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MINERALOGY AND GEOLOGY OF THE VANADIUM-URANIUM DEPOSIT OF THE RIFLE AND GARFIELD MINES, GARFIELD COUNTY, COLORADO

By

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	49

CONTENTS

	Page
Abstract	4
Introduction	5
Geology	6
Stratigraphy	7
Structure	9
Ore deposits	10
Mineralogy	14
General	14
Mineralogy of the vanadium layer	15
Oxidation of the vanadium layer	18
Mineralogy of the galena band	19
Oxidation of the galena band	19
Mineralogy of the green (chromium-bearing) layer	19
Conclusions	20
Literature cited	21

ILLUSTRATIONS

Figure 1. Photograph of No. 3 vein, Garfield mine, showing the mineral layers. The scale of the photograph is indicated by the 6-inch scale on the right side of the picture. Note that the galena band and the vanadium layer cross the laminae with little regard for the bedding. 12

2. Photomicrograph of thin section of typical unoxidized high-grade vanadium ore of the Wingate(?) sandstone. Black is montroseite (M); gray is roscoelite (R); white is quartz (Q). Plane polorized light, 250X 17

MINERALOGY AND GEOLOGY OF THE VANADIUM-URANIUM DEPOSIT OF THE RIFLE AND GARFIELD MINES, GARFIELD COUNTY, COLORADO

By Theodore Botinelly and R. P. Fischer

ABSTRACT

The vanadium-uranium deposit at the Rifle and Garfield mines is in the Wingate(?) sandstone and the overlying Entrada sandstone. Both formations are composed of clean, light-colored, fine-grained, massive, and crossbedded sandstone.

The ore, which consists of vanadium with only a small uranium content, occurs in fine-grained minerals that impregnate the sandstone. It forms three partly overlapping layers, each of which is tabular and lies generally parallel to the major bedding. Each vanadium layer is bordered on one side by a thin band of finely disseminated galena and clausthalite, beyond which is a greenish layer containing a chromium-bearing mineral. The galena band and the chromium-bearing layer lie above the lower and upper vanadium layers but below the middle vanadium layer.

Primary ore minerals of the vanadium layer are roscoelite and a small amount of vanadium-bearing chlorite and montroseite. Base metal sulfides are sparse in the ore but abundant in the galena band. The chromium-bearing layer is similar in appearance to that at Placerville, Colo., where mariposite has been described. Oxidation has not affected the roscoelite appreciably; montroseite and perhaps vanadium-bearing chlorite have oxidized to form secondary vanadium minerals. A little carnotite is present in the oxidized parts of the deposit, but primary uranium minerals have not been recognized.

The deposit is similar to vanadium-uranium deposits of the Plateau but is unique in the high ratio of vanadium to uranium, the lack of carbonaceous material, and the abundance of roscoelite.

INTRODUCTION

The vanadium-uranium deposit at the Rifle and Garfield mines is partly in the Entrada sandstone of Jurassic age and partly in an underlying sandstone that has been questionably correlated with the Wingate sandstone of Triassic age. Both formations are composed entirely of clean, fine-grained, massive sandstone. This deposit, like those in the Entrada near Placerville, Rico, and Durango, Colo., has been worked mainly for vanadium; the uranium content of the ore is so low that it has had only byproduct value. In addition to the low uranium content, these deposits in the Entrada and Wingate(?) sandstones differ from most of the vanadium-uranium deposits in other formations on the Colorado Plateau in that abundant shaly and carbonaceous material is lacking. Otherwise all these deposits are quite alike, and all are of the same general type.

The Rifle and Garfield mines are on the East Rifle Creek about 13 miles northeast of Rifle, Garfield County, Colo. The Rifle mine, on the east side of the creek, was worked from 1925 to 1932, during World War II, and again in the late forties and early fifties. Mine workings extend for more than 7,000 feet eastward from the outcrop along the creek. The Garfield mine, on the west side of the creek, was worked mainly during World War II, though a small amount of mining was done before then and some development has been done since the war. The workings extend several hundred feet westward from the outcrop.

