fig. 30). The bands along the shaly layers consist of lean black vanadium oxide ore and brown iron oxides, which apparently are products of alteration and redeposition of material that was once part of the nodules.

second zone (fig. 29*B*) resembles the first, but vanadyl vanadates and some oxides, rauvite, and possibly uranium oxides are the principal ores; the margins of the ore bodies and some rolls are more irregular; and the ore is richer and most of it is concentrated in bands rather than in disseminations. Vanadiferous clay, the principal vanadium mineral of the first zone, is much less common, and the yellow carnotite minerals (carnotite, tyuyamunite, and metatyuyamunite) were not observed. The principal minerals are greenish-black or blue-black corvusite, $V_2O_4 \cdot 6V_2O_5 \cdot H_2O$, which is abundant; black montroseite, $VO(OH)$ or $(V,Fe)O(OH)$; and undetermined uranium oxides and rauvite (Stern, T. A., U. S. Geological Survey, oral communication, March 1953). In many of the older stopes, orange pascoite, $2CaO \cdot 3V_2O_5 \cdot 11H_2O$ (Weeks and Thompson, 1953, p. 59), coats the richer ore and indicates the ore is partly oxidized. The ore-bearing sandstones are stained by limonite, and gypsum fills small fractures.

The margins of the tabular bodies and some of the rolls are somewhat more irregular and the ore minerals are less widely and less evenly distributed through the rock than in the first zone, but the boundaries of the ore bodies grade more abruptly into barren wall rock. The ore bands and rolls are bluish black, owing to the vanadyl vanadate and oxide minerals. Fewer and leaner masses of disseminated ore lie between the rolls and ore bands (fig. 29*B*) than in the first zone; in general, however, the ore of the second zone is richer and less evenly distributed than that of the first. In places, lean disseminations of reddish-brown vanadium ore occur. This ore apparently consists of a mixture of vanadyl vanadates, some red hewettite ($CaV_6O_{16} \cdot 9H_2O$), and iron oxides, and it contains 2 to 3 percent V_2O_5.

A few widely scattered irregular nodules of rich montroseite-corvusite-uranium oxide ore are found in the second zone closely associated with bands and masses of disseminated vanadium oxides.

THIRD ZONE

The deepest zone, exposed in the "500" and "600" levels, contains numerous rich black concretions, nodules, bands, spotty disseminations, a few very irregular rolls of vanadium and uranium oxides, and iron and copper sulfides (figs. 29*C* and 30). The nodules contain very high grade ore, ranging from 10 to 30 percent V_2O_5 and 0.1 to 0.75 percent U_3O_8 (Mr. Yard Beckman, lessee of Bitter Creek mine, oral communication, 1952); however, the quantity of uranium in individual nodules differs greatly. The nodules occur as irregular lumps that have sharp projections, as knobby and "amoeboid" bodies, and as ellipsoidal concretions, all of which may be from a few inches to 5 feet across (figs. 29*C* and 30). Many of the bands also consist of rich ore, but the grade is lower than that of the nodules. The disseminations are relatively small, spotty, and local. Some disseminations consist of a lean brown

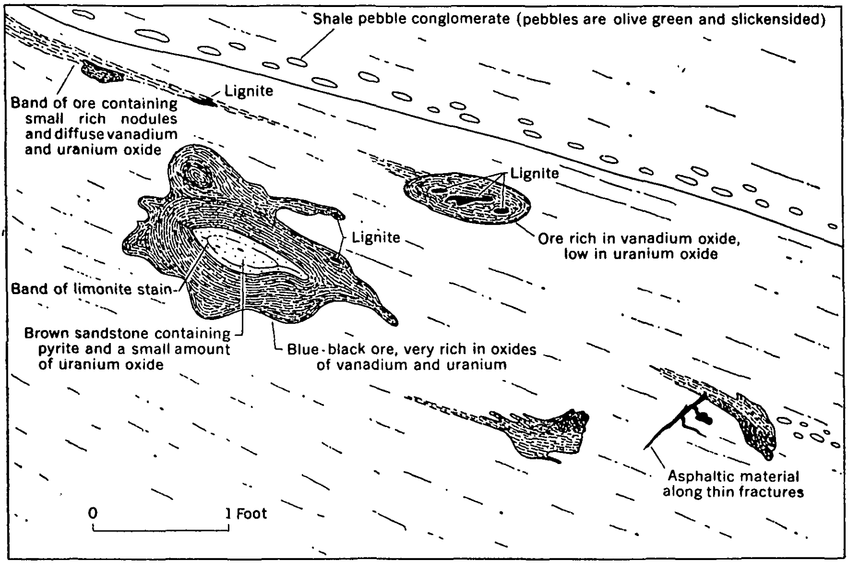

FIGURE 30.—Black vanadium and uranium oxide nodules in light-brown sandstone at the "600" level. Original pyrite has been altered to limonite except in the nodules.

mixture of vanadium and iron oxides. The rolls are composed of very rich ore but are imperfectly formed (fig. 29*C*). Within some rolls irregularly shaped barren masses interrupt the roll surfaces. Smoothly curving diffusion bands are rare.

