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GEOLOGY OF THE ROC CREEK QUADRANGLE, MONTROSE COUNTY, COLORADO

By E. M. Shoemaker

Trace Elements Memorandum Report 706

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Dr. Phillip L. Merritt, Assistant Director
Division of Raw Materials
U. S. Atomic Energy Commission
16th and Constitution Avenue, N. W.
Washington 25, D.C.

Dear Phil:

Transmitted herewith is one copy of TEM-706, "Geology of the Roc Creek quadrangle, Montrose County, Colorado," by E. M. Shoemaker, July 1954.

We are asking Mr. Hosted to approve our plan to publish this report in the Quadrangle Map Series.

Sincerely yours,

Andrew Brown

W. H. Bradley
Chief Geologist

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UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

GEOLOGY OF THE ROC CREEK QUADRANGLE MONTROSE COUNTY, COLORADO*

By

By E. M. Shoemaker

July 1954

Trace Elements Memorandum Report 706

This preliminary report is distributed without editorial and technical review for conformity with official standards and nomenclature. It is not for public inspection or quotation.

*This report concerns work done on behalf of the Division of Raw Materials of the U. S. Atomic Energy Commission.

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ILLUSTRATION

Preliminary geologic map and sections of the Roc Creek Quadrangle, Colorado . . . . In envelope

GEOLOGY OF THE ROC CREEK QUADRANGLE, MONTROSE COUNTY, COLORADO

By Eugene M. Shoemaker

ABSTRACT

The Roc Creek quadrangle is one of eighteen 7 1/2-minute quadrangles covering the principal carnotite-producing area of southwestern Colorado. The geology of these quadrangles was mapped by the U. S. Geological Survey for the U. S. Atomic Energy Commission as part of a comprehensive study of carnotite deposits. The rocks exposed in the eighteen quadrangles consist of crystalline rocks of pre-Cambrian age and sedimentary rocks that range in age from late Paleozoic to Quaternary. Over much of the area the sedimentary rocks are flat lying, but in places the rocks are disrupted by high-angle faults and northwest-trending folds. Conspicuous among the folds are large anticlines having cores of intrusive salt and gypsum.

Most of the carnotite deposits are confined to the Salt Wash sandstone member of the Jurassic Morrison formation. Within this sandstone, most of the deposits are spottily distributed through an arcuate zone known as the "Uravan mineral belt". Individual deposits range in size from irregular masses containing only a few tons of ore to large, tabular masses containing many thousands of tons. The ore consists largely of sandstone selectively impregnated and in part replaced by uranium and vanadium minerals. Most of the deposits appear to be related to certain sedimentary structures in sandstones of favorable composition.

INTRODUCTION

The U. S. Geological Survey mapped the geology of the Roc Creek quadrangle, Colo., as part of a comprehensive study of carnotite deposits. The study, covering the principal carnotite-producing area in southwestern Colorado, included detailed examination of mines and geologic mapping of eighteen 7 1/2-minute quadrangles, of which the Roc Creek quadrangle is one. Parts of the texts accompanying these maps have been standardized; these parts comprise some descriptions of geologic formations and general descriptions of regional structural setting, geologic history, and ore deposits. A comprehensive report presenting in greater detail the geologic features of the entire area and interpretations of these features is in preparation. Work was started in the area in 1939 as a cooperative project with the State of Colorado Geological Survey Board and the Colorado Metal Mining Fund, and was continued through 1945 as a wartime strategic minerals project. Since 1947 the Geological Survey has been continuing this geologic study on behalf of the Division of Raw Materials of the U. S. Atomic Energy Commission. The Roc Creek quadrangle was mapped in 1948 and 1949.

The Roc Creek quadrangle covers about 59 square miles in Montrose County, Colo., and lies in the Canyon Lands division of the Colorado Plateau physiographic province. The quadrangle is a rugged area of mesas and canyons. Total relief within the quadrangle is about 3,200 feet; altitudes range from about 4,700 feet in the canyon of the Dolores River to 7,864 feet on Carpenter Ridge. The Dolores River and its tributaries drain the area.

No accurate information on rainfall is available, but the annual precipitation is probably between 10 and 15 inches; the area is semiarid and supports a moderate growth of juniper and piñon on rocky terrain and abundant sagebrush where soils are thick. Cacti and sparse grass are widely distributed. Part of the quadrangle is accessible over a system of dry-weather roads, but Sewemup Mesa in the northern part is accessible with difficulty even on foot.

REGIONAL GEOLOGY

Rocks exposed in the 18 quadrangles mapped consist of crystalline pre-Cambrian rocks and sedimentary rocks that range in age from late Paleozoic to Quaternary. Crystalline rocks crop out only in the northeastern part of the area along the flanks of the Uncompahgre Plateau; the rest of the area is underlain by sedimentary rocks. The latest Paleozoic and earliest Mesozoic beds wedge out northeastward against the crystalline pre-Cambrian rocks, but later Mesozoic units were deposited on top of the pre-Cambrian rocks. Over most the region the sedimentary beds are flat lying, but in places they are disrupted by high-angle faults, or folded into northwest-trending monoclines, shallow synclines, and strongly developed anticlines.

The largest of the folds is the Uncompahgre Plateau uplift, a fold nearly 100 miles long that traverses the northeastern part of the area. Well developed anticlines having intrusive cores of salt and gypsum underlie Sinbad Valley, Paradox Valley, and Gypsum Valley in the central part of the area; the Dolores anticline in the southwestern part of the area probably has a salt-gypsum core, although it is not exposed.

The Roc Creek quadrangle lies in the northern part of the area, about 10 miles southwest of the Uncompahgre Plateau. The northwest corner of the quadrangle includes part of Sinbad Valley, and the southern part of the quadrangle includes part of Paradox Valley.

STRATIGRAPHY

The oldest rocks exposed in the Roc Creek quadrangle are of Pennsylvanian age and are exposed in the floors of Sinbad Valley and Paradox Valley, and locally along Roc Creek Canyon and Garvey Gulch. Rocks of Permian (?) and Triassic age also crop out in Sinbad Valley, Paradox Valley, and the canyon of Roc Creek, and Triassic beds are exposed in the canyons of the Dolores River and its tributaries as well. Jurassic rocks crop out along the sides of the valleys, in the canyon walls, and on the benches, slopes, and mesas. Recent deposits of wind-blown material and sheet wash are widely distributed on the mesas and on the valley floors, and landslide debris occurs on Carpenter Ridge and in the western end of Paradox Valley.

