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CARNOTITE DEPOSITS IN THE CARRIZO MOUNTAINS AREA, NAVAJO INDIAN RESERVATION, APACHE COUNTY, ARIZONA, AND SAN JUAN COUNTY, NEW MEXICO

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ABSTRACT

The Carrizo Mountain area comprises about 950 square miles in the northeastern corner of Arizona and an adjoining narrow strip of northwestern New Mexico. Intrusive igneous rocks make up most of the mountain mass and Mesozoic sedimentary rocks are exposed on its flanks.

The carnotite deposits are in the Salt Wash sandstone member of the Morrison formation. These deposits yielded about 22,000 tons of ore between May 1942 and February 1944. Renewed mining activity in the area began in 1948.

The ore deposits consist of sandstone impregnated with carnotite and a vanadium-bearing mica. The ore contains from 0.1 to about 0.5 percent U_3O_8 and 1.0 to 5.0 percent V_2O_5, and much of the ore contains more lime as cementing material than does typical ore from Colorado and Utah. Most of the ore bodies are roughly tabular masses which are also irregular in plan, but some are elongate, podlike masses, less common and less well-developed than those in Colorado and Utah. In general the deposits tend to form clusters in ill-defined areas. The deposits are believed to have formed from ground-water solutions

shortly after the accumulation of the enclosing sands, and localization of the deposits does not appear to have been influenced by regional deformation, or igneous activity.

The area is relatively unexplored, compared to areas in Colorado and Utah, and continued exploration probably will yield new discoveries. Prospecting should be restricted to the Salt Wash sandstone member of the Morrison formation which contains all the known carnotite deposits. As these deposits tend to be grouped in clusters, prospecting along and behind the exposures of closely spaced deposits will probably be most fruitful. Surface prospecting may yield new discoveries north and west of the Carrizo Mountains, in the area south of Red Rock Trading Post, and in the Chuska Mountains to the south. South of about latitude 36° 30' N., the Salt Wash is considered unfavorable for ore deposits.

INTRODUCTION

Purpose, scope, and acknowledgments. --The Carrizo Mountains area is in the Navajo Indian Reservation, Apache County, Ariz., and San Juan County, N. Mex. Plate 1 shows the geology, in part generalized, and the location of the known carnotite deposits. The map is planned to aid in prospecting for and developing carnotite deposits by directing attention to the outcrop of the ore-bearing Salt Wash sandstone member of the Morrison formation. This report describes briefly the geology of the area and the general character of the deposits. Suggestions for prospecting also are included.

Most of the field work on which this preliminary report is based was done by the Geological Survey, United States Department of the Interior, as part of the strategic-minerals program during World War II. The area was mapped and studied by D. C. Duncan and W. L. Stokes in October and November 1942, and by Stokes and G. M. Sowers in April 1945. A report was prepared by Stokes in 1946, but it was withdrawn from publication because of security regulations at that time. Since then the report has been revised by R. P. Fischer to include information obtained from detailed work now in progress by the Geological Survey. This work, for the United States Atomic Energy Commission, includes a project of detailed mapping of the area, under the supervision of J. D. Strobell, and a regional stratigraphic study of the ore-bearing and associated rocks, under L. C. Craig. Acknowledgment is due Mr. H. S. Stafford of the Atomic Energy Commission and Mr. S. K. Smyth of Climax Uranium Company, who have furnished the map locations of the newly discovered carnotite deposits in the northwest part of the Chuska Mountains.

Geography. --The area consists of a 30-minute quadrangle, comprising about 950 square miles, in the northeast corner of Arizona and a narrow strip in the adjoining part of northwest New Mexico. Altitudes range from about 4,600 feet at the San Juan River in the northeast corner of the area to about 9,400 feet in the Carrizo Mountains. The mountain flanks and surrounding country, where most of the carnotite-bearing rocks are exposed, have altitudes of 5,000 to 7,000 feet.

East, north, and northwest of the Carrizo Mountains, the surface has low relief and is easily accessible, with only a few scattered buttes and mesas; whereas southwest and south of the mountains the surface is rugged and much dissected by canyons with intervening steep-walled mesas. Patches of dune sand are common on the less dissected parts of the area. The climate is semiarid. Stream channels, most of which are dry during a large part of the year, radiate from the mountains and ultimately join the San Juan River north of the area.

GEOLOGY

With the exception of a small mass of Permian strata in the Carrizo Mountains and outcrops of Tertiary beds in the Chuska Mountains, all the exposed sedimentary rocks in the area are of Mesozoic age. These rocks are covered in places by a thin veneer of outwash gravels, dune sand, or Recent alluvium. All of the known carnotite deposits in the Carrizo Mountains area are in the Salt Wash sandstone member of the Morrison formation.

