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GEOLOGY OF THE GATEWAY QUADRANGLE, MESA COUNTY, COLORADO

By Fred W. Cater, Jr.

Trace Elements Memorandum Report 696

UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

(200)

IN REPLY REFER TO:

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
WASHINGTON 25, D. C.

FEB 1 6 1954

AEC - 579/4

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-696, "Geology of the Gateway quadrangle, Mesa County, Colorado," by Fred W. Cater, Jr., December 1953.

On May 28, 1953, Mr. Hosted approved our plan to publish this report in the Survey's Quadrangle Map Series.

Sincerely yours,

Dwight M. Lemmon
for W. H. Bradley
Chief Geologist

FEB 1

Geology and Mineralogy

This document consists of 26 pages,
plus 1 figure.
Series A

UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

GEOLOGY OF THE GATEWAY QUADRANGLE, MESA COUNTY, COLORADO*

By

Fred W. Cater, Jr.

December 1953

Trace Elements Memorandum Report 696

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-696

GEOLOGY AND MINERALOGY

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GEOLOGY OF THE GATEWAY QUADRANGLE, MESA COUNTY, COLORADO

by Fred W. Cater, Jr.

ABSTRACT

The Gateway 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 Gateway 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 Gateway quadrangle is one. Parts of the texts accompanying these maps have been standardized; these parts comprise some descriptions of geologic formations and general descriptions of regional structural setting, geologic history, and ore deposits. A comprehensive report presenting in greater detail the geologic features of the entire area and interpretations of these features is in preparation. Work was started in the area in 1939 as a cooperative project with the State of Colorado Geological Survey Board and the Colorado Metal Mining Fund, and was continued through 1945 as a wartime strategic minerals project. Since 1947 the Geological Survey has been continuing this geologic study on behalf of the Division of Raw Materials of the Atomic Energy Commission. The Gateway quadrangle was mapped in 1949.

The Gateway quadrangle covers about 58 square miles in Mesa County, Colo., and lies in the Canyon Lands division of the Colorado Plateau physiographic province. The southern part of the quadrangle is a rugged area of mesas and steep-walled canyons; the northern part, in general, is less precipitous, except for the picturesque butte called The Palisade in the northwest part and the Unaweep Canyon section in the northeast corner. Total relief within the quadrangle is about 3,460 feet; altitudes range from about 4,540 feet in the canyon of the Dolores River to 8,000 feet in the extreme northeast corner of the quadrangle. The Dolores River and its tributaries drain the quadrangle.

No accurate information on rainfall is available, but the annual precipitation is probably between 10 to 20 inches, depending on the altitude; 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. Most of the quadrangle is accessible over 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 from late Paleozoic to Quaternary. Crystalline rocks crop out only in the northeastern part of the area along the flanks of the Uncompahgre Plateau; the rest of the area is underlain by sedimentary rocks. The latest Paleozoic and earliest Mesozoic beds wedge out northeastward against the crystalline pre-Cambrian rocks, but later Mesozoic units were deposited on top of the pre-Cambrian rocks. Over most 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 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 Gateway quadrangle lies in the northwestern corner of the 18 quadrangle area, about midway between the Uncompahgre Plateau to the northeast and Sinbad Valley to the southwest.

STRATIGRAPHY

The oldest rocks in the Gateway quadrangle are crystalline rocks of pre-Cambrian age that crop out over a large area in the northeastern part. Overlapping these crystalline rocks are sedimentary rocks of Permian (?) age which are extensively exposed over much of the quadrangle. Rocks of Triassic age crop out on the steep middle slopes of buttes and mesas and form relatively narrow outcrop patterns, whereas Jurassic rocks crop out broadly on the upper slopes and on the tops of buttes and mesas. Cretaceous rocks cap the highest parts of Tenderfoot Mesa and the mesa in the southwest corner of the quadrangle. Quaternary deposits include fanglomerate, extensive talus and sheet wash deposits, terrace gravel, deposits of wind-blown material on the tops of mesas, and alluvium on valley floors.

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 Gateway quadrangle into Utah.

Pre-Cambrian rocks

A complex of crystalline pre-Cambrian rocks crops out over an area of several square miles in the northeastern part of the quadrangle. No attempt was made to outline on the map the different rocks in the complex. Most abundant of the rocks is a gray medium-grained granite; engulfed in this granite are small masses and xenoliths of hornblende and biotite schists and gneisses that have undergone different degrees of assimilation. The gray medium-grained granite has been intruded by large, irregular masses and dikes of pink coarse-grained granite, dikes of pegmatite and aplite, and, in the area between Wright Draw and Unaweep Canyon, dark hornblende-rich dikes. The older, more abundant gray granite has been altered considerably in places; the dark minerals have been replaced in part by chlorite and epidote, whereas the younger pink coarse-grained granite appears to be essentially fresh. The entire complex in this area has been sheared, faulted, and crushed.

