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GEOLOGY OF THE ATKINSON CREEK QUADRANGLE, MONTROSE COUNTY, COLORADO

By E. J. McKay

Trace Elements Memorandum Report 691

UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

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IN REPLY REFER TO:

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

FEB 1 ? 1954

AEC - 351/4

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-691, "Geology of the Atkinson Creek quadrangle, Montrose County, Colorado," by E. J. McKay, August 1953.

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

Sincerely yours,

for W. H. Bradley
Chief Geologist

Geology and Mineralogy

This document consists of 32 pages,
plus 1 figure.
Series A

UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

GEOLOGY OF THE ATKINSON CREEK QUADRANGLE, MONTROSE COUNTY, COLORADO*

By

E. J. McKay

August 1953

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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-691

GEOLOGY AND MINERALOGY

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GEOLOGY OF THE ATKINSON CREEK QUADRANGLE, MONTROSE COUNTY, COLORADO

by E. J. McKay

ABSTRACT

The Atkinson Creek quadrangle is one of eighteen $7\frac{1}{2}$-minute quadrangles covering the principal carnotite-producing area of southwestern Colorado. The geology of these quadrangles was mapped by the U. S. Geological Survey for the Atomic Energy Commission as part of a comprehensive study of carnotite deposits. The rocks exposed in the eighteen quadrangles consist of crystalline rocks of pre-Cambrian age and sedimentary rocks that range in age from late Paleozoic to Quaternary. Over much of the area the sedimentary rocks are flat lying, but in places the rocks are disrupted by high-angle faults, and northwest-trending folds. Conspicuous among the folds are large anticlines having cores of 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 Atkinson Creek quadrangle, Colo., as a 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 $7\frac{1}{2}$-minute quadrangles, of which the Atkinson Creek quadrangle is one. Parts of the texts accompanying these maps have been standardized; these parts comprise some descriptions of geologic formations and general descriptions of regional structural setting, geologic history, and ore deposits. Comprehensive reports presenting in greater detail the geologic features of the entire area and interpretations of these features are in preparation. Work was started in the area in 1939 as a cooperative project with the State of Colorado and the Colorado Metal Mining Fund and was continued through 1945 as a wartime strategic minerals project. Since 1947 the Geological Survey has been continuing this geologic study on behalf of the Division of Raw Materials of the Atomic Energy Commission. The Atkinson Creek quadrangle was mapped in 1949.

The Atkinson Creek quadrangle comprises an area of 59 square miles between the Uncompahgre Plateau and the San Miguel River in Montrose and Mesa Counties, Colo., and lies in the Canyon Lands subdivision of the Colorado Plateau physiographic province. The surface of the quadrangle slopes southwestward and, except for the northeastern corner, is a southwestward sloping plateau cut into numerous mesas by steep-sided canyons.

The northeastern corner rises abruptly along a line of steeply tilted "flatirons" to the edge of the Uncompahgre Plateau. Total relief is about 4,000 feet; altitudes range from about 4,930 feet along the San Miguel River in the southwest corner of the quadrangle to nearly 9,000 feet on the Uncompahgre Plateau in the northeast corner. All drainage within the quadrangle is southwesterly either to the San Miguel River or to the Dolores River, which lies a short distance west of the quadrangle.

No accurate information on rainfall is available, but the annual precipitation is probably between 10 and 15 inches; the area is semiarid and supports a moderate growth of juniper and piñon on rocky terrain and abundant sagebrush where soils are thick. Cacti and sparse grass are widely distributed. 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 in age from late Paleozoic to Quaternary. Crystalline rocks crop out only in the northeastern part of the area along the flanks of the Uncompahgre Plateau; the rest of the area is underlain by sedimentary rocks. The latest Paleozoic and earliest Mesozoic beds wedge out northeastward against the crystalline pre-Cambrian rocks, but later Mesozoic units were deposited on top of the pre-Cambrian rocks. Over most of the region the sedimentary rocks are flat-lying, but in places they are disrupted by high-angle faults or folded into northwest-trending monoclines, shallow synclines, and strongly developed anticlines. The largest of the folds is the Uncompahgre Plateau uplift, a fold nearly 100 miles long that traverses the northeastern part of the area. Well-developed anticlines having intrusive cores of salt and gypsum underlie Sinbad Valley, Paradox Valley, and Gypsum Valley in the central part of the area; the Dolores anticline in the southwestern part of the area probably has a salt-gypsum core, although it is not exposed.

The Atkinson Creek quadrangle lies in the northeastern part of the 18-quadrangle area a few miles northeast of Paradox Valley. The southwest flank of the Uncompahgre Plateau uplift crosses the northeast corner of the quadrangle.

