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RESOURCE COMPILATION SECTION

GEOLOGY OF THE HORSE RANGE MESA QUADRANGLE, COLORADO

By Fred Cater, Jr.,
with a section on "The Mines" by A. L. Bush, Henry Bell III,
and C. F. Withington

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Trace Elements Memorandum Report 699

UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

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JAN 29 1954

AEC - 352/4

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-699, "Geology of the Horse Range Mesa quadrangle, Colorado," by Fred W. Cater, Jr., with a section on "The Mines" by A. L. Bush, Henry Bell III, and C. F. Withington, August 1953.

Mr. Hosted approved on September 15, 1953 our plan to publish this report in the Survey's Quadrangle Map Series.

Sincerely yours,

Andrew Brown

for W. H. Bradley
Chief Geologist

Geology and Mineralogy

This document consists of 28 pages, plus 1 figure.
Series A.

UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

GEOLOGY OF THE HORSE RANGE MESA QUADRANGLE COLORADO*

By

Fred W. Cater, Jr.

with a section on "The Mines" by

A. L. Bush, Henry Bell III, and C. F. Withington

August 1953

Trace Elements Memorandum Report 699

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 partly on behalf of the Division of Raw Materials of the U. S. Atomic Energy Commission.

USGS - TEM- 699

GEOLOGY AND MINERALOGY

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GEOLOGY OF THE HORSE RANGE MESA QUADRANGLE, COLORADO

by Fred W. Cater, Jr., with a section on

"The Mines" by A. L. Bush, Henry Bell III, and C. F. Withington

ABSTRACT

The Horse Range Mesa 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 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 Horse Range Mesa 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 Horse Range Mesa quadrangle is one. Part 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 Atomic Energy Commission. The Horse Range Mesa quadrangle was mapped in 1945, and some revisions were made in 1949.

The Horse Range Mesa quadrangle covers about 59 square miles in San Miguel 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 2,205 feet; altitudes range from about 5,360 feet in the canyon of the Dolores River to 7,565 feet on Summit Point. The Dolores River and its tributaries drain the area.

No accurate information on rainfall is available, but the annual precipitation is probably between 10 to 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. Cactus and sparse grass are widely distributed. The south half of the quadrangle is accessible over a system of dry-weather roads and Colorado Highway 80, but the north half is accessible only by horseback or by 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 beds were deposited on top of the pre-Cambrian rocks. Over most of 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 Uncompahagre 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 Horse Range Mesa quadrangle lies in the southern part of the eighteen quadrangle area between the Gypsum Valley anticline on the northeast and the Dolores anticline on the southwest.

STRATIGRAPHY

The oldest rocks exposed in the Horse Range Mesa quadrangle are the Upper Triassic rocks that crop out in Summit Canyon. Jurassic rocks crop out in the canyon walls and on the benches and slopes below the mesas; the exposed area of Jurassic rocks is more than three-quarters of the total area of the quadrangle. Cretaceous rocks cap the mesas. Recent deposits of wind-blown material and sheet wash are widely distributed on top of the mesas and along the benches, and considerable alluvium has been deposited along the Dolores River.

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 Horse Range Mesa quadrangle into Utah.

Chinle formation

The Upper Triassic Chinle formation consists of red to orange-red siltstone, with interbedded red fine-grained sandstone, shale, and limestone-pebble and clay 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 clay 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 differ in bedding characteristics; some layers are massive, whereas 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 more resistant ledges of sandstone and conglomerate.

The base of the Chinle formation is not exposed in the Horse Range Mesa quadrangle. The formation, as projected from adjoining quadrangles, probably ranges from 475 feet to 525 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 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 from 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, appear to dip 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 Horse Range Mesa quadrangle the Wingate sandstone is about 275 feet thick.

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 Horse Range Mesa quadrangle ranges in thickness from 180 to 210 feet. 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.

The thickness of the Navajo sandstone in the Horse Range Mesa quadrangle ranges within wide limits; in McIntyre Canyon an incomplete section nearly 300 feet thick is exposed, whereas in Summit Canyon a complete section is only about 50 feet thick.

San Rafael group

In this area the San Rafael group of Middle and Late Jurassic age comprises, in ascending order, the Carmel formation, the Entrada sandstone, and the Summerville formation. The Carmel formation and Entrada sandstone were mapped as a single unit 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 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. In many places the upper part of the formation contains scattered barite nodules as much as an inch across.