Schist and gneiss, probably belonging to the same series as the masses engulfed in the older granite, are exposed in Unaweep Canyon a few miles northeast of the quadrangle; Peale (1877) believed these rocks to be of Archean age. Hunter (1925), in the nearby Gunnison River area, assigned similar metamorphic rocks to the Archean and the granitic intrusions to the Algonkian or early Paleozoic.

Cutler formation

The Permian (?) Cutler formation consists of maroon, purple, red, and mottled light-red cross-bedded arkosic sandstone and conglomerate, and small quantities of reddish-brown sandy mudstone. It crops out extensively over much of the quadrangle, and where the base is exposed in the vicinity of Wright Draw and Ute Creek, the formation rests unconformably on a highly irregular, hilly surface of pre-Cambrian rocks. Grains of quartz, fresh feldspar, and dark minerals, pebbles and boulders of granite gneiss, schist, and quartzite--materials derived almost entirely from the pre-Cambrian--are mixed together in poorly sorted, rudely cross-bedded layers and lenses. Small amounts of reddish-brown sandy mudstone are distributed through the coarser material as thin irregular layers that delineate the otherwise obscure bedding.

The Cutler formation in the Gateway quadrangle forms a wedge between the pre-Cambrian rocks and the overlying Triassic beds. The formation is absent on the high mesa in the northeastern corner of the quadrangle, and the Triassic rocks rest directly on the pre-Cambrian; a few miles to the southwest the formation is several thousand feet thick. A well drilled about 4 miles southwest of the edge of the Cutler in the canyon of the Dolores River, about 4 miles northwest of Gateway, Colo., penetrated more than 7,800 feet of red arkose before reaching the pre-Cambrian basement. This thick sequence of beds probably includes not only rocks of Permian age, but of Pennsylvanian as well. Abrupt thinning of the formation towards its source area on the Uncompahgre uplift, coarseness of the material, and rude bedding indicate the Cutler in this area was deposited as a fanglomerate.

Moenkopi formation

The Lower Triassic Moenkopi formation unconformably overlies the Cutler formation and crops out as steep slopes and ledges on the sides of buttes and mesas. The formation consists of three distinct members in this area, a lower member of poorly sorted sandy mudstone, a middle member characterized by beds of arkosic conglomerate and conglomeratic arkose and an upper member of thinly bedded shale and lesser amounts of fine-grained sandstone. These members are shown on the map.

The lower member of the Moenkopi formation consists almost entirely of brick-red, poorly sorted, regularly bedded sandy mudstone and silty sandstone in which grains range in size from clay particles to granules as much as 3 mm across. A bed of gypsum as much as 6 feet thick occurs locally, either at the base of the member or separated from the underlying Cutler formation by a thin conglomerate bed consisting of reworked Cutler. The gypsum bed at the base of the member, the lack of sorting, and the regular bedding, suggest ponding of the area at the beginning of Moenkopi deposition, followed by rapid dumping of sediment into a body of standing water. The lower member thins eastward by onlap and by truncation of the upper beds from a maximum thickness of about 180 feet in the southwestern part of the quadrangle to a vanishing edge near the eastern margin.

The middle member of the Moenkopi formation consists of purple and reddish-brown ledge-forming beds of conglomeratic arkose separated by beds of reddish-brown and chocolate-colored sandstone and shale. The conglomeratic beds are cross-laminated, fill channels cut in underlying beds, and show current lineations and ripple marks. Shale beds are marked in places by mud cracks. These sedimentary structures are indicative of fluviatile deposition. From a maximum thickness of about 200 feet in Cave Canyon on the west side of the Dolores River, the middle member thins eastward by truncation of the upper beds and pinches out entirely on the east side of the river in the vicinity of Larsen Canyon.

The upper member of the Moenkopi formation consists predominantly of reddish-brown and chocolate-brown shale and sandstone. The shale is micaceous; some bedding planes are sheeted with minute flakes of mica. Individual laminae in the shale are paper-thin, and ripple-bedding is pervasive. Thin beds of coarse-grained sandstone are scattered throughout the member. A predominance of shale and uniformity of bedding suggest that the upper member of the Moenkopi was deposited in a body of shallow water, perhaps marginal to a sea. In the Gateway quadrangle the upper member is exposed only in John Brown Canyon where it thins eastward from a thickness of about 100 feet to a vanishing edge.