The deposit at the Rifle and Garfield mines presents an unusually good opportunity to study and interpret some geochemical relations that are more confusing elsewhere. Not only is this deposit well exposed in the mines and at the outcrop, so the character of the ore and the habits of the ore bodies can be readily observed, but also these features are more consistent than in many of the Plateau deposits. Even so, in spite of these advantages, the geologic factors that influenced localization of the deposit have not been recognized, and the genesis cannot yet be explained.

The mines and surrounding area were studied and mapped by the junior author, assisted by W. L. Stokes and L. E. Smith, in the summer of 1944. The area was revisited by the junior author in 1954, to bring the geologic map of the mine workings up to date, during which time he was assisted for intervals of several days each by D. C. Hedlund, E. B. Ekren, R. T. Chew, III, H. S. Johnson, and D. D. Haynes. The present report is based on this field work and the samples collected at that time; these samples and thin sections from them were studied by the senior author.

GEOLOGY

The area lies on part of the Grand Hogback monocline, a fold that flanks the White River Plateau uplift to the north and east, and which exposes rocks ranging from Precambrian to Tertiary in age. Rocks in the immediate vicinity of the Rifle and Garfield mines consist of sedimentary formations of Triassic, Jurassic, and Cretaceous ages. Only the Wingate(?) sandstone (Triassic) and the Entrada sandstone (Jurassic), which contain the ore deposit in these mines, will be described in detail.

Stratigraphy

The Chinle formation of Triassic age underlies the Wingate(?) and consists of a few hundred feet of red, fine-grained sandstone and shale. In the vicinity of the mines the upper few feet of the Chinle is altered to gray, and in a few places the lowest ore layer (No. 1 vein) passes down into the top of this altered zone.

The sandstone unit between the Entrada sandstone and the Chinle formation has been questionably correlated with the Wingate sandstone by Thomas, McCann, and Raman (1945). This Wingate(?) is a light-brown fine-grained sandstone with large-scale crossbedding inclined southward. It crops out in a nearly vertical cliff. As it is a hard and brittle sandstone, it is fractured by many vertical joints, both at the outcrop and underground. This formation ranges in thickness from 30 to 75 feet in the vicinity of the mines, and it pinches out a few miles east of the mines. The Wingate(?) contains the principal ore body (No. 1 vein) in the Rifle mine.

The Entrada sandstone is white to light gray and predominantly fine-grained but with large, well-rounded grains scattered through it. Crossbedding is prominent; the planes are curved, but, in contrast to the Wingate(?), they are not inclined in a common direction. The formation is soft and friable and weathers to rounded cliffs and steep slopes; jointing is not as conspicuous as in the Wingate(?). The Entrada ranges from 75 to 125 feet in thickness. It contains the ore bodies (No. 2 and No. 3 veins) in the Garfield mine and several small masses of ore in the Rifle mine.

The total thickness of the Wingate(?) and Entrada sandstones is fairly constant but thins gradually from 175 to 140 feet eastward through the area. Each unit alone, however, has a greater local range in thickness than do the two units combined, for the Entrada was deposited on an uneven, eroded surface of the Wingate(?), so that a local thinning of the Wingate(?) is accompanied by a compensating thickening of the Entrada.

The Entrada sandstone is overlain by the Morrison formation of Jurassic age. The Morrison is about 500 feet thick. The lower 150 feet consists of several lenticular sandstone strata that are gray to greenish-gray, medium-grained, and interbedded with red, green, and gray mudstone. The sandstone beds contain a few small deposits of uranium-vanadium ore, which will not be described in the report. The upper part of the Morrison consists of mudstone that is predominantly green or gray but in part varicolored, with a few thin and lenticular beds of sandstone, siltstone, and limestone.

