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GEOLOGY OF THE RED CANYON QUADRANGLE, MONTROSE COUNTY, COLORADO

By E. J. McKay
with a section on "The Mines" by D. A. Jobin

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Trace Elements Memorandum Report 705

UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

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Dr. Phillip L. Merritt, Assistant Director
Division of Raw Materials
U. S. Atomic Energy Commission
P. O. Box 30, Ansonia Station
New York 23, New York

Dear Phil:

Transmitted herewith is one copy of TEM-705, "Geology of the Red Canyon quadrangle, Montrose County, Colorado," by E. J. McKay with a section on "The Mines" by D. A. Jobin, August 1953.

Mr. Hosted approved on August 27, 1953, our plan to publish this report in the Survey's Quadrangle Map Series.

Sincerely yours,

for W. H. Bradley
Chief Geologist

UNCLASSIFIED

Geology and Mineralogy

This document consists of 31 pages,
plus 1 figure.
Series A

UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

GEOLOGY OF THE RED CANYON QUADRANGLE, MONTROSE COUNTY, COLORADO*

By

E. J. McKay,

with a section on "The Mines" by

D. A. Jobin

August 1953

Trace Elements Memorandum Report 705

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.

USGS - TEM-705

GEOLOGY AND MINERALOGY

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ILLUSTRATION

Preliminary geologic map and section of the Red Canyon quadrangle, Colorado . . . . In envelope

GEOLOGY OF THE RED CANYON QUADRANGLE, MONTROSE COUNTY, COLORADO

by E. J. McKay, with a section on "The Mines" by D. A. Jobin

ABSTRACT

The Red Canyon quadrangle is one of eighteen $7\frac{1}{2}$-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 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 intrusives 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 Red Canyon quadrangle, Colo., in connection with 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 7½-minute quadrangles, of which the Red Canyon quadrangle is one. Parts of the texts accompanying these maps have been standardized; these parts comprise some descriptions of geologic formations and general statements concerning 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 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 these geologic studies on behalf of the Division of Raw Materials, Atomic Energy Commission. The Red Canyon quadrangle was mapped in 1949.

The Red Canyon quadrangle covers about 59 square miles in Mesa and Montrose Counties, Colo., and lies in the Canyon Lands division of the Colorado Plateau physiographic province. The quadrangle is an area of gently sloping mesas cut by deep, steep-walled canyons. In general the southwestern part of the quadrangle slopes to the northeast, and the northeastern part to the southwest. Total relief within the quadrangle is about 2,300 feet; altitudes range from about 4,700 feet where the Dolores River leaves the quadrangle to 7,000 feet in the extreme southwestern corner of the quadrangle. The Dolores River and its tributaries drain the entire quadrangle.

No accurate rainfall information is available, but the annual precipitation is probably between 10 and 15 inches; the area is semi-arid and supporting a moderate growth of juniper and piñon on rocky terrain, and abundant sagebrush where soils are thick. Cacti of several varieties and sparse grass are widely distributed. Alfalfa and some corn are grown in river and creek bottoms. Most of the quadrangle is accessible by State Highway 141 and a system of dry weather roads.

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 strata wedge out northeastward against the crystalline pre-Cambrian rocks, but later Mesozoic units were deposited on top of the pre-Cambrian rocks. Over most of the region the sedimentary rocks 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 Red Canyon quadrangle lies in the north-central part of the area in the syncline between the Paradox Valley anticline and the Uncompahgre Plateau uplift. The southeast end of the Sinbad Valley anticline and the Roc Creek salt plug, a southeastern unit of the Sinbad Valley structure, are a short distance west of the quadrangle.

STRATIGRAPHY

The oldest rocks exposed in the Red canyon quadrangle are of Late Triassic age and are exposed in the bottom of the canyon at the junction of the San Miguel and Dolores rivers. Jurassic rocks crop out in the canyon walls and on benches and slopes below the mesas, whereas Cretaceous rocks cap the mesas. Recent deposits of stream gravel, sheet wash, and wind-blown material are widely distributed on canyon floors, along the benches, and on mesa tops.

The stratigraphic sequence is similar to that studied by Baker (1933) and Dane (1935) in nearby areas in Utah; most of the formations can be traced continuously from the Red Canyon quadrangle into Utah.