Montroseite, a small amount of corvusite, and unidentified black uranium oxides are the principal ores in the third zone. Vanadiferous clays apparently are rare or absent. Pyrite is abundant and occurs as small disseminated grains in the black nodules, as uranium-bearing concretions, and as sparsely disseminated grains in unoxidized parts of the ore-bearing sandstone. Grains of chalcopyrite were noted in several nodules. Barite is present, but gypsum is rare or absent. Limonite locally forms diffusion bands around the nodules and rolls, and it is intermixed with vanadium oxides and vanadates in local patches of brown disseminated ores, which are more typical of the second zone. In some places these brown ores contain hewettite, $CaV_6O_{16}\cdot 9H_2O$, in soft red masses.

Carbonaceous material (fig. 30) consisting of fossil wood and other plant fragments is common. It is shiny black and resembles asphalt but appears to consist mostly of lignite mixed with small quantities of a viscous liquid substance resembling gilsonite, thucolite, or anthraxolite. In a very few places the liquid fraction has flowed into adjacent small cracks (fig. 30). Most of the carbonaceous material in the ore zone contains vanadium or uranium, but most of it in the barren rock does not. Many of the ore nodules and concretions enclose or adjoin the carbonaceous areas.

The rock is moist in the third zone, and pools of ground water have collected in the deepest parts of the mine. The zone appears to be at the upper limit of either the main ground-water table or a local perched water table.

Some of the host sandstone is brown and stained with limonite, but the rest is white or gray and contains pyrite grains instead of limonite. Where the sandstone is yellow or brown, many of the vanadium-uranium nodules are large, have irregular shapes (fig. 29*C*), and are surrounded by diffusion bands of limonite; bands and disseminations of leaner vanadium ore commonly occur near them. The boundaries of the nodules are not as sharp as they are in the white or gray sandstone, and the nodules have large centers of lean ore. Irregular rolls occur in the yellow or brown sandstone, but they are not common. More limonite and less pyrite are present than in the white or gray sandstone.

In the white or gray sandstone the vanadium–uranium nodules and concretions are commonly well rounded and have few projections. They are probably composed mostly of montroseite, uraninite, and pyrite. They occur as isolated black ellipsoids in barren sandstone associated with a few adjacent bands or disseminations of ore. The boundaries of the concretions are sharp. Some of the concretions are concentrically banded and closely resemble manganese oxide concretions. The concretionary ore in white or gray sandstone is believed to represent the upper edge of a fourth zone of unoxidized ores.

ZONING OF OTHER DEPOSITS IN THE URAVAN AREA

Zoning of vanadium-uranium ores is found in many of the more deeply buried deposits in the "Uravan mineral belt." In most of these deposits only the first and second zones are present, but in some the third zone is present. The black ores of the second and third zones occur in places where the rock cover is sufficiently thick (Weeks and Thompson, 1953, p. 11–12). The change in the zoning of the ores is gradual over a distance of several miles in some places, as in the Long Park group of mines (Fischer and Hilpert, 1952, fig. 5). The group of ore bodies is in a line nearly parallel to the regional strike, and the thickness of the overlying rocks increases gradually toward the southeast. The northwestern part of the group contains carnotite and vanadiferous clay ores beneath thin cover. The black ores of the second zone begin to occur in small patches, exposed in Long Park No. 6 mine, as the cover becomes thicker southeastward. Long Park No. 1 mine, about half a mile southeast of Long Park No. 6 and at greater depth, contains only the black oxide bands, rolls, and disseminations of the second zone. The ore body exposed in the Whitney mine, half a mile southeast of Long Park No. 1 and beneath the deepest cover at Long Park, contains nodular ore similar to that of the third zone at Bitter Creek.

The ore body of the Virgin mine is located down dip at the east edge of Long Park. The mine was the deepest in the "Uravan mineral belt" in 1952, reaching a depth of 345 feet. Here are found blanket deposits of black vanadium-uranium oxide ores that contain coffinite, a black uranium mineral having an X-ray pattern like that of thorite (Stief, Stern, and Sherwood, 1955). The ore is even less oxidized than that at Bitter Creek.