The Dakota(?) sandstone of Cretaceous age overlies the Morrison and consists of gray and brown sandstone and shale. It is about 80 feet thick.

The Mancos shale, also of Cretaceous age, lies on the Dakota(?). It consists of several thousand feet of gray shale.

Structure

The rocks in the vicinity of the Rifle and Garfield mines generally dip southward at moderately low angles, but this attitude is modified locally by faults and minor flexures. Within the mines, beds dip southward at angles ranging from about 15° to 30°.

Three sets of faults are present; two sets dip nearly vertical and the third dips at low angles. Of the two high-angle sets, one trends generally eastward and is the stronger and apparently the older. One fault has been traced for several miles and has a maximum displacement of a few hundred feet; most faults of this set, however, are shorter and have displacements of less than 100 feet. The other set of high-angle faults trend southeastward, rarely exceed a few tens of feet in displacement, and have not been traced for more than a few thousand feet. Faults of both sets are exposed in the mines, but none of these have displacements exceeding 10 feet.

The low-angle faults are reverse faults with displacements ranging from a small fraction of an inch to as much as a foot. All dip southward and for the most part follow the bedding planes or cut across the beds at small angles. They are conspicuous in massive sandstone and probably resulted from bedding plane sliding at the time of folding. They appear to be younger than the high-angle fractures.

Joints are common, especially in the hard sandstone units, such as the Wingate(?). All the joints dip at high angles, and most strike easterly and southeasterly, parallel to the two sets of nearly vertical faults.

Below the zone of oxidation, some of the joints and a few of the high-angle faults contain thin, discontinuous veinlets of calcite and marcasite; where oxidized these fractures are iron stained. In the Chinle formation, some of the joints and faults are bordered by a narrow band of alteration, which has changed the color of the rock from red to gray, and which is similar in appearance to the zone of alteration that is present at the top of the Chinle in the vicinity of the ore deposit.

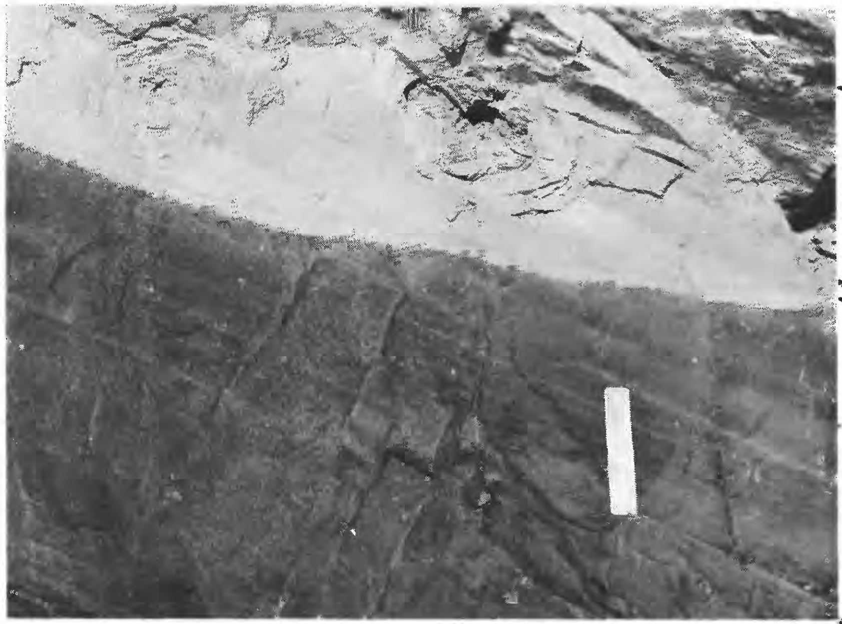
ORE DEPOSITS

The ore consists of sandstone impregnated with fine-grained vanadium and uranium minerals. These minerals color the rock gray, and in general, the color darkens as vanadium content increases. Most of the ore that has been mined contains between 1 and 3 percent V_2O_5. No plant fossils or other carbonaceous material has been recognized in the ore-bearing sandstone, except for small pellets of asphalticlike material that occur sparsely along a few joints.