Chinle formation

The Chinle formation of Upper Triassic age consists of red to orange-red siltstone with interbedded red fine-grained sandstone, shale, and limestone-pebble and mud-pellet conglomerate. These lithologic units are lenticular and discontinuous. The lower part of the formation contains numerous lenses of a highly distinctive limestone-pebble and mud-pellet conglomerate; in places the lowermost lenses contain quartz pebbles or consist of a relatively clean quartz grit. These quartz-bearing lenses are probably the stratigraphic equivalent of the Shinarump conglomerate, which is widely distributed in eastern Utah.

and northern Arizona. Much of the Chinle formation consists of indistinctly bedded red siltstone that breaks into angular fragments. Evenly bedded shale is rare. The sandstone layers vary in bedding characteristics; some layers are massive, others are cross-bedded, and still others are conspicuously ripple-bedded. Almost everywhere the formation crops out as a steep slope broken in places by ledges of more resistant sandstone and conglomerate.

The base of the Chinle formation is not exposed in the Red Canyon quadrangle. The formation as projected from adjoining quadrangles, probably ranges from 300 feet to 450 feet in thickness.

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 wall, stained and streaked in places with a surficial red and black desert varnish. Vertical joints cut out 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 crossbedded 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 rather poorly cemented and crumbles easily; this quality probably accounts for the readiness with which the rock disintegrates in faulted areas.

In the Red Canyon quadrangle the Wingate sandstone ranges in thickness from 300 to 340 feet.

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 limestone, shale, and sandstone. The sandstone is composed of rounded to sub-rounded quartz grains and minor quantites 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 recessions 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 Red Canyon quadrangle is about 180 feet thick but locally it may be 10 to 20 feet thicker or thinner. The irregular bedding, channel filling, and range in thickness of sandstone beds all indicate a fluviatile origin for the Kayenta formation.

Navajo sandstone.--The eastern edge of the Navajo sandstone follows an irregular course through the westernmost part of Colorado, and the only Navajo in the quadrangle is an irregular lobe and a few disconnected lenses that crop out in the northwestern part. The Navajo, which conformably overlies the Kayenta formation, is a massive, fine-grained, gray to buff, clean quartz sandstone. Tangential cross-beds of tremendous size leave little doubt of the eolian origin of the sandstone, although at Roc Creek the cross-beds are not so large and horizontal bedding planes are more common than in other areas. A few thin gray discontinuous limestone beds containing nodules of chert occur at places in the sandstone. The sandstone is friable and weathers to rounded topographic forms where exposed on slopes or benches and to vertical cliffs where protected by overlying rocks. It reaches a maximum thickness in the quadrangle of 80 feet.

San Rafael group

In this area the San Rafael group, of Middle and Late 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 in a narrow band along the canyon walls of the Dolores River and its tributaries. 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, soft, horizontally bedded siltstone, mudstone, and sandstones. 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.

The Carmel formation ranges from less than 10 feet to 90 feet in thickness. This large range appears to be due chiefly to deposition on irregular, eroded surfaces of Navajo sandstone or beds of Kayenta formation. 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 a prominent break, into the Entrada sandstone. The Entrada sandstone, known locally as the "slick rim" because of its appearance, is perhaps the most strikingly 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 parallel-bedded units and sweeping, eolian-type cross-bedded units. The parallel-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 planes of bedding and lamination. The Entrada sandstone in the Red Canyon quadrangle is 80 to 150 feet thick.

Summerville formation.--The Summerville formation generally crops out as a steep, debris-covered slope, with very few good exposures. Where exposed, the Summerville exhibits a remarkably 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 shale 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 autochthonous 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. In the vicinity of Mesa Creek the sandstone beds in the lower part of the formation thicken and form a prominent ledge 20 to 30 feet thick. Commonly the sandstone beds are ripple-marked, and in places they show small-scale low-angle cross-bedding.

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. Regionally the upper part of the Entrada and the lower part of the Summerville intertongue, and the contact does not occur everywhere at the same stratigraphic horizon. 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 overlying shale and mudstone of the Morrison formation are similar to beds of the Summerville.

In the Red Canyon quadrangle the Summerville formation is about 100 feet thick.

Morrison formation

The Morrison formation, of Late Jurassic age, is of special interest economically because of 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 member. In the Red Canyon quadrangle the Morrison formation ranges in thickness from 700 to 800 feet, with the Brushy Basin shale member forming slightly more than half the total thickness. In some areas the thicknesses of the members 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. Features indicative of fluviatile origin such as ripple marks, current lineations, rill marks, and cut-and-fill structures are abundant.