STRATIGRAPHY

The oldest rocks in the Atkinson Creek quadrangle are of pre-Cambrian age and are exposed along the southwest flank of the Uncompahgre Plateau. The Pennsylvanian Hermosa formation does not crop out in the quadrangle, although it is exposed in nearby areas. Sedimentary rocks of the Cutler formation of Permian age are in depositional contact with pre-Cambrian crystalline rocks in Mesa Creek, about 8 miles northwest of the head of Atkinson Creek. Near West Creek, about 20 miles northwest of the head of Atkinson Creek, the Moenkopi formation of Lower Triassic age rests on an angular unconformity that truncates the underlying Cutler beds. Although rocks of the Cutler and Moenkopi formations are not exposed in the Atkinson Creek quadrangle, both the Cutler and the Moenkopi are drawn in the structure cross-section of the accompanying map. The oldest exposed sedimentary rocks in the quadrangle are those of the Chinle formation of Upper Triassic age. Rocks of Jurassic age form cliffs, steep slopes, and broad benches along the San Miguel River and its tributaries, and steep "flatirons" along the southwest flank of the Uncompahgre Plateau. The mesas are capped by

Cretaceous rocks. Deposits of wind-blown material, sheet wash, and remnants of old pediment gravels are widely distributed on the mesa tops, and alluvium and stream gravels cover the bottoms of the valleys.

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 Atkinson Creek quadrangle into Utah.

Pre-Cambrian complex

The pre-Cambrian rocks are a complex of intrusive and metamorphic crystalline rocks exposed along the southwest flank of the Uncompahgre Plateau. Exposures are poor except in the deep canyons between "flatirons", which are formed by the overlying steeply upturned sedimentary beds. The dominant rock is a coarse-grained pink granite that is cut by dikes of granite pegmatite. Within the pink granite are xenoliths of gneiss, schist, and quartzite.

Relations between the coarse-grained pink granite and the older igneous and metamorphic rocks are shown better in exposures about 20 miles northwest of the quadrangle, in the vicinity of West Creek and Ute Creek. There, large bodies of gray gneissic granite intrude gneiss and schist. These rocks have been intruded in turn by coarse-grained pink granite. Youngest of the exposed pre-Cambrian rocks are dikes of pink porphyritic and light-gray fine-grained granite.

The schist and gneiss in the West Creek area were referred to as Archean in age by Peale (1877). Hunter (1925) assigned similar rocks in the nearby Gunnison River region, to the Archean and the granitic intrusions to late Algonkian or early Paleozoic age. Because crystalline rocks are insufficiently exposed in the region mapped, they have been treated as undifferentiated pre-Cambrian.

Chinle formation

The Chinle formation of the Upper Triassic consists of red to orange-red mudstone, siltstone, sandstone, and limestone-pebble and mudstone-pebble conglomerate. The formation crops out along the sides and on top of the Uncompahgre Plateau, where it rests directly on pre-Cambrian rocks. The peneplained surface of pre-Cambrian rocks on which the Chinle was deposited was nearly flat, and in places the upper few feet of rock underlying this surface weathered to form a red residual clay. This weathering occurred before the Chinle formation was deposited. The lower 2 feet of the formation consists of a red, generally coarse-grained sandstone with angular pebbles of quartz, feldspar, and igneous rocks. The remainder of the formation consists of red and orange-red interbedded siltstone, mudstone, and resistant, discontinuous, thin-bedded and cross-bedded sandstones. The sandstone lenses are generally more highly cross-bedded and are thicker and more abundant near the top of the formation. The Chinle formation probably was deposited under fluviatile conditions. The Chinle, where exposed in the Atkinson Creek quadrangle, is about 200 feet thick, but it thickens to 450 feet in Paradox Valley, about 15 miles to the southwest.

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 formation

The Wingate sandstone conformably overlies the Chinle formation. In the Atkinson Creek quadrangle the Wingate sandstone forms steep hogbacks and bluffs along the flank and top of the Uncompahgre Plateau. Because the Wingate in this quadrangle is fractured and leached, it does not form the vertical reddish-brown cliffs characteristic of the Wingate of most of the Colorado Plateau. 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 poorly cemented and crumbles easily; this quality probably accounts for the readiness with which the rock disintegrates in faulted areas. In the Atkinson Creek quadrangle the Wingate sandstone is about 200 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 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 formation is about 60 feet thick near the base of the "flatirons" on the flank of the Uncompahgre Plateau. Although the lower part of the Kayenta is not exposed in the southwestern corner of the quadrangle, it probably has a thickness of nearly 180 feet in this area.