Hermosa formation

The Hermosa formation in the Roc Creek quadrangle comprises a lower member composed predominantly of salt and gypsum called the Paradox member, and an upper member composed of arkose, some red beds, and limestone.

Paradox member

Crumpled beds of the Paradox member, the lower member of the Pennsylvanian Hermosa formation crop out on the floor of Sinbad Valley, Paradox Valley, and in the canyon of Roc Creek. The outcrops include gypsum, micaceous sandstone, arkose, limestone, and limestone breccia and conglomerate. At depth, below the zone of leaching, salt is the most abundant single constituent. Beds of the Paradox member are so highly contorted that neither the stratigraphic sequence nor the true thickness can be determined accurately. At least 2,000 feet of Paradox beds are exposed in Sinbad Valley in the Roc Creek and adjacent quadrangles, but the original thickness of salt, that was probably interbedded with this sequence and is now leached away, is unknown. A well, in Paradox Valley east of the Roc Creek quadrangle, was drilled entirely in rocks of the Paradox member, chiefly salt, to 11,000 feet and did not penetrate the base of the member. Undoubtedly the beds at this locality have been greatly thickened by lateral flowage.

Upper member

Steeply dipping beds of the upper member of the Hermosa formation are exposed in isolated belts of outcrop in Sinbad Valley and Paradox Valley. In Sinbad Valley a section of gray arkose with some productid-bearing limestone is exposed on the southwest side of the valley, and a contorted belt of limestone and arkosic sandstone is enclosed in deformed beds of the Paradox member in the center of the Valley. In Paradox Valley a section of reddish sandstone and sandy limestone containing large fusilinids appears to be succeeded conformably of arkoses of the Cutler formation, and is cut off by faults at the base. About 500 feet of beds are exposed in each of the belts of outcrop, but the relationship of the various exposed sections is unknown.

Cutler formation

The Cutler formation of Permian (?) age comprises a sequence of maroon and purple conglomerate and arkose, and red-brown sandy mudstone. Conglomerate and arkose beds contain grains of fresh feldspar and dark minerals and pebbles and boulders of granite, gneiss, schist, and quartzite--materials derived almost entirely from the pre-Cambrian rocks that underlie the Uncompahgre Plateau. Rudely bedded layers, channeling, and ripple marks are common features of the formation.

The Cutler formation thickens from a knife-edge on the flank of the Uncompahgre Plateau to several thousand feet a few miles southwest of the uplift. A well drilled in the canyon of the Dolores River near the town of Gateway, Colo., several miles north of the Roc Creek quadrangle and about 4 miles southwest of the edge of the Cutler, penetrated more than 7,800 feet of red arkose before reaching the pre-Cambrian basement. It seems probable that this thick sequence of beds includes not only rocks of Permian (?) age, but of Pennsylvanian as well. Abrupt thinning of the formation toward its source area, coarseness of the material, and rudely bedded layers indicate the Cutler in this area was deposited as a fanglomerate.

About 1,000 feet of the Cutler formation are exposed in two isolated outcrops in the Roc Creek and about 2,000 feet in the walls of Paradox Valley. Although the Cutler rests on the Hermosa formation with apparent conformity near the Carpenter Ridge truck road, it evidently overlaps upturned Hermosa beds south of the Sunrise mine, but the critical relations are hidden by faulting.

Moenkopi formation

In Colorado the Moenkopi formation of Lower Triassic age is divided into three lithologic units: 1) a lower member, composed chiefly of poorly sorted sandy mudstone; 2) a middle member, characterized by beds of conglomerate and conglomeratic sandstone; and 3) an upper member, composed chiefly of fine-grained sandstone and shale. The formation in the Roc Creek quadrangle reaches a maximum thickness of 800 feet on the northeast side of Sinbad Valley and is cut out entirely by angular unconformity against the upthrust masses of Paradox member of the Hermosa formation, in Sinbad Valley and Paradox Valley.

Lower member

The lower member of the Moenkopi formation unconformably overlies the Cutler formation. It characteristically crops out as a smooth steep slope or a nearly vertical cliff. It consists almost entirely of brick-red poorly sorted sandy mudstone and silty sandstone in which the grains range from clay size to granules with a maximum diameter of 3 mm. A bed of massive white gypsum as much as 6 feet thick is present locally at the base of the member. The gypsum bed at the base of the member, together with even bedding, lack of sorting, and uniform thickness of the member, suggests an initial ponding of the area at the beginning of Moenkopi deposition followed by rapid dumping of sediment in a body of standing water. Toward the Uncompahgre Plateau the lower member wedges out both by truncation at the top and by onlap.

In the Roc Creek quadrangle the lower member reaches a maximum thickness of 150 feet in the canyon of Roc Creek. It is cut out by angular unconformity at the base of the overlying middle member in both Sinbad Valley and Paradox Valley.

Middle member

The middle member of the Moenkopi formation overlies the lower member unconformably. It consists of purplish and red-brown conglomeratic arkosic ledge-forming beds of sandstone separated by interbedded red-brown and chocolate-brown silty shale and thin layers of fine- and coarse-grained sandstone. Near the Uncompahgre Plateau the ledge-forming sandstone beds are more conglomeratic and constitute the dominant part of the member. Sandstone beds are cross-laminated and show channeling, current lineation, and abundant ripple marks. Shale beds are marked in places by mud cracks. These features suggest fluviatile deposition. The undersurfaces of the thicker sandstone beds are marked by convoluted patterns of small ridges and knobs due to compaction of underlying shale and are a diagnostic feature of the middle member of the Moenkopi formation.

The middle member of the Moenkopi formation reaches a maximum thickness of 250 feet in Sinbad Valley.

Upper member

The upper member of the Moenkopi formation lies conformably on the middle member and grades from red-brown and chocolate-brown shale and sandstone at the base to light-brown sandstone and gypsiferous brown shale at the top. Thin beds of light-maroon coarse-grained sandstone are scattered throughout the member; these are commonly highly gypsiferous. The relatively abundant gypsum gives rise to a fluffy soil which gives the whole member a light-brown color when viewed from a distance.