The ore occurs in three layers, which the miners call the No. 1, No. 2, and No. 3 "veins" in ascending order. These layers are tabular and lie generally parallel to the major bedding or formational contacts, but in detail they cross the bedding and in a few places even the formational contacts. The No. 1 vein is the principal ore layer in the Rifle mine. It lies mostly in the Wingate(?) sandstone, but in at least two places it thickens sufficiently to extend up into the lower part of the Entrada sandstone, and in a few places it crosses into the upper foot of the underlying Chinle formation. The No. 2 vein is discontinuous. It forms the principal ore body in the Garfield mine and a few small- to moderate-sized ore bodies in the Rifle mine. The No. 2 vein is in the Wingate(?) sandstone at one place in the Rifle mine, where it connects with the No. 1 vein. All of the other known ore bodies in the No. 2 vein are in the Entrada and do not obviously connect with the No. 1 vein. The No. 3 vein is known only in the Garfield mine, where it forms two ore bodies in the Entrada. One small body has been mined at the outcrop, and it is about 20 feet above the No. 2 vein. The second ore body in the No. 3 vein lies several feet above the ore layer of the No. 2 vein in the main workings of the mine and the two layers join along the northwest edge of the mine.

Each of the layers is strikingly asymmetric vertically across the layer. Each shows the same asymmetry, but the middle layer (No. 2 vein) is a mirror image (or upside down) with respect to the lower and upper layers (No. 1 and No. 3 veins, respectively). The asymmetric characteristics of the No. 3 vein are shown and described in figure 1. The No. 1 vein shows exactly the same characteristics, and in the same vertical sequence; No. 2 vein shows exactly the same characteristics but in a reverse vertical sequence.

The No. 1 vein in the Rifle mine forms an elongate ore body that has been followed by mining for about 7,000 feet in a northeasterly direction from its outcrop on East Rifle Creek. The ore is generally thicker and lower grade on the north side of the body, and the limit of minable ore to the north is mainly an assay wall. On the south side, on the other hand, the layer thins gradually until it is too narrow to mine profitably, but the grade of the thin ore is generally higher than average



Chromium-bearing layer: pale green; contains sparse finely disseminated galena in lower part. The layer itself is not evident in this photograph, but slightly greater concentrations of the chromium mineral along some of the more favorable laminae is shown by slightly darker shades of gray.

Galena band: finely disseminated galena, forming a layer about inch thick; locally so ill-defined as to be not apparent; two thin galena bands are present in places, and are separated from each other by about inch of barren material.

Barren or weakly mineralized layer: generally 1 inch or less thick; absent in places.

Vanadium-bearing layer (ore): gray sandstone grading downward into brownish-gray sandstone in lower half of ore layer (lower part of the layer in this picture), generally not evident where the ore layer is several feet or more thick; commonly the lower half of the ore layer is slightly more radioactive than the upper half; top of ore layer is commonly well defined, as in picture, but the bottom of the layer generally is less well defined.

Figure 1. Photograph of No. 3 vein, Garfield mine, showing the mineral layers. The scale of the photograph is indicated by the 6-inch scale on the right side of the picture. Note that the galena band and the vanadium layer cross the laminae with little regard for the bedding.

for the deposit. In a few places along the south edge of the deposit, the layer passes from the Wingate(?) sandstone into the top foot of the altered zone of the underlying Chinle formation. The No. 1 vein also is in the altered zone at the top of the Chinle on the west side of East Rifle Creek.

Where the ore in the Rifle mine is thick, the upper and lower limits of the layer usually are not well defined, and the asymmetric character of the ore layer is not obvious; similarly, the associated galena band and chromium-bearing layer are not recognizable or are poorly developed.