The Carmel formation ranges from 20 feet to 50 feet in thickness in the Horse Range Mesa quadrangle. This range appears to be due chiefly to deposition on an irregular, eroded surface of Navajo sandstone. 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 in diameter 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 Entrada sandstone is 75 to 150 feet thick in the Horse Range Mesa quadrangle.

Summerville formation

The Summerville formation generally crops out as a steep, debris-covered slope, with few good exposures. Where exposed the Summerville exhibits a remarkably uniform 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.

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 the overlying shales and mudstones of the Morrison formation are similar to beds of the Summerville.

The Summerville formation in the Horse Range Mesa quadrangle ranges in thickness from 70 feet to 195 feet.

Morrison formation

The Upper Jurassic Morrison formation 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. In the Horse Range Mesa quadrangle the Morrison formation ranges in thickness from 625 to 775 feet. 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. 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 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 28 to 370 feet in thickness. Local changes in thickness of as much as 30 feet are common.

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 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 shale and mudstone 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 bentonitic material during periods of wet weather. Scattered through the shale and mudstone are thin beds of fine-grained 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 more abundant in the Brushy Basin shale member than in the Salt Wash sandstone member, especially in some 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 represented by the mudstone and shale.

The Brushy Basin shale member ranges from 330 to 425 feet in thickness in the Horse Range Mesa quadrangle; local variations in thickness of 20 to 30 feet are common 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.

The Burro Canyon formation in the Horse Range Mesa quadrangle ranges from 90 to 230 feet in thickness; in general the formation thins toward the southwest corner of the quadrangle. Abrupt local variations in thickness of 10 to 30 feet are common.

Dakota sandstone

The Dakota sandstone of Early and Late Cretaceous age crops out in this quadrangle as the capping beds on the mesa back of Summit Point and on Horse Range Mesa. 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 in diameter. 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 the beds that remain attain a thickness of about 50 feet.

Quaternary deposits

The deposits of Quaternary age consist of terrace gravel, wind-deposited material, alluvium, talus, and landslides. 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. Gravel and alluvium occur along the Dolores River. Considerable talus covers many of the steeper slopes. Because these various deposits, except for the terrace gravel, are difficult to differentiate in places, they have not been separated on the geologic map. Large landslides consisting mostly of Brushy Basin debris cover considerable areas in the north half of the quadrangle.

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 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 stocklike 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 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 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 Horse Range Mesa quadrangle

Parts of three large structural features cross the Horse Range Mesa quadrangle; these are the southwest flank of the Gypsum Valley salt anticline, the Disappointment syncline, and the Dolores anticline. The crest of the Gypsum Valley salt anticlines has collapsed, owing to the removal of much salt by solution and flowage. The southwest edge of this collapsed area is marked by the faults and the relatively sharp narrow anticline and syncline at the northeast end of Steamboat Hill. From the edge of this collapsed area the beds dip southwestward to the trough of the Disappointment syncline, a broad, shallow downwarp that plunges southeast and flattens out to the northwest. The Dolores anticline is an asymetrical northwesterly plunging fold. The northeast limb of this anticline dips much more steeply than does the southwest limb. The anticline probably has an intrusive core of salt as does the Gypsum Valley anticline, but unlike the Gypsum Valley anticline this core is nowhere exposed. Two systems of faults cut the northeast flank of the anticline, an easterly trending system in the vicinity of Horse Range Mesa and northwesterly trending system in the area between Summit Canyon and Bush Canyon. A set of transverse northeasterly trending faults cut the rocks in the vicinity of Cape Horn.

Structural history

In order to understand the structural history of the Horse Mesa 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 Horse Range Mesa 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 times, 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 of Pennsylvanian age 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 after the Cutler was deposited 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, balances 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 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 during the Eocene (Hunt, written communication), 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 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 groundwater 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 readjustments are still continuing.

MINERAL DEPOSITS

The only commercially important mineral deposits in the Horse Range Mesa quadrangle are those that contain uranium, vanadium, and radium. Although deposits containing these metals were discovered in 1899 near Roc Creek, about 22 miles north of the Horse Range Mesa 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.