Black ores of the second and third zones are found in ore bodies of Club Mesa (Fischer and Hilpert, 1952, fig. 4) that lie beneath thick caps of rock (fig. 31), even though the ore bodies may lie up the dip

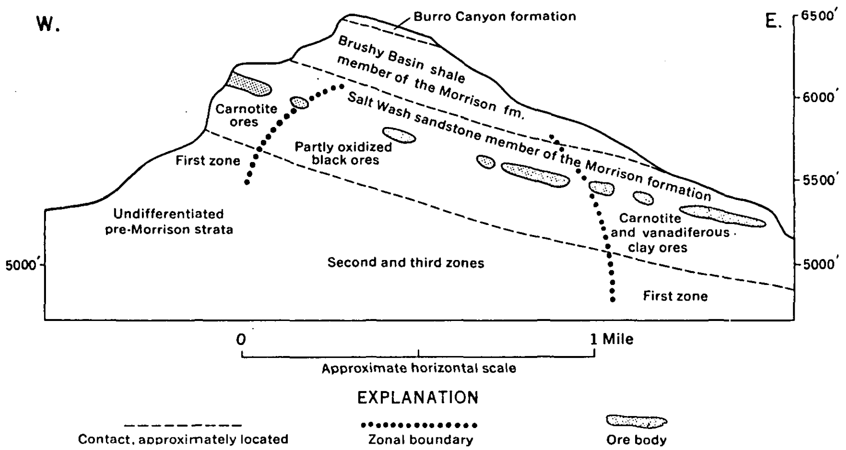

FIGURE 31.—Generalized section eastward through Club Mesa, Uravan, Colo., showing relations of zones to ore bodies and to thickness of cover.

from the outcrop. The strata in Club Mesa strike northwestward and dip gently northeastward. Ore bodies near the rim of the mesa (those of the Club, Mill No. 2, and Saucer Basin mines) are overlain by a thin cover of rock and consist of vanadiferous clay and carnotite ores. Ore bodies beneath the thick overlying rock near the central mesa cap of the Burro Canyon formation (that of the LaSal mine, those to the west and north of the LaSal mine, and the westernmost part of that of Mill No. 1 mine) consist mostly of blue-black ores that contain corvusite, a little montroseite, rauvite, black uranium minerals, and probably some vanadiferous clays—all typical of the second, or partly oxidized, zone. Ore found by deep drilling beneath the central mesa cap is black and unoxidized, similar to that at the Virgin mine.

ORIGIN OF THE ZONES

Further geologic study of the Bitter Creek ore deposit and of other ore deposits in the "Uravan mineral belt" is needed before the origin of the zones can be stated with certainty.

The zonation probably indicates progressive oxidation of primary concretionary vanadium–uranium oxide deposits containing iron and copper sulfides to secondary vanadiferous clays and carnotite. Primary oxide deposits blanket ore known to exist in many places beneath thick rock cover and beneath the water tables, such as at the Virgin mine, Long Park group; La Sal No. 2 mine, Gateway district, Colorado; and Mi Vida mine, Monticello district, Utah. Above the water table and nearer the surface the primary oxide deposits have been oxidized through several progressive stages to carnotite and vanadiferous clay ores (Weeks, Cisney, and Sherwood, 1953; Weeks and Thompson, 1953). Oxidation of sulfides to oxides in the Bitter Creek ores most certainly occurs in the pyrite and chalcopyrite associated with the vanadium and uranium minerals.

Concretionary montroseite black ore that contains unoxidized sulfides occurs only in small blocks of gray and white sandstone exposed in the deepest, moist parts of the mine. These blocks may be remnants of a fourth zone, not yet fully exposed, in which oxidation of the primary ores has not started.

The rest of the ore in the third zone is in yellow or brown limonite-stained sandstone and probably represents initial stages of oxidation. For example, only some of the sulfides (pyrite and chalcopyrite) have been oxidized, and considerable quantities of these sulfides remain in the nodules. The irregular knobby nodules of black vanadium ores (fig. 30) may represent incipient stages of enlargement by diffusion and disintegration of spheroidal concretions of the primary ores of the fourth zone. Diffusion and disintegration may have been caused, at least in part, by slow solution in waters acidified by the oxidation of the associated sulfides. A diffusion band of brown limonite has formed around the dissolving nodules (fig. 29*C*). As the margins of the nodules moved outward by diffusion, expanding centers of lean ore developed. The disseminations and bands of lean blue-black vanadium ores that surround the partly disintegrated nodules may consist mainly of corvusite reprecipitated from acidic vanadium-bearing solutions. Reprecipitation probably occurred when alkaline ground water neutralized the solutions as they moved from the vanadium oxide nodules through more permeable parts of the adjacent rock.

Figure 29*C* illustrates the diffusion of two nodules near the edge of a sandstone lens between layers of shale. The larger nodule is believed to represent a more advanced state of diffusion than the smaller one. It is more irregular, has a larger central core of lean ore, is completely surrounded by a diffusion band of limonite, and from it bands of lean vanadyl vanadate ore and brown iron oxides appear to have advanced in two directions along the layers of shale. If the larger nodule had diffused and disintegrated further, it might have developed into a roll similar to the one shown in figure 29*B*.