Bedding is uniform except for small-scale cross-lamination in some of the thin sandstone beds; ripple marks are abundant. A predominance of shales and uniformity of bedding suggests that the upper Moenkopi was deposited in a body of shallow water perhaps marginal to a sea.

In the Roc Creek quadrangle the upper member of the Moenkopi formation reaches a maximum thickness of 340 feet in Sinbad Valley.

Chinle formation

The Chinle formation of Upper Triassic age consists of bright-red and red-brown mudstone, siltstone, sandstone, and limestone-pebble and mudstone-pebble conglomerate. The formation forms steep slopes. A discontinuous unit of maroon and lavender coarse-grained pebbly sandstone, which locally reaches a thickness of 60 feet, is present in places at the base of the formation. This unit is probably the stratigraphic equivalent of the Shinarump conglomerate, which is widespread in Utah. Thin purple limestone beds and lenses of limestone pebble and mudstone-pebble conglomerate are commonly interbedded with red mudstone and siltstone in the lower half of the Chinle. Fine-grained sandstone beds, common in the upper part of the formation, are thicker and closer spaced toward the top. The Chinle grades in places into the overlying Wingate sandstone, although the break in slope between the cliff-forming Wingate and the slope-forming Chinle is generally abrupt. In contrast to the uniform bedding in the Moenkopi formation, the bedding in the Chinle is irregular, and individual sandstone beds cannot be traced more than a few hundred feet along the outcrop.

The Chinle formation reaches a maximum thickness of about 700 feet in Sinbad Valley. It wedges out in the center of Sinbad Valley and Paradox Valley permitting the overlying Wingate sandstone to rest directly on Pennsylvanian beds.

Glen Canyon group

The Glen Canyon group, of Jurassic (?) age, comprises, in ascending order, the Wingate sandstone, the Kayenta formation, and the Navajo sandstone.

Wingate sandstone

The Wingate sandstone conformably overlies the Chinle formation. The sandstone is a massive, fine-grained rock composed of clean, well-sorted quartz sand. It typically crops out as an impressive red or dark-brown wall, stained and streaked in places with a surficial red and black desert varnish. Vertical joints cut the sandstone from top to bottom; the spalling of vertically jointed slabs largely causes the recession of the cliff. The sandstone is divided into horizontal layers by extensive bedding planes spaced 2 to 50 feet apart. Within each horizontal layer the sandstone is cross-bedded on a magnificent scale; great sweeping tangential cross-beds of eolian type, in places extending across the entire thickness of the horizontal layer, are disposed in all directions. The sandstone is poorly cemented and crumbles easily; this quality probably accounts for the readiness with which the rock disintegrates in faulted areas.

In the Roc Creek quadrangle the Wingate sandstone ranges in thickness from 150 feet on the south side of Sinbad Valley to about 350 feet along the northeast rim of Sinbad Valley.

Kayenta formation

The Kayenta formation conformably overlies the Wingate sandstone; the contact between the two formations is gradational in most places. The formation is notable for its variety of rock types. Sandstone, red, buff, gray, and lavender in color, is the most abundant type; but the formation also contains considerable quantities of red siltstone, thin-bedded shale, and conglomerate. The conglomerate contains pebbles of sandstone, shale, and limestone. The sandstone is composed of rounded to subrounded quartz grains and minor quantities of mica, feldspar, and dark minerals. Most of the sandstone is thin bedded, cross-bedded in part, and flaggy; some is massive. Individual sandstone beds are lenticular and discontinuous and interfinger with shale and, in places, with conglomerate. The Kayenta typically crops out in a series of benches and ledges. The ledges in many places overhang recesses where softer beds have eroded back. The lower part of the formation is more firmly cemented and forms resistant, thick ledges that protect the underlying Wingate sandstone from erosion.

The Kayenta formation in the Roc Creek quadrangle ranges in thickness from 140 feet in the lower canyon of Roc Creek to 300 feet on Sewemup Mesa. Abrupt local changes in thickness of 10 to 20 feet are common. The irregular bedding, channel filling, and range of thickness all indicate a fluviatile origin.

Navajo sandstone

The Navajo sandstone conformably overlies the Kayenta formation. The Navajo is a gray to buff massive fine-grained clean quartz sandstone. Tangential cross-beds of tremendous size leave little doubt of the eolian origin of the sandstone. The sandstone weathers by disintegration and tends to develop rounded topographic forms where exposed on slopes or benches, and vertical cliffs where protected by overlying rocks. A 6-foot bed of limestone is present locally on Sewemup Mesa.

The Navajo sandstone ranges in thickness from a featheredge near the eastern end of the canyon of the Roc Creek to a maximum thickness of 100 feet in the upper canyon of Roc Creek and western Paradox Valley.

San Rafael group

In this area the San Rafael group, of Middle and Upper Jurassic age, comprises, in ascending order, the Carmel formation (Middle and Upper Jurassic), the Entrada sandstone (Upper Jurassic), and the Summerville formation (Upper Jurassic). The group crops out chiefly in a narrow band along the sides of Carpenter Ridge. The Carmel formation and the Entrada sandstone were mapped together because in most places they form a narrow outcrop.

Carmel formation and Entrada sandstone

The Carmel formation consists largely of red to buff, nonresistant, horizontally bedded siltstone, mudstone, and sandstone. In some localities the basal beds consist of reworked Navajo sandstone. Pebbles and angular fragments of white and gray chert, as much as an inch across, are scattered rather abundantly through the lower part of the formation and less abundantly through the upper part. These chert pebbles and angular fragments are sufficiently abundant locally to form layers of conglomerate. Included in these layers are scattered greenish-gray, red, and yellow quartzite pebbles and boulders as large as

5 by 8 inches. In many places the upper part of the formation contains scattered barite nodules as much as an inch across. No definite evidence indicates that the Carmel formation of this area is of marine origin as is the Carmel of central Utah, but the probabilities are that the Carmel of southwestern Colorado was deposited in shallow water marginal to a sea.