Most of the deposits are restricted to the upper layer of sandstone lenses in the Salt Wash sandstone member, but within this layer the deposits have a spotty distribution. Ore bodies range from small irregular masses containing only a few tons of ore to large tabular masses containing several thousand of tons; but most ore bodies are relatively small and contain only a few hundred tons. The ore consists mainly of sandstone impregnated within uranium- and vanadium-bearing minerals.

Mineralogy

The most common ore minerals are carnotite and a fine-grained, vanadium-bearing micaceous mineral. Carnotite ($K_2(UO_2)_2(VO_4)_2 \cdot 3H_2O$) is a yellow, fine-grained, earthy or powdery material. Tyuyamunite ($Ca(UO_2)_2(VO_4)_2 \cdot nH_2O$) 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 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 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 sulfides, are more abundant, and uranyl vanadates are scarce 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 of 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 these 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 dip direction of the cross-bedding in the sandstone. These relations strongly suggest that primarily 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 geologist believe field relations in pre-Morrison formations at White Canyon (Benson, and others, 1952) and Temple Mountain in Utah, indicate that the deposits may be genetically related to faults and fractures. At the Rajah mine near Roc Creek, in Colorado, ore occurs along a fault and horsetails out into the wall rock.

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 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 originated at depth from an igneous source and ascended along fractures. After these solutions mingled with circulating ground waters, the minerals 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, 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 material 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 encounters not only most of the difficulties in the penesyngenetic hypothesis, but 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 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. If the deposits have a hypogene origin, then the localities where favorable host rocks are near or co-extensive with areas of more intense deformation may be especially favorable for finding ore.

The southern part of the Horse Range Mesa quadrangle is probably the most likely area for finding ore because of the presence of favorable rocks. Although many of the mines are 2 or 3 miles from known faults, the presence of considerable faulting and fracturing in the general area may have some bearing on the unusual concentration of deposits in this part of the quadrangle.

The mines

by A. L. Bush, Henry Bell III, and C. F. Withington

Most of the deposits in the Horse Range Mesa quadrangle are in lenticular sandstone beds in the upper part of the Salt Wash sandstone member. Generally the deposits are in sandstone beds 30 to 60 feet thick. However, the deposits in a belt along the Dolores River in the southeastern part of the quadrangle are in sandstone beds 60 to 90 feet thick.

Radium group

The major deposits of the Radium group, the Radium Nos. 2, 5, 6, 7, and 8 mines, have been collectively the most productive mines in the quadrangle. The Radium No. 7 mine has yielded ore measurable in tens of thousands of tons, almost twice as much as from the next largest mine.

The ore minerals, carnotite and a micaceous vanadium clay mineral, mainly impregnate the sandstone. In places fossil plant remains and mudstone pebbles in the ore are richly mineralized. Small amounts of copper are present in and near the ore, mostly as stains of the carbonates, azurite and malachite; subordinately as copper-uranium and copper vanadium minerals disseminated in the sandstone. Copper sulfide (chalcocite) nodules, about one-half inch across are also present, but are rare.

The ore deposits are irregularly tabular layers that in general parallel the bedding of the sandstone, but in detail cut across it. Most of the deposits are rudely oval in plan, ranging in size from a few tens of feet to several hundreds of feet across. The largest deposit (at the Radium No. 7 mine) is about 800 feet long by 400 feet wide. Ore bodies within the deposits consist both of rolls, with well-defined limits, and more gradual thickenings of the tabular layers, with less well-defined or poorly defined limits. The ore bodies are commonly pod-like or crescent-shaped masses that are several feet across and range from 10 to 100 feet or more in length. A little less than half the total production probably has come from rolls.

In addition to these deposits in the Salt Wash, two small deposits in a conglomeratic lens near the base of the Brushy Basin shale member have been mined. The ore in these deposits is patchy, and lower grade than in the deposits in the Salt Wash.

Lower group

The Lower group of mines are the second most productive in the Horse Range Mesa quadrangle. The largest deposit in this group has been mined for a distance of 1, 200 feet and is essentially continuous along the outcrop for a distance of 2, 000 feet. The deposit ranges in thickness from a few inches to several feet. Associated with the micaceous vanadium clay mineral and carnotite are copper carbonate stains, some disseminated copper-vanadium and copper-uranium minerals and, less commonly, nodules of copper sulfide (chalcocite). The copper-silver selenide (eucairite) has been found in small veinlets and in nodules associated with chalcocite.