Although none of the ore bodies in the No. 2 vein in the Rifle mine have been completely explored by mining or drilling, they appear to be moderately small bodies that are not connected with one another by mineralized material. All those known to contain material of approximate commercial grade and thickness lie satellitic to or fringe the ore body in the No. 1 vein in plan projection; none have yet been found that directly overlie minable ore in the lower layer. Only one of the ore bodies in the No. 2 vein is known to be connected with the No. 1 vein.

The altered zone at the top of the Chinle formation ranges from a feather edge to 8 feet in thickness. The contact with the unaltered rock beneath is well defined but uneven and crosses the bedding. Where fresh, the altered rock is greenish-gray and contains finely disseminated cubic crystals of pyrite; at the outcrop the altered zone is buff.

Beneath the ore body in the Rifle mine the altered zone ranges from 2 to 8 feet in thickness, and there is no obvious systematic relationship between the thickness of this zone and the thickness or grade of ore.

Nevertheless, generally speaking, the altered zone is thicker beneath and near the ore body, and it decreases in thickness away from the deposit. On the west side of East Rifle Creek the altered zone thins to a vanishing point about 2,000 feet from the deposit and is absent beyond that point. Its character and habit are similar to the zone of altered mudstone near uranium-vanadium deposits in the Morrison formation elsewhere on the Plateau.

MINERALOGY

General

The vanadium deposit of the Rifle and Garfield mines consists of sandstone impregnated with roscoelite, a few other vanadium minerals, a few common base-metal sulfides, and the lead selenide clausthalite. The Entrada and Wingate(?) sandstones, in which the ore occurs, are fine-grained, moderately sorted, feldspathic orthoquartzites.

As shown in figure 1, the galena band and the vanadium layer cross the laminae with little regard for the bedding. Where mineralization has been strong the ore is massive and very dark colored and the bedding of the sandstones is almost completely obscured. The massive ore grades into ore where mineralization has been weaker and has emphasized the bedding by selectively impregnating certain of the crossbedding laminae.

Similarly the galena band where it crosscuts bedding is made up of short thin laminae of high concentrations of sulfides parallel to the bedding arranged en echelon in a band crossing the bedding.

Mineralogy of the vanadium layer

Unoxidized vanadium ore in the Rifle mine contains roscoelite, vanadium-bearing chlorite, montroseite, pyrite, marcasite, galena, sphalerite, and chalcopyrite. These are arranged roughly in order of decreasing abundance. The ore minerals and associated minerals occupy the intergranular area in the sandstone. In some bands of rich ore the quartz grains are corroded.

Roscoelite, according to Heinrich and Levinson (1955), is a vanadium mica with vanadium substituting for aluminum in the tetrahedral layer. A composition of $K(V,AL)_2ALSi_3O_{10}(OH)_2$, which contains one vanadium atom per tetrahedral layer in the unit cell, would contain about 17 percent V_2O_5(Wells and Brannock, 1946). Roscoelite in thin section is brown with a faint tinge of green and has weak pleochroism and high birefringence. It occurs as fine-grained masses with irregular structure surrounding the quartz grains. It is the dominant ore mineral_/.

_/ Samples collected by R. M. Garrels, separation by R. G. Coleman, X-ray analyses by J. C. Hathaway: personal communication J. C. Hathaway.

Relatively little is known about vanadium-bearing chlorites. They may be magnesium aluminum silicates with vanadium substituting for aluminum. In the ore from Rifle vanadium chlorite is very similar in habit and occurrence to roscoelite. It is distinguished from roscoelite by its relatively low birefringence.

Montroseite is a vanadium oxide mineral. As used here the term montroseite includes montroseite, VO(OH), and paramontroseite, VO_2, (Evans and Block, 1953; and Evans and Mrose, written communication). The various phases are not easily distinguished except by X-ray analysis. Ideally montroseite is a vanadium III compound, VO(OH); iron (II) may substitute for vanadium, requireing some vanadium IV to balance the ionic charges. Specimens of montroseite oxidize readily to paramontroseite in air.