Navajo sandstone

In the Atkinson Creek quadrangle the Navajo sandstone is discontinuous and consists of isolated lenses. It crops out only near the southwestern corner of the quadrangle. The sandstone conformably overlies the Kayenta formation. The contact with the Kayenta is gradational in some places, sharp and undulating in others. The Navajo is a homogeneous gray to buff, fine-grained clean quartz sandstone. Thin gray discontinuous limestone beds containing chert nodules occur in places in the sandstone. In nearby areas tangential cross-beds of tremendous size, indicative of eolian deposition, are typical of the Navajo; but where the Navajo crops out at Uravan, tangential cross-beds are not so large and horizontal bedding planes are more common than elsewhere. The thickness of the Navajo in the Atkinson Creek quadrangle ranges from a featheredge to 30 feet.

San Rafael group

In this area, the San Rafael group, of Middle and Late Jurassic age, includes in ascending order the Carmel formation, the Entrada sandstone, and the Summerville formation. The group crops out in the canyon of the San Miguel River and in hogbacks bordering the Uncompahgre Plateau. 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, soft, horizontally bedded siltstone, mudstone, and sandstone. In some localities the basal beds consist of reworked Navajo sandstone. Pebbles and angular fragments of white and gray chert, as much as an inch across, are scattered rather abundantly through the lower part of the formation and less abundantly through the upper part. These chert pebbles and angular fragments are sufficiently abundant locally to form layers of conglomerate. Included in these layers are scattered greenish-gray, red, and yellow quartzite pebbles and boulders as large as 5 by 8 inches. In many places the upper part of the formation contains scattered barite nodules as much as an inch across.

The Carmel formation ranges from a knife-edge to 30 feet in thickness in the quadrangle. This range appears to be due chiefly to deposition on irregular, eroded surfaces of Navajo sandstone or beds 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 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 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, where exposed in the Atkinson Creek quadrangle, is about 80 feet thick.

Summerville formation

The Summerville formation generally crops out as a steep, debris-covered slope, with very few good exposures. Where exposed the Summerville exhibits a remarkably even, thin, horizontal bedding. Beds are predominantly red of various shades, although some beds are green, brown, light yellow, or nearly white. Sandy and silty shale are the most abundant kinds of rock, but all gradations from 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 autochthonous red and green chert are widespread. A thin, discontinuous bed of dark-gray dense fresh-water limestone occurs in the upper part of the formation. Sandstone beds are thicker and sandstone is more abundant in the lower part of the formation than in the upper part. 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 shale and mudstone of the Morrison formation are similar to beds of the Summerville.

The Summerville formation is about 80 feet thick in the Atkinson Creek quadrangle.

Morrison formation

The Morrison formation, of Late Jurassic age, is of special interest economically because of the uranium- and vanadium-bearing deposits it contains.

The formation comprises two members in this area; the lower is the Salt Wash sandstone member and the upper is the Brushy Basin shale member. In the Atkinson Creek quadrangle the Morrison formation ranges in thickness from 700 to 800 feet, with the Brushy Basin shale member generally forming somewhat more than half the total thickness. In some areas the thicknesses of the members vary independently, whereas in other areas a thinning in one member is accompanied by a thickening in the other.

Salt Wash sandstone member

The Salt Wash sandstone member ordinarily crops out above the slope-forming Summerville formation as a series of thick, resistant ledges and 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. Individual lenses are more or less surrounded 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 saurian bones are found locally.

The thickness of the Salt Wash sandstone member is about 300 feet, although locally it varies as much as 30 feet.

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, very hard, silicified rock that breaks with a conchoidal fracture. The silica impregnating these beds may have been released during the devitrification of volcanic debris in adjacent beds. Beds of chert-pebble conglomerate a few inches to 25 feet thick, occur at intervals throughout the member. These conglomerate beds are commonly dark rusty red and form conspicuous resistant ledges. Silicified saurian bones and wood are much more abundant in the Brushy Basin shale member than in the Salt Wash sandstone member, especially in some of the conglomerate beds.

The Brushy Basin shale member, like the Salt Wash sandstone member, undoubtedly was deposited under fluviatile conditions. The conglomerate and sandstone lenses mark stream channels that crossed flood plains on which were deposited the fine-grained sediments now represented by the mudstone and shale.

The Brushy Basin shale member ranges from 400 to 500 feet in thickness: local variations in thickness of 20 to 30 feet are common throughout the quadrangle.