The deposits in the Lower group are typical of those deposits in which rolls are well-developed. The deposit consists of an essentially continuous layer of rather low-grade disseminated ore in which are well-developed rolls with sharply defined margins. These rolls may be as much as 200 feet long and from 5 to 40 feet wide and are oriented in a predominant southeast direction. Most of the production has come from these rolls although rich concentrations of carnotite have been found in fossil logs. These fossil logs have an orientation similar to the orientation of the rolls, the average dip direction of cross-bedding and to the long dimensions of the ore deposits.

Charles T. mines

Production from the Charles T. mines ranks third in importance within the quadrangle. Carnotite and the micaceous vanadium clay mineral are the common ore minerals. In their most common association, the ore minerals impregnate the sandstone. Many mudstone seams, pebbles, and galls, in or adjacent to the ore deposits, have a high vanadium content. Fossil logs and other carbonaceous material are richly mineralized. The ore deposits are irregularly tabular layers, rudely oval in plan.

Overlapping tabular layers, generally parallel to the bedding of the sandstone, are separated by a few inches to several feet of barren sandstone. Most of the ore bodies are rolls; the largest roll is 200 feet or more long, 10 to 25 feet wide and up to 17 feet thick. The rolls commonly are sinuous in plan, generally with a northerly or northeasterly trend. As much as 70 percent of the total ore production probably has come from rolls. The remainder has come from less well defined masses of ore.

Georgeto and Veta Mad

These mines are in the belt along the Dolores River where the upper sandstone beds of the Salt Wash member are 60 to 90 feet thick. The mines are in ore deposits near the middle of these thick beds. The ore minerals, carnotite and the micaceous vanadium clay mineral, are in the common associations, impregnating sandstone and replacing fossil carbonaceous material. Small amounts of gypsum are present with the replaced fossil logs. In addition, small amounts of copper are present as copper sulfide (chalcocite) nodules surrounded by a halo of copper carbonates (azurite and malachite). A few of these nodules also contain small amounts of a copper-silver selenide (eucairite).

The ore deposits are rudely oval, irregularly tabular layers. Most ore bodies consist of thickenings of the ore layer, with well-defined undulant upper and lower limits. Some rolls and a few richly mineralized fossil logs are present. Two ore layers have been productive at each mine; where these ore layers overlap they are separated by 5 to 20 feet of barren sandstone.

Upper group mines

The mines in the Upper group lie in the top sandstone bed of the Salt Wash member. The ore consists mostly of small rolls connected by thin tabular bodies of mineralized material. They range from a few tons to a few hundred tons each. One trend of the rolls ranges from east to slightly south of east. Carbonaceous material in the form of trash and fossil logs is present. The ore consists of carnotite and the micaceous vanadium-bearing mineral. A few small pods of high-grade material have also been found.

Other mines and prospects

Several other small mines and prospects are present in the southern half of the quadrangle. All of them are in the upper part of the Salt Wash sandstone member. They include the Middle group mines, the Ned group mines, and the Ellison mine. The ore minerals and associations are similar to those in the other mines in the quadrangle. Nearly all the deposits are small tabular layers containing rolls; most of the mining has been of these small rolls.

In the extreme northeastern corner of the quadrangle there are a few small mines and prospects. All these lie in the upper part of the Salt Wash sandstone member, in blocks downfaulted into Gypsum Valley. The deposits are small tabular bodies which trend northwest. The ore-minerals are typical of those of the other mines in the quadrangle.

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LIST OF PATENTED CLAIMS

1. Haymaker Extension
2. Haymaker
3. Sunset
4. Rainbow
5. Last Chance
6. Cougar
7. Little Mariel
8. Chico
9. Lookout
10. Uncle Sam
11. Alice
12. Cacti
13. Mildred
14. Veta Mad
15. Georgeto
16. Dan
17. Little Yolande
18. Herbert
19. Vanadium
20. Ocumpaugh
21. Ellison
22. Hawkeye
23. Big Four
24. Grant
25. Canyon View
26. Black Fox
27. University
28. Jessie
29. Colorado Maiden
30. Ned
31. Little Dick