Montroseite occurs as very small opaque, black, bladed crystals with high luster, in radial aggregates and in individual crystals, which occur with roscoelite in the spaces between the sand grains (fig. 2).

Vanadium has valences of +2, +3, +4, and +5; but vanadium III is the lowest valence state found in nature and vanadium III compounds such as montroseite and roscoelite are probably deposited under reducing conditions as suggested by Evans (written communication).

Chromatographic contact prints_/ made on polished sections of

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_/ For details of this technique see Willimas and Nakhala, 1951.

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unoxidized ore with no visible montroseite, showed dispersed vanadium in the matrix material. The dispersion is irregular with numerous small centers of high concentration. Roscoelite is probably not affected by the acids used in making the prints and the vanadium is probably derived from either vanadium-bearing chlorite or vanadium-bearing clay. The chromatographic prints indicate that vanadium chlorite or vanadium-bearing clay is dispersed through the unoxidized ore.

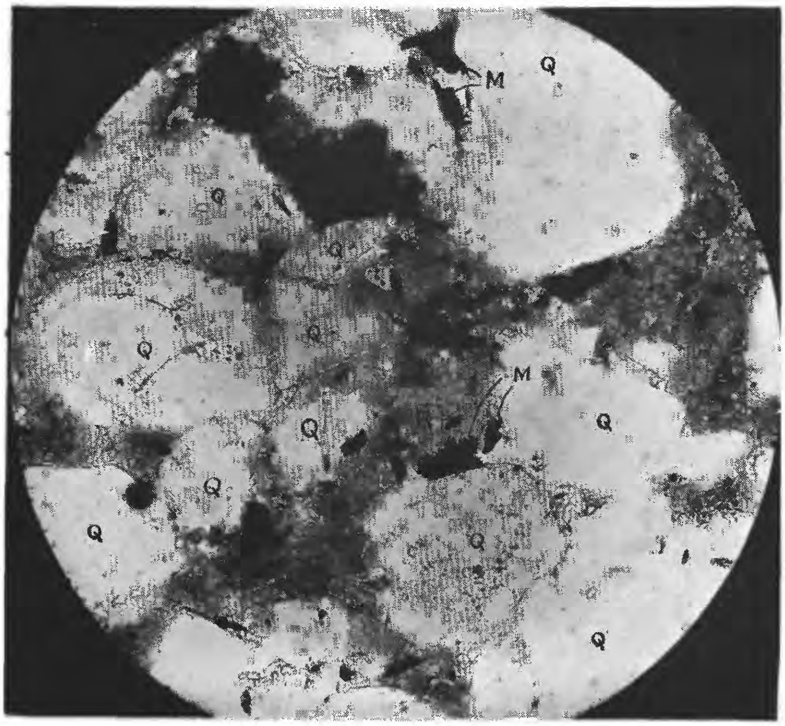

Figure 2. Photomicrograph of thin section of typical unoxidized high-grade vanadium ore of the Wingate(?) sandstone. Black is montroseite (M); gray is roscoelite (R); white is quartz (Q). Plane polarized light, 250X.

Pyrite, marcasite, galena, sphalerite, and chalcopyrite are sparsely distributed throughout the ore. They occur as small discrete grains disseminated among the ore minerals in the space between the sand grains.

No low-valance uranium minerals were found, but it is speculated that uranium may occur in fine-grained uraninite. Uranium in the unoxidized ore of other deposits of this type occurs in uraninite and coffinite. Very little, if any, organic material is present in the Entrada sandstone in the Rifle area and coffinite in almost every case elsewhere on the Colorado Plateau is associated with organic material.