Burro Canyon formation

The name of 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 that cap most of the high mesas adjacent to the Uncompahgre Plateau. The bulk of the formation consists of white, gray, and red sandstone and conglomerate that form beds as much as

100 feet thick. These beds are massive, irregular, and lenticular. Cross-bedding and festoon-bedding are prevalent throughout the formation. The sandstone is poorly sorted and consists of quartz and lesser amounts of chert. The conglomerate consists largely of chert pebbles but intermixed are pebbles of quartz, silicified limestone, quartzite, sandstone, and shale. In places beds are highly silicified. A considerable part of the formation consists of bright-green mudstone and shale, and locally these predominate over the sandstone and conglomerate. Thin, discontinuous beds of dense gray limestone crop out in a few scattered localities. The formation was undoubtedly deposited under fluviatile conditions. The lower contact is indistinct in many places and appears to interfinger with the upper part of the Brushy Basin shale member; elsewhere local erosion surfaces intervene and the contact is sharp. The upper contact is an erosion surface of regional extent.

In the Atkinson Creek quadrangle the Burro Canyon formation is 100 to 120 feet thick.

Dakota sandstone

The Dakota sandstone of Cretaceous age crops out as capping beds on Spring Creek and Atkinson mesas. It consists principally of flaggy, gray, yellow, and brown sandstone; less abundant are conglomerate, carbonaceous shale, and impure coal. Some of the sandstone is fine-grained and thin-bedded, but much of it is coarse-grained and cross-bedded. Scattered through the sandstone are irregular, discontinuous beds and lenses of conglomerate containing chert and quartz pebbles as much as 2 inches across. Plant impressions are fairly common in the sandstone but are preserved best in the gray shale. The entire thickness of the Dakota sandstone is not preserved in the quadrangle; the beds remaining have a maximum thickness of 80 feet.

Quaternary system

Extensive deposits of light-red, sandy and silty material cover benches and mesa tops. This material appears to be mostly wind deposited, although much of it has been reworked by water and mixed with sheet wash. These deposits have not been mapped where they are unusually spotty, discontinuous, or less than 1 foot thick; the greatest observed thickness in some dry washes on mesa tops is about 10 feet. Gravel beds containing considerable quantities of well-rounded pebbles of both intrusive and extrusive rocks cover some of the benches above the San Miguel River. The San Miguel River Valley is floored with a mixture of stream-deposited sand, sediments derived from disintegration of rocks on the valley walls, and wind-blown silt.

Capping the Dakota sandstone in secs. 17 and 18, T. 48 N., R. 16 W., are pediment gravels containing pebbles of pegmatite, granite, gneiss, and schist derived from pre-Cambrian rocks of the Uncompahgre Plateau. Landslide material is fairly common on the flanks of the Uncompahgre Plateau.

STRUCTURE

Regional setting

Many geologic structures on the Colorado Plateau are so large that a 7½-minute quadrangle covers only a small part of any complete structural unit. The larger structural units consist of salt anticlines, 45 to 80 miles long; uplifted blocks, 50 to 125 miles long, bounded by monoclinal folds; and domical uplifts, 8 to 20 miles long, around stock-like and laccolithic intrusions.

The salt anticlines trend northwest and lie in a group between eastward-dipping monoclines on the west side of the Plateau and westward-dipping monoclines on the east side of the Plateau. The cores of these anticlines consist of relatively plastic salt and gypsum, derived from the Paradox member of the Hermosa formation and intruded into overlying 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 Atkinson Creek quadrangle

The Atkinson Creek quadrangle straddles the San Miguel River syncline which lies between the Paradox Valley anticline to the southwest and the Uncompahgre Plateau uplift to the northeast. Most of the rocks dip at angles of less than 5°; only on the flanks of the Uncompahgre uplift are the dips steeper. Within a mile of the axis of the San Miguel syncline, dips do not exceed 2°. The syncline plunges imperceptibly to the northwest. Sedimentary rocks on the southwest flank of the Uncompahgre Plateau uplift have been faulted and monoclinally folded by upward movement of the underlying pre-Cambrian basement rocks. The trend of the sedimentary beds along the fold is irregular and ranges from N. 40° W. to N. 70° W.; locally the beds dip vertically. In places the strongly folded beds are cut by reverse faults. A graben, probably the result of gravity adjustment to the uplift, lies southwest of the steeply dipping beds on the flank of the uplift. A small fault that cuts the beds at the lower end of Atkinson Creek may reflect gravity adjustment to the abstraction of salt in the Hermosa formation.

Structural history

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

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

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

Then, during the middle Tertiary, the entire Colorado Plateau was uplifted. This uplift rejuvenated the streams and increased ground-water circulation. The crests of the anticlines were breached, and the underlying salt was exposed to rapid solution and removal. With the abstraction of the 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 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 Atkinson Creek quadrangle are those that contain uranium, vanadium, and radium. Although deposits containing these metals were discovered in 1899 near Roc Creek about 6 miles northwest of the Atkinson Creek 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.