The Carmel formation grades upward, in most places without prominent breaks, into the Entrada sandstone. The Entrada sandstone, known locally as the "slick rim" because of its appearance, is perhaps the most picturesque of all the formations in the plateau region of Colorado. The smoothly rounded, in places bulging, orange, buff, and white cliffs formed by this sandstone are a distinctive and scenic feature of the region. Horizontal rows of pits, resulting from differential weathering and ranging from a few inches to a foot or more across, are characteristic of these cliffs. The Entrada consists of alternating horizontally bedded units and sweeping, eolian-type cross-bedded units. The horizontally bedded units are most common in the basal part and in the uppermost, lighter-colored part of the Entrada, whereas the cross-bedded units are dominant in the middle part. The Entrada sandstone differs from the somewhat similar Wingate sandstone and Navajo sandstone by the sorting of sand into two distinct grain sizes. Subrounded to subangular quartz grains mostly less than 0.15 mm in diameter make up the bulk of the sandstone. The sandstone also contains larger grains, which are well-rounded, have frosted surfaces, and range from 0.4 to 0.8 mm in diameter; most of these grains are of quartz, but grains of chert are scattered among them. Most of the larger grains are distributed in thin layers along bedding planes.

The combined thickness of the Entrada sandstone and Carmel formation ranges from 100 feet near the southeastern end of Sinbad Valley to 230 feet on Carpenter Ridge.

Summerville formation

The Summerville formation generally crops out as a steep, debris-covered slope, with few good exposures. Where exposed the Summerville exhibits a remarkable even, thin, horizontal bedding. Beds are predominantly red of various shades, although some beds are green, brown, light yellow, or nearly white. Sandy and silty shale are the most abundant kinds of rock but all gradations from claystone to clean, fine-grained sandstone are interbedded with them. Well-rounded amber-colored quartz grains with frosted or matte surfaces are disseminated throughout most of the formation, including those beds consisting almost entirely of claystone. Thin beds of authigenic red and green chert are widespread. A thin, discontinuous bed of dark-gray dense fresh-water limestone occurs in the upper part of the formation. Sandstone beds are thicker and sandstone is more abundant in the lower part of the formation than in the upper part. Commonly the sandstone beds are ripple-marked, and in places they show small-scale low-angle cross-bedding. In the Roc Creek quadrangle near the base of the Summerville formation is a bed of fine-grained sandstone which forms a prominent ledge up to 30 feet thick in the western part of the canyon of Roc Creek. To the northwest this bed can be traced into the Moab tongue of the Entrada formation, and to the south and east it grades into interbedded sandstones and shales of the lower part of the Summerville formation. In this report this bed is included in the Summerville.

The Summerville formation rests conformably on the Entrada sandstone, and, although a sharp lithologic change marks the contact, no cessation of deposition separated the two formations. The upper contact of the Summerville is uneven and channeled, and the channels are filled by the overlying basal sandstones of the Morrison formation. Locally, however, the contact is difficult to determine, because the overlying shales and mudstones of the Morrison formation are similar to beds of the Summerville.

The Summerville formation ranges in thickness from 60 feet in Sinbad Valley to 140 feet in the upper canyon of Roc Creek.

Morrison formation

The Morrison formation, of Upper Jurassic age, is of special interest economically because of the uranium- and vanadium-bearing deposits it contains. The formation comprises two members in this area; the lower is the Salt Wash sandstone member and the upper is the Brushy Basin shale member. The Salt Wash sandstone member and the Brushy Basin shale member in general are of approximately equal thickness. In some areas, however, their thicknesses vary independently, whereas in other areas a thinning in one member is accompanied by a thickening in the other.

Salt Wash sandstone member

The Salt Wash sandstone member ordinarily crops out above the slope-forming Summerville formation as a series of thick, resistant ledges and broad benches. Sandstone predominates and ranges in color from nearly white to gray, light buff, and rusty red. Interbedded with the sandstone are red shale and mudstone and locally a few thin lenses of dense gray limestone. Sandstone commonly occurs as strata traceable as ledges for considerable distances along the outcrop, but within each stratum individual beds are lenticular and discontinuous; beds wedge out laterally, and other beds occupying essentially the same stratigraphic position wedge in. Thus, any relatively continuous sandstone stratum ordinarily consists of numerous interfingering lenses, with superposed lenses in many places filling channels carved in underlying beds. Lenses are separated in places by mudstone and contain mudstone seams. Most of the sandstone is fine- to medium-fine-grained, cross-bedded, and massive; single beds or lenses may attain a maximum thickness of 120 feet. The ripple marks, current lineations, rill marks, and cut-and-fill structures indicate the Salt Wash was deposited under fluviatile conditions.

The sandstone consists largely of subangular to subrounded quartz grains, but orthoclase, microcline, and albite grains occur in combined amounts of 10 to 15 percent. Chert and heavy-mineral grains are accessory. Considerable quantities of interstitial clay and numerous clay pellets occur in places, especially near the base of some of the sandstone lenses. Fossil wood, carbonaceous matter, and saurian bones occur locally.

The Salt Wash sandstone member ranges from 200 to 370 feet in thickness in the quadrangle.

Brushy Basin shale member

The Brushy Basin shale member contrasts strongly in over-all appearance with the underlying Salt Wash sandstone member. Although the lithologic differences are marked, the contact between the two members is gradational. The mapped contact, taken as the base of the lowermost layer of conglomerate lenses, is arbitrary in many respects, and probably does not mark an identical stratigraphic horizon in all localities.

The Brushy Basin shale member consists predominantly of varicolored bentonitic shale and mudstone, with intercalated beds and lenses of conglomerate and sandstone, and a few thin layers of limestone. Because of its high proportion of soft, easily eroded bentonitic shale and mudstone, the Brushy Basin member forms smooth slopes covered with blocks and boulders weathered from the more resistant layers of the member and from the overlying formations. The shales and mudstones are thin-bedded and range in color from pure white to pastel tints of red, blue, and green. Exposed surfaces of the rock are covered with a loose, fluffy layer of material several inches thick, caused by the swelling of the bentonitic material during periods of wet weather. Scattered through the shale and mudstone are thin beds of fine-grained very hard silicified rock that breaks with a conchoidal fracture. The silica impregnating these beds may have been released during the devitrification of volcanic debris in adjacent beds. Beds of chert-pebble conglomerate, a few inches to 25 feet thick, occur at intervals throughout the member. These conglomerate beds are commonly dark rusty red and form conspicuous resistant ledges. Silicified saurian bones and wood are much more abundant in the Brushy Basin shale member than in the Salt Wash sandstone member, especially in some of the conglomerate beds.