The lithologic character, topographic expression, and thickness of the Mesozoic strata are summarized in table 1. Table 1 also identifies the several divisions shown on the map (pl. 1) and the map symbols and patterns used to identify them.

The Carrizo Mountains, which occupy the central part of the area, are composed of porphyritic intrusive bodies and masses of deformed and slightly metamorphosed sedimentary strata. The outline of this complex is shown on plate 1, but no detailed geologic study has been made of the mountains. Small patches of Salt Wash sandstone member of the Morrison formation are known to be present in places in the mountains, however, and some carnotite is reported in them.

ORE DEPOSITS

History and production. --Carnotite deposits were discovered in the area about 1918 and

Table 1. --Generalized section of the sedimentary rocks in the Carrizo Mountains area

Map Symbol	Age	Stratigraphic Unit		Lithologic character, topographic expression, and thickness
kmd	Cretaceous	Mancos shale		Shale, thin-bedded, gray. Forms slopes. Only basal part present.
kd		Dakota sandstone		Conglomeratic sandstone, weathers yellow-brown. Forms cliffs and caps mesas. 30 to 200 feet thick
Jmu	Jurassic	Morrison formation	Upper part of Morrison formation (three upper units shown collectively on map).	Shale, gray, light green, and pink; minor thin beds of conglomeratic sandstone. Forms steep slopes. 150 to 350 feet thick. Sandstone, yellowish gray, friable; minor thin beds of greenish-gray shale. Forms cliffs and short slopes. 140 to 270 feet thick. Shale, grayish-red, and sandstone, pale-red to white, friable. Forms low cliffs and steep slopes. 150 to 500 feet thick.
Jms			Salt Wash sandstone member (carnotite-bearing, shown separately on map).	Sandstone, light-brown to white, fine-grained, cross-laminated lenticular beds, and minor thin beds of grayish-red shale. Carnotite deposits may occur at any stratigraphic position in this unit. Forms irregular cliffs and caps broad benches and mesas. 60 to 220 feet thick.
JTr		San Rafael group (undifferentiated on map).		Sandstone, pale-red to light-brown. Forms rounded cliffs. 20 to 60 feet thick. Sandstone, reddish-brown and light-brown, interbedded. Forms prominent banded cliffs or red earthy slopes. 50 to 150 feet thick. Limestone, light-gray. Present only in eastern part of area. Feather edge to 5 feet thick. Sandstone, reddish-orange to reddish-brown. Forms vertical cliffs or steep slopes. 40 to 90 feet thick. Shale, grayish-red, and thin-bedded sandstone, brown to white. Forms prominent benches. Present only in western part of area. 45 to 115 feet thick.
	Jurassic(?)	Glen Canyon group (undifferentiated on map).		Sandstone, white and reddish-orange, thick parallel beds with large-scale cross-lamination. Forms high vertical or smoothly rounded cliffs with ledgy slopes at base. 700 to 800 feet thick.
	Triassic	Triassic "Red Beds" (undifferentiated on map).		Shale, red to purple, with some red to white sandstone, and conglomerate, and gray limestone. Forms badlands topography. Up to 900 feet thick, base not exposed.

many claims were located in the next few years. Little mining was done until 1942, however, when war conditions increased the demand for vanadium-bearing ore. From May 1942 through February 1944, the area yielded about 22,000 tons of ore averaging 2.25 percent V_2O_5 [1]; the uranium content is not known. This ore was produced from deposits on the east, north, and west flanks

[1] Compiled by the Geological Survey from Metals Reserve Company records.

of the Carrizo Mountains. The less accessible country southwest of the mountains was prospected during this period, and though many deposits were found, further development was halted because of the decline in ore requirements in 1944. Activity started again in 1948, and since then many mines have resumed operation, new mines have been developed, and new discoveries have been made, particularly in the southern part of the area.

The ore. --The carnotite deposits in the Carrizo Mountains area are similar in most respects to those in the larger and more productive districts of Colorado and Utah[2].

The ore, consisting mostly of sandstone impregnated with ore minerals, contains from 0.1 to more than 0.5 percent U_3O_8 or more and from 1.0 to 5.0 percent V_2O_5. Fossil-plant remains are present in most deposits in the area, and some are mineralized, but high-grade replacements of fossil-plants are less common than in Colorado and Utah; large fossil logs are comparatively rare.

Carnotite ($K_2O.2UO_3.V_2O_5.3H_2O$) is the only uranium mineral that has been definitely identified. It is bright yellow, and is disseminated throughout the sandstone, partly replacing fossil plants and coating joint and bedding surfaces.

The identity of the principal vanadium mineral has not been definitely established, although its chemical composition is close to that of roscoelite, the vanadium-bearing mica. It is fine-grained and micaceous, and coats the sand grains, partly or completely filling the pore spaces of the sandstone. It gives a gray or greenish-gray color to the rock. In a few places brightly colored calcium vanadates and dark-colored vanadium oxides are present in sufficient amounts to be considered ore.