All the known deposits in the Atkinson Creek quadrangle are in the upper layer of sandstone lenses in the Salt Wash sandstone member, but within this layer the deposits have a spotty distribution. The ore bodies range from irregular masses containing only a few tons of ore to lenticular masses containing 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 ($K_2(UO_2)_2(VO_4)_2.3H_2O$) is a yellow, fine-grained, earthy or powdery material. Tyuyamunite ($Ca(UO_2)_2(VO_4)_2.nH_2O$), the calcium analogue of carnotite, is also present and is nearly indistinguishable from carnotite. The micaceous vanadium mineral, which formerly was thought to be roscoelite, is not 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 ($nFeO.nV_2O_4.nV_2O_3.nH_2O$., corvusite ($V_2O_4.6V_2O_5.nH_2O$), and hewettite ($CaO.3V_2O_5.9H_2O$). Corvusite and montroseite occur together, forming compact masses of bluish-black ore, whereas hewettite commonly forms stringers and veinlets along joints and fractures. Recent deeper drilling and mining in the Plateau have indicated that below the zone of oxidation, black oxides of uranium and vanadium, accompanied by pyrite and perhaps other sulfides, are more abundant, and uranyl vanadates are scarce and 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.

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

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 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, in Utah. Studies of lead-uranium ratios in ores from the Colorado Plateau indicate that, regardless of where or in what formation found, all the ores are of roughly the same age; and this age is no older than latest Cretaceous (Stieff and Stern, 1952). Some geologists believe field relations in pre-Morrison formations at White Canyon (Benson et al., 1952) and Temple 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 ore. 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 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 suits 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, originating at depth from an igneous source, ascended along fractures. After these solutions mingled with circulating ground waters the minerals were precipitated in favorable beds as much as several miles from the fractures. This hypothesis explains more readily the difficulties, inherent in the penesyngenetic hypothesis, but it 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 it presents some additional ones of its own.

Suggestions for prospecting

Regardless of the actual origin of the deposits, certain habits of the deposits--habits that have been recognized through geologic mapping and exploration experience--are useful as guides for finding ore (Weir, 1952). In southwestern Colorado most of the deposits are in the uppermost sandstone stratum of lenses 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 lenses 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 a considerable amount 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 localities where favorable host rocks are near or coextensive with areas of more intense deformation may be especially favorable for finding ore.

In the Atkinson Creek quadrangle probably the most likely area for finding ore, because of the presence of favorable host rocks, is the southwestern corner, including the west end of Spring Creek Mesa. In the Atkinson

Creek quadrangle, however, the rocks in the vicinity of the faults in the northern part are, for the most part, unfavorable hosts for ore.

The mines

Several small mines are scattered along the edge of Spring Creek Mesa in the southwestern corner of the Atkinson Creek quadrangle. Workings consist of short adits and small open cuts. Several deposits have been found by drilling. Where deep drilling has been required and the costs were too great for individual operators, exploration in the Atkinson Creek quadrangle has been conducted by the Geological Survey on behalf of the Atomic Energy Commission.

Wright mines

The Wright mines are the most productive in the quadrangle. The ore occurs in discontinuous zones near the middle of a lens in the uppermost sandstone stratum of the Salt Wash sandstone member; this lens is about 35 feet thick in the vicinity of the mines but thins rapidly to the northeast. The micaceous vanadium clay mineral and carnotite are disseminated in thin-bedded sandstones. The ore bodies range from a few inches to 8 feet in thickness. They are lenticular, erratic, and spotty and seem to follow, in a general way, mudstone seams separating the thinly laminated sandstones.

Star No. 1 claim

A deposit on the Star No. 1 claim above Atkinson Creek occurs in the lower part of a 60-foot thick sandstone lense. Mineralization is similar to that in the Wright mines but is weak and spotty.

Other workings

Several small prospects are scattered along the outcrop of the Salt Wash sandstone member in the San Miguel River canyon and for a few thousand feet along the lower part of Atkinson Creek. These prospects contain only traces of mineralized material and no production has been recorded from them.

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LIST OF PATENTED CLAIMS (See Map.)

1. Star No. 1
2. All Stars
3. Star No. 3
4. Star No. 4
5. Star No. 5
6. Star No. 6
7. Thursday
8. Friday
9. Star No. 9
10. Star No. 10
11. Wright
12. Star No. 12
13. Little Basin
14. Raymond