The Brushy Basin shale member, like the Salt Wash sandstone member, undoubtedly was deposited under fluviatile conditions. The conglomerate and sandstone lenses mark stream channels that crossed floodplains on which were deposited the fine-grained sediments now represented by the mudstone and shale. No complete section of Brushy Basin shale is exposed in the Roc Creek quadrangle. About 250 feet are preserved on Carpenter Ridge.

Quaternary deposits

Quaternary deposits include older lithified alluvial gravels and younger alluvium, colluvium, reworked loess, and landslide debris. The older deposits, found on the floor of Sinbad Valley and Paradox Valley, are chiefly conglomerate and sandstone cemented by calcareous material. An extensive mantle of more recent alluvium is spread across the floors of Sinbad Valley and Paradox Valley and is also found in the canyons of Roc Creek and the Dolores River. As shown on the map the alluvium includes broad aprons of talus on the valley sides. Scattered patches of sandy silt on Carpenter Ridge are designated alluvium on the map but may be largely wind-deposited. The most extensive landslide, which is on Carpenter Ridge, is of the debris flow type and is composed almost entirely of material derived from the Brushy Basin member of the Morrison formation.

STRUCTURE

Regional setting

Many geologic structures on the Colorado Plateau are so large that a 7 1/2-minute quadrangle covers only a small part of any complete structural unit. The larger structural units consists of salt anticlines, 45 to 80 miles long; uplifted blocks 50 to 125 miles long, bounded by monoclinal folds; and domical uplifts, 8 to 20 miles across, around stocklike and laccolithic intrusions.

The salt anticlines trend northwesterly and lie in a group between eastward-dipping monoclines on the west side of the Plateau and westward-dipping monoclines on the east side of the Plateau. The cores of these anticlines consist of relatively plastic salt and gypsum, derived from the Paradox member of the Pennsylvanian Hermosa formation and intruded into overlying late Paleozoic and early Mesozoic rocks. All the anticlines are structurally similar in many respects, but each exhibits structural pecularities not common to the rest; furthermore, all are more complex than their seemingly simple forms would suggest. Faults, grabens, and collapse and slump structures alter the forms of the anticlines. Erosion has removed much of the axial parts of these anticlines, leaving exposed large intrusive masses of the Paradox member, and forming valleys such as Sinbad Valley, Paradox Valley, and Gypsum Valley in Colorado and similar valleys in Utah. Alternating with these anticlines are broad, shallow, simple synclines.

Structure in the Roc Creek quadrangle

The Roc Creek quadrangle includes the southeastern end of the Sinbad Valley salt anticline and part of the Paradox Valley salt anticline. These two major structures are separated by a relatively narrow syncline whose axis lies just south of the canyon of Roc Creek. The crests and flanks of both anticlines are broken by complex systems of normal faults, the combined displacements of which have lowered the rocks overlying the intrusive cores of the anticlines more than 100 feet. The faults may be separated into at least two generations, as the displacement on some faults is earlier than the development of the present topography, and the displacement on other faults has formed conspicuous fault scarps, some of which are bordered by elongate closed basins. The most striking fault scarp is that which bounds the Hog Trough, a 3-mile long trench in the crest of Sinbad Ridge.

The axial part of the Sinbad Valley anticline has been eroded away in Sinbad Valley leaving exposed a large intrusive mass of the Paradox member of the Hermosa formation. This intrusive mass is a composite of several distinct plugs (Shoemaker, 1951), two of which are exposed within the quadrangle boundaries. They are partially separated by a screen of rocks from the upper member of the Hermosa formation. A third plug, largely unexposed, may underlie the extreme southeast end of the valley. Arcuate zones of intricate faulting on the south and east walls of the valley are roughly coincident with the margin of the underlying intrusive complex.

A relatively isolated salt plug lies just north of Roc Creek at Garvey Gulch. Though beds of the Paradox member of the Hermosa formation are exposed in only three places, the approximate outline of the plug is indicated by arcuate faults in the Mesozoic rocks that cap the plug. It is nearly circular in plan and a little over a mile across. East of the Roc Creek plug the Sinbad Valley anticline dies out, and the system of normal faults that follows the crest of the anticline fans out into a "fishtail" of small faults.

In Paradox Valley the intrusive complex of Paradox beds of the Hermosa formation is mostly covered with alluvium. The sinuous trend of upper Hermosa beds turned up at the edge of the intrusion suggests that the intrusion is composed of more than one discrete structural unit, as is the case in Sinbad Valley. One plug may be located southwest of the Sunrise mine, and another southwest of the Carpenter Ridge truck road. Mesozoic rocks overlying the intrusive complex at the western end of Paradox Valley are depressed in a large faulted syncline, only a small part of which is included in the Roc Creek quadrangle. In the vicinity of the Carpenter Ridge truck road the flank of the Paradox Valley anticline has subsided toward the intrusive core along a broad zone of small faults containing many slices and wedges.

STRUCTURAL HISTORY

In order to understand the structural history of the Roc Creek quadrangle, it is necessary to understand the structural history of the adjoining part of southwestern Colorado. Parts of this history are still in doubt, because no clear record remains of some events; the record of other events, although legible, is subject to different interpretations. All the events described in the following discussion affected the Roc Creek quadrangle either directly or indirectly, although the evidence for some of them is not visible within the boundaries of the quadrangle.