Calcite partly cements most of the sandstone of the Morrison formation, and is present in various amounts in the ore. Much of the ore in the Carrizo Mountains area contains considerably more lime than does typical ore from Colorado and Utah. Ore containing more than 6 percent $CaCO_3$, or that containing more than a 3:1 ratio of $CaCO_3$ to V_2O_5, is classed as "high-lime ore." As high-lime ore is difficult to treat in the mills, it is purchased by AEC only under special contract, usually at a slightly lower price than ore in which the lime content is low.

Ore bodies. --Most of the ore bodies in the Carrizo Mountains area are irregular tabular layers. These layers are nearly parallel to the major bedding to the sandstone, but a close examination shows that they cross the bedding at various angles. The thickness of the layers ranges from a feather edge to as much as 15 feet. The ore bodies are also irregular in plan, and they range from several feet to a few hundred feet in width. Small bodies consisting of layers less than a foot thick are minable only if they are at or near the surface and high grade.

Some individual ore bodies, as well as some masses of ore in the tabular layers, are elongate and podlike. Such masses generally are called "rolls" by miners, but rolls are neither as common nor as well developed in the Carrizo Mountains area as in the Colorado-Utah region.

Some of the deposits in the area consist of two layers of ore that partly or completely enclose a thin lens-shaped mass of yellow-stained, essentially barren sandstone containing fragments of fossil plants. Although the ore layers are mostly thin, in places they thicken irregularly, particularly where the two layers merge at the edge of the enclosed lens, forming a pod-like mass or roll.

Although isolated ore bodies are known, in general the bodies are clustered in ill-defined areas a few thousand feet across. (See pl. 1). Within these clusters, many bodies are connected by thin, weakly mineralized layers. These layers are not continuous between all ore bodies, however, so that even within the clusters much of the ground is non-ore-bearing.

Origin. --The carnotite deposits are thought to have formed from ground-water solutions, which were introduced into the ore-bearing beds shortly after the sands accumulated, and then localized by physical and chemical conditions within the Morrison formation. It is not possible to predict the exact location of carnotite ore deposits, because the conditions under which the ore was formed are not clearly understood. Nevertheless, it is evident that these conditions were widespread and favored the formation of carnotite deposits in many places in the area.

The localization of the deposits does not appear to have been influenced by structures resulting from regional deformation, igneous activity, nor by the topographic development of the area. In some deposits exposed at the surface, however, the original metal distribution may have been somewhat rearranged by secondary concentration or leaching at the outcrop. In these places, the character and grade of the ore may be expected to change slightly behind the natural exposures.

[2] Fischer, R. P., Vanadium deposits of Colorado and Utah: U. S. Geol. Survey Bull. 936-P, 1942.

SUGGESTIONS FOR PROSPECTING

Compared with many of the carnotite-producing areas in Colorado and Utah, the Carrizo Mountains area is relatively unexplored and undeveloped, and continued prospecting can be expected to yield new discoveries. Although all of the geologic conditions that influenced the localization of ore have not been definitely determined, certain observed facts regarding the distribution and character of the deposits are useful as guides for prospecting.

All of the known carnotite deposits in the Carrizo Mountains area are in the easily recognizable Salt Wash sandstone member of the Morrison formation, and prospecting should be restricted to this member (pl. 1). On the west, southwest, and northwest sides of the mountains all the deposits are in the lower half of this member; southeast of the mountains no deposits have been found in the lower 50 feet of the member, but the middle part is ore-bearing.

Most of the known deposits in the Carrizo Mountains area are grouped in poorly defined clusters, usually only a few thousand feet in width. (See pl. 1.) Prospecting along and behind the outcrops that show closely spaced deposits offers the best opportunity for the discovery of additional ore. Thin, weakly mineralized layers connect many of the ore bodies within clusters; these layers should be followed in searching for new ore.

Between these clusters, even where the Salt Wash member is well exposed, only a few small deposits have been found. Prospecting in such ground can not be expected to yield many new deposits. On the other hand, undiscovered clusters of deposits can be expected in the ore-bearing sandstone where it is poorly exposed or covered.

A few miles south of the southern margin of the Carrizo Mountains area (latitude 36° 30'), the Salt Wash is very fine-grained, contains a high proportion of shale, and is considered unfavorable for carnotite ore. Several miles farther south the Salt Wash thins to a feather edge.

Surface prospecting might yield new discoveries north and west of the Carrizo Mountains, where the Salt Wash member of the Morrison formation is poorly exposed between sand dunes and in shallow washes on widespread benches; in the relatively inaccessible Chuska Mountains, where exposures are poor; and along the poorly exposed outcrop south of Red Rock Trading Post. The Salt Wash member is present and might be ore-bearing in the central part of the Carrizo Mountains.