Chinle formation

Throughout most of the Colorado Plateau, beds of the Upper Triassic rest unconformably on older rocks. This relationship is strikingly evident in the Gateway quadrangle and adjacent areas. As the Uncompahgre Plateau is approached from the west, the Upper Triassic Chinle formation rests in turn first on the Lower Triassic Moenkopi formation, then on the Cutler formation, and finally, in the northeastern corner of the quadrangle, on pre-Cambrian rocks. Except for disturbances incident to later faulting and uplift, this erosion surface below the Chinle is remarkably flat.

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 very 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 Chinle formation is about 300 feet thick in the southwestern part of the Gateway quadrangle; it thins progressively northeastward to a minimum of 120 feet in the northeastern part of the quadrangle.

Glen Canyon group

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

Wingate sandstone

The Wingate sandstone conformably overlies the Chinle formation. The sandstone is a massive, fine-grained rock composed of clean, well-sorted quartz sand. It typically crops out as an impressive red or dark brown wall, stained and streaked in places with a surficial red and black desert varnish. Vertical joints cut the sandstone from top to bottom; the spalling of vertically jointed slabs largely causes the recession of the cliff. The sandstone is divided into horizontal layers by extensive bedding planes spaced 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 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 Gateway quadrangle the Wingate sandstone ranges in thickness from 290 to about 400 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 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 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 Gateway quadrangle ranges in thickness from slightly less than 90 feet in the northeastern corner of the quadrangle to nearly 220 feet around Cave Canyon in the southwestern corner. Abrupt local changes in thickness of 10 to 20 feet are common. The irregular bedding, channel filling, and changes 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.

From a vanishing edge that runs between Maverick and Bull Canyons northwestward through the forks of Larsen Canyon, the Navajo thickens westward to about 120 feet in John Brown Canyon.

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 and on the sides of buttes and mesas. The Carmel formation and the 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 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 quartzitic pebbles and cobbles 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.

In the Gateway quadrangle the Carmel formation ranges from less than 5 feet to 50 feet in thickness. This large range appears to be due chiefly to deposition on irregular, eroded surfaces of the Navajo sandstone or of the 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 prominent breaks, 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 scenic feature of the region. Horizontal rows of pits resulting from differential weathering and ranging from a few inches to a foot or more across are characteristic of these cliffs. The Entrada consists of alternating horizontally bedded units and sweeping, eolian-type cross-bedded units. The horizontally bedded units are most common in the basal part and in the uppermost, lighter-colored part of the Entrada, whereas the cross-bedded units are dominant in the middle part. The Entrada sandstone differs from the somewhat similar Wingate sandstone and Navajo sandstone by the sorting of sand into two distinct grain sizes. Subrounded to subangular quartz grains mostly less than 0.15 mm in diameter make up the bulk of the sandstone. The sandstone also contains larger grains, which are well-rounded, have frosted surfaces, and range from 0.4 to 0.8 mm in diameter; most of these grains are of quartz, but grains of chert are scattered among them. Most of the larger grains are distributed in thin layers along bedding planes.

The Entrada sandstone attains a thickness of nearly 200 feet in the southwestern corner of the quadrangle; it thins northeastward to about 100 feet thick in the northeastern corner.

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, gray, 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 beds consisting almost entirely of claystone. Thin beds of authigenic red and green chert are widespread. A thin discontinuous bed of dark-gray dense fresh-water limestone occurs in the upper part of the formation. Sandstone beds are thicker and sandstone is more abundant in the lower part of the formation than in the upper part. Commonly the sandstone beds are ripple-marked, and in places they show small-scale low-angle cross-bedding. In the western part of the quadrangle these lowermost sandstone beds thicken and form a prominent ledge 25 to 40 feet thick. To the west, in Utah, these beds can be traced into the Moab tongue of the Entrada sandstone; to the south and east they grade into sandstones and shales of the lower part of the Summerville. In this report these beds are included in the Summerville.

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

In the Gateway quadrangle the Summerville formation ranges in thickness from about 75 feet to about 95 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 Gateway quadrangle the Morrison formation ranges in thickness from 600 to 670 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 differ 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 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. Ripple marks, current lineations, rill marks, and cut-and-fill structures indicate that the Salt Wash member was deposited under fluviatile conditions.

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

The Salt Wash sandstone member ranges from 280 to 340 feet in thickness.