The sandstone consists largely of subangular to subrounded quartz grains, but othoclase, microcline, and albite grains occur in combined amounts of 10 to 15 percent. Chert and heavy-mineral grains are accessory. Considerble 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 are found locally.

The Salt Wash sandstone member has an average thickness of about 300 feet, although locally the thickness varies 30 feet or more.

Brushy Basin shale member.--The Brushy Basin shale member contrasts strongly in overall 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 bentonite 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 bentonite 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 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 several inches thick, caused by the swelling of the bentonite 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 flood plains on which were deposited the fine-grained sediments now represented by the mudstone and shale.

The Brushy Basin shale member ranges from 400 to 500 feet in thickness; erratically distributed local variations in thickness of 20 to 30 feet are prevalent throughout the quadrangle.

Burro Canyon formation

The name Burro Canyon formation was proposed by Stokes and Phoenix (1948) for the heterogeneous sequence of Lower Cretaceous conglomerate, sandstone, shale, and thin lenses of limestone that overlies the Morrison formation. The Burro Canyon characteristically crops out as a cliff or a series of thick, resistant ledges. The bulk of the formation consists of white, gray, and red sandstone and conglomerate that form beds up to 100 feet thick. These beds are massive, irregular, and lenticular. Cross-bedding and festoon-bedding are prevalent throughout the formation. The sandstone is poorly sorted and consists of quartz and lesser amounts of chert. The conglomerate consists largely of chert pebbles, but intermixed are pebbles of quartz, silicified limestone, quartzite, sandstone, and shale. In places beds are highly silicified. A considerable part of the formation consists of bright green mudstone and shale, and locally these predominate over the sandstone and conglomerate. Thin, discontinuous beds of dense, gray limestone crop out in a few scattered localities. The formation was undoubtedly deposited under fluviatile conditions. The lower contact is indistinct in many places and appears to interfinger with the upper part of the Brushy Basin shale member; elsewhere local erosion surfaces intervene and the contact is sharp. The upper contact is an erosion surface of regional extent.

In the Red Canyon quadrangle the Burro Canyon formation ranges from 100 to 140 feet in thickness.

Dakota sandstone

The Dakota sandstone, of Early and Late Cretaceous age, crops out extensively as capping beds on the mesas because of its resistance to erosion. The Dakota consists principally of gray, yellow, and buff flaggy sandstone;

less abundant are conglomerate, carbonaceous shale, and impure coal. Some of the sandstone is fine-grained and thin-bedded, but much of it is coarse-grained and cross-bedded. Scattered through the sandstone are irregular, discontinuous beds and lenses of conglomerate containing chert and quartz pebbles as much as 2 inches across. Interfingering with the sandstone beds are thin-bedded gray and black carbonaceous shales and thin coal seams and beds. Plant impressions abound in both the sandstone and the shale. The entire thickness of the Dakota sandstone is not exposed in the quadrangle; the upper beds have been stripped off by erosion, but as much as 100 feet of Dakota beds are preserved in a few places.

Quaternary alluvium

The deposits of Quaternary age consist of wind-deposited material, alluvium, and talus debris. Extensive deposits of light red sandy and silty material mantle the benches and mesa tops. This material appears to be mostly wind-deposited, although much of it has been reworked by water and intermixed with sheet wash. These deposits have not been mapped where they are unusually spotty, discontinuous, or less than a foot thick; the greatest observed thickness in some dry washes on mesa tops is about 10 feet. Terrace gravels containing pebbles and cobbles of various intrusive and extrusive igneous rocks occur at several levels above the Dolores and San Miguel Rivers. The river valleys are covered with mixtures of stream-deposited sediments, fan deposits, and wind-blown material. Considerable talus debris covers many of the steeper slopes. Because these various deposits, other than the terrace gravels, are difficult to differentiate in some places, they have not been separated on the geologic map.

STRUCTURE

Regional setting

Many geologic strucutres on the Colorado Plateau are so large that a 7½-minute quadrangle covers only a small part of any complete structural unit. The larger structural units consist 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 stock-like and laccolithic intrusions.