The chemical and physical processes involved in the formation of rolls are not well understood. Rolls may represent the advancing diffusion fronts of acidic solutions containing vanadium and uranium derived from many nodules and pyritized areas. The curved diffusion fronts may have formed by reaction between acidic vanadium-bearing solutions near the curved edges of the sandstone lenses and alkaline, oxygen-bearing vadose waters percolating through the more permeable centers of the lenses.

The second zone, which consists of rolls of blue-black vanadium ore (fig. 29*B*) and a few nodules, may represent an intermediate oxidation stage. Most of the nodules that once occurred in the zone have been dissolved. The rolls probably developed from the dissolved nodules by a redeposition process, such as the one suggested in the two preceding paragraphs. The pyrite and chalcopyrite have been oxidized and some of the resulting sulfate ions have been deposited as gypsum. The carbonaceous material has been further altered by the solution and removal of the asphaltic fraction, leaving only the lignite.

The shallowest zone (fig. 29*A*) represents a more complete oxidation stage. The vanadium and uranium minerals, which oxidize in several stages and more slowly than the iron and copper sulfides, have further diffused and oxidized to vanadiferous clays and yellow carnotite minerals. The fact that the average grade of ore per cubic yard mined from the first zone is about equal to that mined from the less oxidized zones below, strongly suggests that the surface ores are more diffused and that they have been oxidized rather than leached. In diffused ores, such as the vanadiferous clays, the uranium and vanadium content of small samples is less, owing to the wider dispersion of the minerals of these ores throughout the rock, and to the oxidation of the minerals to minerals that contain smaller percentages of the elements in them.

The zones may have originated in several other ways, as follows: (1) They may represent progressive changes in the original deposition of the ores caused by differences in the ore-bearing solutions or in local conditions, such as increased quantities of carbonaceous fragments; (2) the nodular ores near the present water table may have resulted from a redeposition and secondary enrichment of ores deposited as bands and rolls in the first and second zones, the first zone being an oxidation product of the second zone; (3) large deposits of carnotite, which are typical of the "Uravan mineral belt," seem to be coincident with the area of the Pennsylvania evaporite basin (Weeks and Thompson, 1953), which may be the source of the potassium that locally forms primary carnotite ores.

Further study of the deposit is needed to explain (1) the rather abrupt change from the black vanadate roll type of ore body of the second zone to the nodular and concretionary ore body of the third zone, without a marked transition zone; (2) the scarcity of discernible "ghosts" of dissolved nodules in the upper parts of the deposit; (3) the ellipsoidal black nodules in the gray and white sandstone, which may be primary ores or may represent another transition stage developed from a still earlier form of ore deposit; and (4), if the nodular types of ore are primary, the formation of vanadium-uranium concretions under reducing conditions.

SUMMARY

Three distinct zones and small remnants of a possible fourth zone are exposed in the Bitter Creek mine.

First zone.—Vanadiferous clays, carnotite minerals, limonite, and gypsum in very well developed rolls, bands, and disseminations. The ore is low grade, oxidized, and occurs in brown sandstone.

Second zone.—Blue-black vanadium ores and possibly uranium oxides, associated with limonite, in less regular and less well developed rolls, in many bands, and in less diffuse disseminations. Nodules are few and widely spaced. The ore is richer than that in the first zone. A gradational change occurs between this zone and the first zone.

Third zone.—Rich black vanadium-uranium oxide ore in irregular nodules and concretions, in a few rich bands, and in incipient irregular rolls, forming a spotty ore body. Pyrite and chalcopyrite are present but are partly oxidized to limonite. Within this zone are small areas of white and gray sandstone. None of the sulfides in the sandstone are oxidized, and the black oxides in the sandstone are in ellipsoidal concretions.

The zones probably were formed as a result of oxidation of primary black concretionary ores and associated sulfides. The oxidation of the sulfides by ground water at or near the ground-water table could have resulted in the formation of acidic solutions that redissolved the black oxide ores and redeposited them in rolls between solution fronts. Redeposition probably occurred as the solutions were neutralized by and reacted with descending vadose alkaline waters. Further oxidation may have produced the vanadiferous clays and the carnotite stains.

Zoning of this type is not restricted to the Bitter Creek mine but may be common throughout the "Uravan mineral belt." The recent mining has exposed many other black ores beneath the thicker parts of the mesa caps. As mining increases in the areas of thicker cover, a much larger proportion of the ores obtained will probably be black oxide ores rather than vanadiferous clays and carnotite ores.

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U. S. GOVERNMENT PRINTING OFFICE: 1957