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 of material several inches thick, caused by the swelling of the bentonitic material during periods of wet weather. Scattered through the shale and mudstone are thin beds of fine-grained 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 320 to 350 feet in thickness; 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 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 entire thickness of the Burro Canyon formation is not exposed in the quadrangle; the upper beds have been stripped off by erosion, but the beds that remain attain a maximum thickness of 210 feet in the southwestern corner of the quadrangle.

Quaternary deposits

Quaternary deposits consist of a fanglomerate capping low ridges in the valley of West Creek, gravel beds capping terraces along the Dolores River and West Creek, alluvial fill along some of the major stream courses, wind-deposited material, talus, and landslide material. The fanglomerate consists of a light-red heterogeneous, poorly sorted accumulation of silt, sand, pebbles, and boulders derived almost entirely from Mesozoic formations. The material is somewhat indurated and stands in vertical cut banks as much as 100 feet high. The fanglomerate was deposited as sheet wash and talus on an irregular, sloping surface possibly during or even before early Pleistocene time.

The gravel beds that cap terraces along the Dolores River and West Creek occur at different altitudes up to about 400 feet above the streams. The composition of the pebbles indicate that many were derived from the San Juan Mountains. Two gravel beds half a mile southwest of the mouth of Casto Draw rest on terraces carved from the fanglomerate. These gravel beds are believed to have been deposited by an ancient river whose abandoned channel now forms the remarkable Unaweep Canyon. This canyon cuts directly across the Uncompahgre Plateau from Whitewater on the northeast to Gateway on the southwest. Peale (1877) believed the canyon was carved by the Gunnison River, but it seems at least as probable that it is a former channel of the Colorado River.

Gravel and alluvium cover not only the beds of the Dolores River and West Creek but also some of the intermittent stream channels, especially those tributary to West Creek. Deposits of light-red sandy and silty material mantle parts of 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. Considerable talus covers many of the steeper slopes, and landslide material consisting largely of Brushy Basin debris occurs on the west side of the Dolores River Canyon below the mouth of Cave Canyon and in the southwestern corner of the quadrangle. Because the alluvium, talus, wind-deposited material, and sheet wash are difficult to differentiate in some places, they have not been separated on the geologic map.

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 northwesterly and lie in a group between eastward-dipping monoclines on the west side of the Plateau and westward-dipping monoclines on the east side of the Plateau. The cores of these anticlines consist of relatively plastic salt and gypsum, derived from the Paradox member of the 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 Gateway quadrangle

Two large structural features cross the Gateway quadrangle; these are the broad Dolores River syncline in the southwestern part, and the faulted monoclinal fold fronting the Uncompahgre Plateau in the northeastern part. In the southwestern part of the quadrangle the Mesozoic beds dip less than 2°, but dips increase to the northeast and between Bull Hill and the eastern margin of the quadrangle the dips are about 4°. The Permian (?) Cutler beds commonly dip more steeply. The steeper dips in the Cutler formation in part reflect steeper angles of original dip, especially in those beds nearer the contact with pre-Cambrian basement rocks; nevertheless, some component of these steeper dips is the result of tilting prior to deposition of Triassic beds. The Dolores River syncline trends northwest and plunges southeast at a low angle. The monoclinal fold along the flank of the Uncompahgre Plateau uplift also trends northwest, but the fold is not as well-marked in the Gateway quadrangle as it is to the southeast because the beds along the sharpest part of the fold have been largely stripped away and only the pre-Cambrian basement rocks remain. The fault, along which Birch Creek has carved its channel, marks the southwest side of a large graben then diagonally crosses the adjacent Pine Mountain quadrangle.

Structural history

In order to understand the structural history of the Gateway 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 Gateway 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 Pennsylvanian Hermosa formation was deposited. These major structural features controlled the pattern and the prevailing northwest-trending grain of the smaller structures later superimposed on them. The boundary between the highland and the basin, which 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, balanced or slightly exceeded the rate of removal of salt by solution and erosion at the surface. Consequently, all the Mesozoic formations to the base of the Morrison formation wedge out against the flanks of the salt intrusions. Salt flowage was not everywhere continuous and at a uniform rate; rather, in many places it progressed spasmodically. Local surges of comparatively rapid intrusion gave rise to cupolas at different times and in different places along the salt masses. At the beginning of 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, C. B., written communication). The region of the salt intrusions was compressed into a series of broad folds, guided and localized by the pre-existing salt intrusions. Although salt flowage was renewed, it seems unlikely that any considerable amount of new salt was forced into the intrusions; flowage probably consisted largely of redistribution of the salt already present. By the end of this period of deformation these folds had attained approximately their present structural forms except for modifications imposed by later collapse of the anticlines overlying the salt intrusions. Owing to the mobility of the rocks in the cores of the anticlines, normal faulting took place along the crests of the anticlines, probably during relaxation of compressive stresses after folding ceased. At this time the crests of the anticlines in places were dropped, as grabens, several hundred to a few thousand feet. A period of crustal quiescence followed, during which the highlands overlying the anticlines and domes were reduced by erosion and topographic relief became low throughout the area.