Weak compressive forces which probably began in early Pennsylvanian time gently warped the region. This warping gave rise to the ancestral Uncompahgre highland, an element of the ancestral Rocky Mountains, and to the basin in which the Paradox member of the Pennsylvanian Hermosa formation was deposited. These major structural features controlled the pattern and the prevailing northwest-trending grain of the smaller structures later superimposed on them. The boundary between the highland and the basin, which closely followed the southwestern margin of the present-day Uncompahgre Plateau, was a steep northwest-trending front, possibly a fault scarp, along which were deposited arkosic fanglomerates during late Pennsylvanian and Permian time. The older fanglomerates interfinger with Pennsylvanian marine sedimentary rocks of the Hermosa formation. The bulk of the fanglomerates probably is of Permian age and belongs to the Cutler formation. Intrusion of salt from the Paradox member, probably initiated by gentle regional deformation, began sometime during deposition of the Permian Cutler formation. Isostatic rise of salt ruptured the overlying Hermosa and Cutler formations, and at the end of Cutler deposition salt broke through to the surface. From then until flowage ceased, late in the Jurassic, the elongate salt intrusions such as those in Paradox Valley and Gypsum Valley stood as actual topographic highs at one place or another along their lengths. The rate of upwelling of additional salt, perhaps accelerated by the increase of the static load of sediments accumulating in the surrounding areas, balanced or slightly exceeded the rate of removal of salt by solution and erosion at the surface. Consequently, all the Mesozoic formations to the base of the Morrison formation wedge out against the flanks of the salt intrusions. Salt flowage was not everywhere continuous and at a uniform rate; rather, in many places it progressed spasmodically. Local surges of comparatively rapid intrusion gave rise to cupolas at different times and in different places along the salt masses. At the beginning of the deposition of the Morrison formation, sediments finally covered the salt intrusions, perhaps because the supply of salt underlying the areas between the intrusions was exhausted. Relative quiescence prevailed throughout the remainder of the Mesozoic and probably through the early part of the Tertiary.

The second major period of deformation probably occurred in the early Tertiary (Hunt, written communication). The region of the salt intrusions was compressed into a series of broad folds, guided and localized by the pre-existing salt intrusions. Although salt flowage was renewed, it seems unlikely that any considerable amount of new salt was forced into the intrusions; flowage probably consisted largely of redistribution of the salt already present. By the end of this period of deformation these folds had attained approximately their present structural form, except for modifications imposed by later collapse of the anticlines overlying the salt intrusions. Owing to the mobility of the rocks in the cores of the anticlines, normal faulting took place along the crests of the anticlines, probably during relaxation of compressive stresses after folding ceased. At this time the crests of the anticlines in places were dropped, as grabens, several hundred to a few thousand feet. A period of crustal quiescence followed, during which the highlands overlying the anticlines and domes were reduced by erosion and topographic relief became low throughout the area.

Then, during the middle Tertiary, the entire Colorado Plateau was uplifted. This uplift rejuvenated the streams and increased ground-water circulation. The crests of the anticlines were breached, and the underlying salt was exposed to rapid solution and removal. With the abstraction of salt, renewed collapse of the anticlines began. Although much of the collapse was due directly to removal of salt by solution, it seems unlikely that all the collapse can be attributed to this process, as was believed by earlier workers in the area. Rather, much of the collapse apparently was caused by flowage of salt from the parts of the anticline still overlain by thick layers of sediments to the parts from which the overlying sediments had been removed. Once the crests of the anticlines had been breached, the relatively plastic salt offered little support for the beds overlying the Paradox member of the Hermosa formation in the flanks of the anticlines; consequently these essentially unsupported beds slumped, probably along fractures and joints formed during earlier flexures. Small faults and folds in Quaternary deposits may indicate that collapse and local readjustments are still continuing.

MINERAL DEPOSITS

Mineral deposits mined in the Roc Creek quadrangle may be classified as uranium-vanadium deposits and copper-silver deposits though no sharp distinction can be made between those deposits which contain chiefly uranium or vanadium and those which contain chiefly copper. The deposits which have been mined for their uranium and vanadium content have been the most important, economically.

Uranium-Vanadium Deposits

Uranium and vanadium were discovered at the Rajah mine in the canyon of Roc Creek in 1899. Intensive mining of the uranium-vanadium ores did not begin in the Plateau region until 1911. Thereafter, the ores were mined primarily for their radium content until 1923, when the Belgian Congo pitchblende deposits began to supply radium. The mines were mostly idle from 1923 until 1937, but since 1937 they again have been exploited intensively, first for vanadium and in more recent years for both vanadium and uranium.

In the Roc Creek quadrangle uranium and vanadium deposits occur in the Chinle formation, the Wingate sandstone, the Kayenta formation, the Entrada sandstone, and the Salt Wash sandstone member of the Morrison formation. In rocks older than the Morrison formation most of the uranium and vanadium deposits also contain copper and are closely associated with faults. The largest and richest deposit in the quadrangle was localized in a fault that brings Salt Wash sandstone in contact with Wingate sandstone at the Rajah mine. Most of the production of uranium outside of the Rajah mine has come from deposits in the uppermost sandstone stratum of the Salt Wash sandstone.

Mineralogy

The most common ore minerals are carnotite and a fine-grained vanadium-bearing micaceous mineral. Carnotite [$K_2(UO_2)_2(VO_4)_2 \cdot 3H_2O$], is a yellow, fine-grained, earthy or powdery material. Tyuyamunite [$Ca(UO_2)_2(VO_4)_2 \cdot 3H_2O$], the calcium analogue of carnotite, is also present and is nearly indistinguishable from carnotite. The micaceous vanadium mineral, which formerly was thought to be roscoelite, is now considered to be related to the nontronite or montmorillonite group of clay minerals. It forms aggregates of minute flakes coating or partly replacing sand grains and filling pore spaces in the sandstone. It colors the rock gray. Other vanadium ore minerals present are montroseite ($nFeO \cdot nV_2O_4 \cdot nV_2O_3 \cdot nH_2O$), corvusite ($V_2O_4 \cdot 6V_2O_5 \cdot nH_2O$), and hewettite ($CaO \cdot 3V_2O_5 \cdot 9H_2O$). Corvusite and montroseite occur together, forming compact masses of bluish-black ore, whereas hewettite commonly forms stringers and veinlets along joints and fractures. Recent deep drilling and mining in the Plateau have indicated that below the zone of oxidation black oxides of uranium and vanadium, accompanied by pyrite and perhaps other sulfides, are more abundant than at the surface, and uranyl vanadates are scarce or absent.