The salt anticlines trend northwest 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 Hermosa formation and intruded into overlying rocks of late Paleozoic and early Mesozoic age. All the anticlines are structurally similar in many respects, but each exhibits structural peculiarities 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 Red Canyon quadrangle

The Red Canyon quadrangle straddles the San Miguel syncline and its counterpart to the northwest, the Dolores River syncline. These synclines form a downwarp between the Paradox Valley and Sinbad Valley anticlines on the southwest and the Uncompahgre Plateau uplift on the northeast. Most of the rocks have angles of dip less than 5°; only on the flank of Paradox Valley anticline are the dips steeper. Within a mile of the synclinal axes dips do not exceed 2°. The southward-plunging axis of the Dolores River syncline and the northwestward-plunging axis of the San Miguel syncline merge in the vicinity of the southern part of Long Mesa. The difference in direction of plunge of the two synclinal axes and the faults in the vicinity of Roc Creek and on Carpenter Flats probably reflects a gravity adjustment to the abstraction of salt from the underlying Paradox member of the Hermosa formation. Salt was extruded in the Roc Creek salt plug a mile or two west of the quadrangle.

Structural history

In order to understand the structural history of the Red Canyon 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 Red Canyon quadrangle either directly or indirectly, although the evidence for some of them is not visible within the quadrangle boundaries.

Mild 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 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 is closely followed by the southwest 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 of the formations of Mesozoic age to the base of the Morrison formation wedge out against the flanks of the salt intrusions. Salt flowage was not everywhere continuous or at a uniform rate; rather, in many places it progressed spasmodically. Local surges of comparatively rapid intrusion gave rise to cupolas at different times in different places along the salt masses. At the beginning of Morrison deposition 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 occurred in the Tertiary--probably before middle Tertiary, but the date cannot be determined accurately. 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 the 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 quiesence followed, during which the highland overlying the anticlines and domes were reduced by erosions, 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 anticlines 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 readjustment are still continuing.

MINERAL DEPOSITS

The only commercially important mineral deposits in the Red Canyon quadrangle are those that contain uranium, vanadium, and radium. Although deposits containing these metals were discovered in 1899 near Roc Creek, at a point 2 miles west of the Red Canyon quadrangle, intensive mining of these 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.

The larger deposits are restricted to the upper layer of sandstone lenses in the Salt Wash sandstone member, but a number of small deposits are in the lower layer. Within both layers the deposits have a spotty distribution. Most ore bodies are relatively small and contain only a few hundred tons. The ore consists mainly of sandstone impregnated with uranium- and vanadium-bearing minerals.

Mineralogy

The most common ore minerals are carnotite and a fine-grained vanadium-bearing micaceous mineral. Carnotite ($K_2 (UO_2)_2 (VO_4)_2.3H_2O$) is a yellow, fine-grained, earthy or powdery material. Tyuyamunite ($Ca(UO_2)_2(VO_4)_2.nH_2O$) 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 montroesite ($nFeO.nV_2O_4.nV_2O_3.nH_2O$), corvusite ($V_2O_4.6V_2O_5.nH_2O$), and hewettite ($CaO.3V_2O_5.9H_2O$). Corvusite and montroseite occur together, forming compact masses of bluish-black ore, whereas hewettite commonly forms stringers and veinlets along joints and fractures. Recent deeper 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 sulfid es, are more abundant, and uranyl vanadates are scare or absent.

Ore bodies

The ore 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 most 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.

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.

Although many rolls are small and irregular, the larger ones are elongate and may extend with little change of direction for more than 100 feet. The elongate rolls in an ore body or group of ore bodies in a given area generally have a common orientation. This orientation is roughly parallel to the elongation to the ore bodies.

Origin of ore

The origin of the uranium-vanadium ores in the Morrison formation is uncertain and controversial. 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 are closely associated with certain sedimentary features. Layers of ore lie essentially parallel to the bedding; most of the deposits occur in the thicker parts and 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 and 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.

Recent investigations have revealed new data bearing on the origin of the ores (Waters and Granger, 1953). 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 Daun 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 found, all the ores 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, et al., 1952) and Temple Mountains in Utah, indicate that the deposits may be genetically related to faults and fractures. At the Rajah mine near Roc Creek, Colorado, ore occurs along a fault and horsetails out into the wall rock.

Two main hypotheses have risen 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 constitutents, but the essential materials 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 authors favor, 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, originating at depth from an igneous source, ascended along fractures. After these solutions mingled with circulating ground water the minerals were precipitated in favorable beds as much as several miles from the fractures. This hpyothesis explains more readily the difficulties, inherent in the penesyngenetic hypothesis, but poses two other difficulties, namely, the hypothetical location of igneous source rocks and the difficulty of proving the connection between fractures and faults and the ore deposits. A third hypothesis, advanced by some geologists, suggests that the source of the ore metals was the volcanic materials in the beds overlying the ore-bearing sandstones and that these metals were subsequently leached and redeposited in the beds that now contain the ore. This hypothesis encountered not only most of the difficulties in the penesyngenetic hypothesis, but it 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, a 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 or is underlain by a considerable amount of gray, altered mudstone 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 Red Canyon quadrangle probably the most likely area for finding ore, because of the presence of favorable host rocks, is the southeastern part lying east of the Dolores River and including the southern part of Atkinson Mesa.