Then, during the middle Tertiary, the entire Colorado Plateau was uplifted. This uplift rejuvenated the streams and increased ground water circulation. The crests of the anticlines were breached, and the underlying salt was exposed to rapid solution and removal. With the abstraction of salt, renewed collapse of the anticlines began. Although much of the collapse was due directly to removal of salt by solution, it seems unlikely that all the collapse can be attributed to this process, as was believed by earlier workers in the area. Rather, much of the collapse apparently was caused by flowage of salt from the parts of the 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 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 Gateway quadrangle are those that contain uranium, vanadium, and radium. Although deposits containing these metals were discovered in 1899 near Roc Creek, about 15 miles south of the Gateway 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.

Although most of the deposits are restricted to the upper layer of sandstone lenses in the Salt Wash sandstone member, a few occur in a lower layer of lenses and still others are in the lowermost lenses of conglomerate in the Brushy Basin shale member. In these lenses the deposits have a spotty distribution. Most ore bodies are relatively small and contain only a few hundred tons, but one is of medium size and contains several thousand 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 ($K_2(UO_2)_2(VO_4)_2 \cdot 3H_2O$), 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 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 non-existent. 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 the ores are found, all are of roughly the same age, and this age is no older than latest Cretaceous (Stieff and Stern, 1952). Some geologists believe field relations in pre-Morrison formations at White Canyon (Benson, and others, 1952) and Temple Mountain in Utah, indicate that the deposits may be genetically related to faults and fractures. At the Rajah mine near Roc Creek, Colo., 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 author favors, is essentially a telethermal hypothesis and assumes the ore to have originated from a hypogene source. Proponents of this hypothesis believe that ore-bearing solutions, originated at depth from an igneous source and ascended along fractures. After these solutions mingled with circulating ground water, 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; (1) the hypothetical location of igneous source rocks, and (2) 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 sandstone member of the Morrison formation. Generally the central or thicker parts of the sandstone lenses are more favorable--many deposits are in sandstone that is 40 feet or more thick; few deposits are in sandstone less than 20 feet thick. Cross-bedded, relatively coarse-grained sandstone is more favorable than thinly or evenly bedded, fine-grained sandstone. Light-yellow-brown sandstone speckled with limonite stain is more favorable than red or reddish-brown sandstone. Sandstone that contains considerable amounts of or is underlain by a considerable thickness 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. If the deposits have a hypogene origin, then localities where favorable host rocks are near or are coextensive with areas of more intense deformation may be especially favorable for finding ore.

In the Gateway quadrangle probably the most likely area for finding ore, because of the presence of favorable host rocks, is Tenderfoot Mesa. Elsewhere the Salt Wash sandstone member is either generally unfavorable or has been removed by erosion.

The mines

A number of deposits are scattered along the outcrop of the lower part of the Morrison formation in the southern part of the quadrangle. Recently, extensions of old deposits and new discoveries on Tenderfoot Mesa have been made as a result of exploratory drilling conducted by the Atomic Energy Commission.

Mammoth mine

The Mammoth mine has been the most productive in the Gateway quadrangle. The ore deposit is in a conglomeratic sandstone lens at the base of the Brushy Basin shale member of the Morrison formation. The deposit is a tabular mass about 300 feet long and has a maximum thickness of 18 feet. Ore minerals are carnotite and the micaceous vanadium clay mineral; these occur as low-grade disseminations in the sandstone. Rolls are not conspicuous in this deposit.

Vanaking No. 1 mine

The deposits being exploited at the Vanaking No. 1 mine are in the upper layer of sandstone lenses in the Salt Wash sandstone member. The deposits are small, and most of the ore is confined to rolls. Ore minerals are carnotite, montroseite, and hewettite.

Other deposits

A number of other small deposits similar to those at the Vanaking No. 1 mine are scattered along the outcrop of the upper layer of the Salt Wash sandstone member on both sides of North Larsen Canyon. At the head of South Larsen Canyon a few small deposits occur not only in the top layer of the Salt Wash but in the lower layers as well. Other small deposits have been found along Maverick Canyon, southwest of the Mammoth mine, and west of the Dolores River between Cave Canyon and John Brown Canyon.

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