Copper minerals in the uranium-vanadium deposits include chiefly malachite and azurite but the unusual copper-bearing vanadates, volborthite [$3CuO \cdot V_2O_5 \cdot 3H_2O$?] and calciovolborthite [$4(Cu, Ca)O \cdot V_2O_5 \cdot H_2O$], may also be present in deposits along Garvey Gulch.

Ore bodies

The uranium-vanadium deposits in the Roc Creek quadrangle exhibit two distinct habits. One group of deposits, with a broad stratigraphic range, is closely associated with the zone of complex faulting developed on the crest of the Sinbad Valley anticline. The other group of deposits, found on Carpenter Ridge and Carpenter Flats, is restricted to the upper part of the Salt Wash sandstone member of the Morrison formation and is largely unassociated with faults. Many features of the ore bodies are common to both groups of deposits.

The ore in deposits associated with faults consists chiefly of sandstone or fault gouge impregnated and replaced by uranium, vanadium, and copper minerals. The ore minerals are distributed in layers, along the bedding and in irregular masses in the sandstone, and along joint and fault surfaces or in the fault gouge. In some of the deposits most of the ore minerals are distributed without apparent regard for the fractures, but in badly broken ground the relation between fractures and the distribution of the minerals is generally capable of several interpretations. Displacement of the faults has been repeated, and as the ore minerals have apparently been partly redistributed by relatively recent ground water, the relation between the distribution of ore minerals and faults and fractures is complex.

The ore in deposits not directly associated with faults consists mostly of sandstone selectively impregnated and in part replaced by uranium and vanadium minerals; but rich concentrations of carnotite and the micaceous vanadium clay mineral are also associated with thin mudstone partings, beds of mudstone pebbles, and carbonized fossil plant material. Many fossil logs replaced by nearly pure carnotite have been found. In general the ore minerals were deposited in irregular layers that roughly followed the sandstone beds. In some deposits the highest-grade concentrations of ore minerals occur in sharply bounded, elongate concretionary structures, called "rolls" by the miners. These rolls are encompassed by rich, veinlike concentrations of the micaceous vanadium-bearing clay mineral that curve across bedding planes. Within these rolls this mineral generally is distributed as diffusion layers, the richer layers commonly lying nearer the margins of the rolls; the distribution of carnotite in the rolls is less systematic.

The ore bodies range from small irregular masses containing only a few tons of ore to large tabular masses containing many thousands of tons of ore. Margins of ore bodies may be vaguely or sharply defined. Vaguely defined margins may have mineralized sandstone extending well beyond the limits of commercial ore; on the other hand, sharply defined margins, such as occur along the surfaces of rolls, ordinarily mark the limits of both the mineralized sandstone and the commercial ore.

Origin of ore

The origin of the uranium-vanadium ores in the Morrison formation is uncertain and controversal. In some respects the deposits are unique, and much of the evidence concerning the genesis of the ore is either not conclusive or appears to be contradictory. In this brief account only a small amount of evidence can be presented and the hypotheses can only be summarized.

Most of the deposits in the Roc Creek quadrangle are closely associated either with certain sedimentary features or with faults. Most of the deposits not associated with faults occur in the thicker parts of the sandstone lenses, commonly near the base of the sandstone lenses; the trend of the long direction of the deposits and the trend of the ore rolls in the sandstone are roughly parallel to the trend of the fossil logs in the sandstone or to the average or resultant dip of the cross-bedding in the sandstone. These relations strongly suggest that primary structures in the sediments were instrumental in localizing most of the ore deposits not associated with faults.

Recent investigations have revealed new data bearing on the origin of the ores. Below the zone of oxidation some of the ore consists chiefly of oxides, such as pitchblende and low-valent oxides of vanadium, and small quantities of sulfides such as pyrite, bornite, galena, and chalcopyrite; fully oxidized and fully hydrated minerals are either rare or nonexistent. A hard variety of uraninite, previously reported only from hydrothermal deposits, has been found in the Gray Dawn mine in San Juan County, Utah (Rasor, 1952), and in the Happy Jack mine in White Canyon, Utah. Studies of lead-uranium ratios in ores from the Colorado Plateau indicate that, regardless of where or in what formation the ores are found, all are of roughly the same age, and this age is no older than latest Cretaceous (Stieff and Stern, 1952). Some geologists believe field relations in pre-Morrison formations at White Canyon (Benson and others, 1952) and Temple Mountain in Utah, indicate that here the deposits may also be genetically related to faults and fractures.

Two main hypotheses have arisen to explain the origin of the ores. The oldest and probably the most widely held is the hypothesis that the ores are penesyngenetic and were formed soon after the enclosing rocks were deposited (Coffin, 1921; Hess, 1933; Fischer, 1937, 1942, 1950; and Fischer and Hilpert, 1952). Later movements of ground water may have dissolved and reprecipitated the ore constituents, but the essential minerals were already present in the host rocks or in the waters permeating them. Although this hypothesis offers a reasonable explanation for the relation of ores to sedimentary features, it faces some difficulty in explaining: (1) the discrepancy between the age of the uranium and the age of the enclosing rock; (2) the broad stratigraphic distribution of uranium occurrences and association of ores with fractures in a few localities; and (3) the hydrothermal aspect of the mineral suites in some ores. The second hypothesis, and the one the author favors, is essentially a telethermal hypothesis and assumes the ore to have originated from a hypogene source. Proponents of this hypothesis believe that ore-bearing solutions, originated at depth from an igneous source and ascended along fractures and, after migrating laterally along permeable strata, were precipitated in favorable beds as much as several miles from fractures. This hypothesis explains more readily the difficulties, inherent in the penesyngenetic hypothesis, but poses two other difficulties; (1) the hypothetical location of igneous source rocks and (2) the difficulty of proving the connection between fractures and faults and most of the ore deposits. A third hypothesis, advanced by some geologists, suggests that the source of the ore metals was the volcanic material in the beds overlying the ore-bearing sandstone and that these metals were subsequently leached and redeposited in the beds which now contain the ore. This hypothesis encounters most of the difficulties in the penesyngenetic hypothesis and presents some additional ones of its own.