Oxidation of the vanadium layer

Oxidation does not affect roscoelite and apparently produces little change in roscoelite ore. Montroseite in montroseite-roscoelite ore follows the course of oxidation common in the uranium-vanadium deposits (Week, Coleman, and Thompson, written communication; Evans, written communication). Melanovanadite, corvusite, and pascoite are formed by oxidation. Probably the vanadium in the vanadium-bearing chlorite is at least partly removed during oxidation and may also form secondary vanadium minerals. Carnotite is present in small amounts coating fractures and impregnating sandstone. Other vanadate minerals are probably present in small amounts but could not be definitely identified. The sulfides are destroyed by oxidation and the usual evidence of their former presence is a brown limonitic stain.

Mineralogy of the galena band

In addition to the galenalike minerals of the galena band, sphalerite, chalcopyrite, and pyrite are also present. Most of the galenalike minerals of the galena band give etch reactions characteristic of clausthalite (PbSe) which suggests that clausthalite is present either as a separate mineral or in solid solution in galena. The presence of selenium was confirmed by microchemical tests and colorimetric analyses.

In general the sulfide minerals occur in larger grains and in larger quantities in the galena band than in the ore. In the galena band mixed grains of chalcopyrite and sphalerite, and chalcopyrite, sphalerite, and galena are also found. Some of the chalcopyrite-sphalerite mixtures show chalcopyrite at the edge of the sphalerite in rim textures that may be the result of unmixing of a solid solution.

Oxidation of the galena band

Oxidation of the galena band destroys the sulfides and produces a limonitic stain. On the mine walls, a pink bloom is formed at or near the horizon of the galena band even in localities where the galena band cannot be definitely located. This pink bloom is native selenium, probably the monoclinic form.

Mineralogy of the green (chromium-bearing)layer

Overlying the galena band in the No. 1 vein is a green layer which is similar in appearance to the vanadium layer. Polished sections of this material show no sulfides except close to the galena band. Thin sections of this layer show a small amount of fine-grained material surrounding the quartz grains. Some of the fine-grained material shows a pleochroism in shades of green. Hess (1913) has described a green layer in the geologically similar deposits at Placerville, Colo., and ascribes the green color to the chromian mica, mariposite.

The green layer at Rifle contains, by spectrographic determinations, as much as 0.X percent chromium.

Oxidation of this green layer apparently produces no change.

CONCLUSIONS

The ore at Rifle shows certain similarities to the uranium-vanadium deposits of other parts of the Colorado Plateau. Certain differences are obvious--the ratio of vanadium to uranium is very high, organic material is practically absent, roscoelite is the predominant vanadium mineral, and secondary vanadium minerals are rare.

The Rifle deposits are similar to uranium-vanadium deposits in the textures, the habits of the ore, and the associated metals. The cause of the difference in primary minerals is not known, but this difference is the cause of rarity of secondary minerals and general resistance to oxidation of these deposits.

The geologic factors that influenced the localization of this deposit have not been recognized and the genesis cannot yet be explained.

LITERATURE CITED

Evans, H. T., and Block, Stanley, 1953, The crystal structure of montroseite, a vanadium member of the diaspore group: Am. Mineralogist, v. 11 and 12, p. 1242-1250.

Heinrich, E. W., and Levinson, A. A., 1955, Studies in the mica group; X-ray data on roscoelite and barium muscovite: Am. Jour. Sci., v. 253, p. 39-43.

Hess, F. L., 1913, Notes on the vanadium deposits near Placerville, Colorado: U. S. Geol. Survey Bull. 530, p. 148, 154.

Thomas, C. R., McCann, F. T., and Raman, N. D., 1945, Mesozoic and Paleozoic stratigraphy in northwestern Colorado and northeastern Utah: U. S. Geol. Survey Oil and Gas Inv., Prelim. Map 16.

Wells, R. C., and Brannock, W. W., 1946, The composition of roscoelite: U. S. Geol. Survey Bull. 950.

Williams, D., and Nakhala, F. M., 1951, Chromatographic contact print method of examining metallic minerals and its applications: Inst. Min. and Metallurgy Trans. v. 60, p. 291.