Many deposits occur in localities remote from areas of intensive structural deformation, and additional deposits will undoubtedly be found in such undeformed localities. However, if the deposits had a hypogene origin, as the authors believe, then the more intensively deformed rocks, such as the rocks both overlying and surrounding the salt intrusions, probably are favorable places to look for new deposits, provided that the favored formations and rock types known to be hosts for ore are present. In the Red Canyon quadrangle, however, the rocks in the vicinity of the faults are, for the most part, unfavorable hosts for ore.

The mines

by D. A. Jobin

Numerous deposits are scattered along the outcrop of the Salt Wash sandstone member of the Morrison formation in the southern half of the quadrangle. Except for the Dolores mines, most of these deposits are small, containing several tons to a few hundred tons of ore.

Recently, extensions of old deposits and new discoveries in this area have been found by extensive drilling programs, especially on Atkinson Mesa. Most of the exploration near old workings and in the shallower drilling areas has been conducted by private operators, but where deeper drilling and higher costs have been too great for individual operators, the exploration has been undertaken by the Geological Survey on behalf of the Atomic Energy Commission.

Dolores mines.--The Dolores mines are the most productive in the Red Canyon quadrangle. Most of the ore has come from the Ophir, Bluebird, and Little Dick workings, which are in a large, poorly defined block of mineralized ground approximately 1,000 feet wide and 3,000 feet long. In this area the ore-bearing sandstone averages 60 to 65 feet in thickness. The upper and lower 15 to 20 feet of this sandstone unit are the chief ore-producing zones, with the major production coming from the upper zone. The ore minerals are carnotite and vanadiferous clay minerals, which occur as low-grade disseminations in the sandstone, with high-grade concentrations confined to rolls and logs or "trash pockets". Montroseite, and hewettite are also present but in small amounts, forming scattered high-grade streaks or patches in the disseminated ore.

Shamrock mines.--The ore deposits at the Shamrock mines are small and commonly have a maximum length of 50 to 200 feet. The ore minerals are carnotite and the micaceous vanadium clay minerals. Rolls in the deposits rarely exceed 30 feet in length and are 3 to 4 feet thick; between rolls the ore is commonly less than 1 foot thick. The trend of individual rolls ranges from east to southeast. All but one of the known deposits are in the lower part of the topmost sandstone stratum of the Salt Wash; the known exception is in the top part of the sandstone immediately below the topmost sandstone. In addition to the deposits exposed by mining operations, a scattering of deposits has been discovered by diamond drilling in the area south of the mine workings.

Raven claim.--Deposits on the Raven claim (no. 69) are fairly extensive but a large part of the ore is probably low-grade and thin. Ore minerals are carnotite and the micaceous vanadium clay. Ore bodies consist of fairly continuous layers of low-grade disseminated ore. The margins of the ore bodies are indefinite, and rolls are rare. The deposits are in the topmost stratum of the Salt Wash sandstone member.

Deposits on Martin Mesa and Carpenter Flats.--Many small mines and prospects are scattered along the outcrops of the Salt Wash sandstone on Martin Mesa and Carpenter Flats. The deposits in the upper sandstone stratum of the Salt Wash are the largest, although they are few in number because most of this stratum has been eroded from the area. This upper sandstone stratum ranges from 10 to 45 feet in thickness. The ore minerals are carnotite and the micaceous vanadium clay minerals. These occur as low-grade disseminations in the sandstone and as high-grade concentrations confined largely to rolls. The rolls trend southeast; the average trend of logs found in the sandstone is northeast. There is a fair chance that additional ore could be found by exploring the ground in the vicinity of the mines.

In Red Canyon, many small mines and prospects are scattered along the outcrop of the lowest sandstone stratum of the Salt Wash. These deposits are small and consist of thin streaks of relatively high-grade ore. These deposits characteristically contain copper carbonate stain, whereas deposits in the upper sandstone stratum rarely contain any visible copper minerals.

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