Suggestions for prospecting

Regardless of the actual origin of the deposits, certain habits of the deposits--habits that have been recognized through geologic mapping and exploration experience-- are useful as guides for finding ore (Weir, 1952). In southwestern Colorado most of the deposits are in the uppermost sandstone stratum in the Salt Wash sandstone member of the Morrison formation. Generally the central or thicker parts of the sandstone lenses are more favorable-- many deposits are in sandstone that is 40 feet or more thick, few deposits are in sandstone less than 20 feet thick. Cross-bedded, relatively coarse-grained sandstone is more favorable than thinly or evenly bedded, fine-grained sandstone. Light-yellow-brown sandstone speckled with limonite stain is more favorable than red or reddish-brown sandstone. Sandstone that contains considerable amounts of gray, altered mudstone or is underlain by a considerable thickness of this rock is more favorable than sandstone containing and underlain by red, unaltered mudstone-- this guide is perhaps the most useful in diamond-drill exploration.

In the Roc Creek quadrangle uranium-vanadium deposits have a wide stratigraphic distribution along certain zones of faulting. The richest ore has been recovered from the fault zones. Nearly all the known deposits along the zone of complex faulting in the crest of the Sinbad Valley anticline occur in Mesozoic rocks overlying the salt intrusions. Mesozoic rocks overlying the salt intrusions, such as the south side of Sinbad Valley, the Mesozoic cap of the Roc Creek plug, and possibly an area near the head of Garvey Gulch, may therefore be favorable ground for prospecting.

The mines

Rajah mine

The Rajah mine is developed in two types of ore. The richest ore, and apparently the larger part of the production, has come from a fault zone along which the Salt Wash sandstone member of the Morrison formation has been dropped against Wingate sandstone. In the fault zone, which is several feet wide, the ore occurs as lenses and pods in the fault gouge and breccia, and as stringers along the planes of slippage. Most of the ore left in the stopes is near the footwall of the fault zone. Some of the ore taken from pods in the fault was very high in grade. The initial shipment from the mine, made in 1898, consisted of 10 tons of ore that averaged over 20 percent U_3O_8 and 15 percent V_2O_5.

Ore has also been produced from two layers in the Salt Wash sandstone extending away from the fault into the hanging wall. Uranium, vanadium, and copper minerals are disseminated in relatively thin layers that follow the bedding of the sandstone. Very little mineralized material has been found in the Wingate sandstone on the footwall of the fault. The ore in the fault occurs both above and below the known levels of mineralization in the walls.

Other deposits associated with faults

Another deposit in which the principal production appears to have come from a fault is in prospects just north of the Rajah mine. Here the Summerville formation is faulted against the Kayenta formation, and beds in both walls of the fault as well as the fault gouge are mineralized. In other prospects north of the Rajah mine, small irregular ore bodies are found in fractured Wingate sandstone, and red beds of the Chinle formation are altered to green-gray and locally are impregnated with traces of copper, uranium, and vanadium minerals against some faults. On small prospects along faults east of the Rajah mine, copper-uranium-vanadium deposits occur in the Kayenta formation. In Sinbad Valley copper-vanadium deposits have been exposed in small prospects near faults in the Wingate and Entrada sandstones.

Radium Cycle mine

The Radium Cycle mine is developed in a faulted segment of the upper sandstone stratum of the Salt Wash sandstone. The ore forms a series of overlapping lenses and irregular discontinuous layers intimately associated with lenses of mudstone and mudstone pebble conglomerate. Some ore replaces fossil logs. Weakly mineralized ground is also localized along the hanging wall of a fault that displaces the deposit.

Deposits on Carpenter Ridge

The ore deposits on Carpenter Ridge occur in several separate lenses of sandstone that constitute the uppermost sandstone stratum of the Salt Wash in this area. Most of the known deposits are small and are associated with beds of mudstone and mudstone pebble conglomerate in the sandstone. Well-developed rolls are rare, and the deposits are diversely oriented. The ore is characterized by noteworthy amounts of copper.

Deposits on Carpenter Flats

Four deposits have been mined in the upper sandstone stratum of the Salt Wash sandstone on Carpenter Flats. The deposits lie approximately in a northwest trending line, but neither the ore bodies nor well-developed rolls in the ore bodies appear to show a systematic trend. The ore is associated with carbonaceous and clay pebble-bearing sandstone. One deposit, in a sandstone lens lower in the Salt Wash, is localized around three northwest trending fossil logs, which apparently yielded a small amount of rich ore.

Copper-silver deposits

Copper-silver deposits were first discovered and worked in Sinbad Valley sometime in the 1870's or 1880's, and they have been worked and prospected intermittently since that time. Production in the Roc Creek quadrangle has been limited to a few carloads of high-grade ore shipped before World War I from the Sunrise mine in Paradox Valley.

Both vein deposits and disseminated deposits of copper ore have been found in the Roc Creek quadrangle. The Sunrise mine is in a vein in the Wingate sandstone. The vein is localized along a normal fault that extends northeast from a distant bulge in the intrusive core in the Paradox Valley salt anticline. According to Fischer (1936) two types of ore have been produced from separate levels in the Sunrise mine. Primary ore in the upper level consists chiefly of massive chalcopyrite with minor amounts of bornite and luzonite (enargite). In the lower level the ore is composed of massive chalcocite, with some barite and calcite, which fills fractures in the fault breccia. Both types of ore are partly replaced by copper and iron oxides and by malachite. Though no dominantly silver-bearing minerals are present, the high-grade ore contains 6 to 10 ounces of silver per ton. Somewhat similar vein deposits have been prospected along nearby faults southeast of the Sunrise mine.

Disseminated deposits of copper have been found in the Wingate sandstone and Kayenta formation near faults in Sinbad Valley. The ore consists of malachite, azurite, and sparse chalcocite impregnating the sandstone in layers and small irregular bodies. The location of some of these deposits is indicated by prospect symbols on the map. Traces of copper minerals are widely scattered in the faulted terrain on the south side of Sinbad Valley and have been found in the Chinle formation and the Salt Wash sandstone member of the Morrison formation as well as in the sandstones of the Glen Canyon group. Small deposits of disseminated copper carbonates, unaccompanied by visible uranium or vanadium minerals, are also found in several formations near Garvey Gulch and in Salt Wash sandstone beds on Carpenter Flats.

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