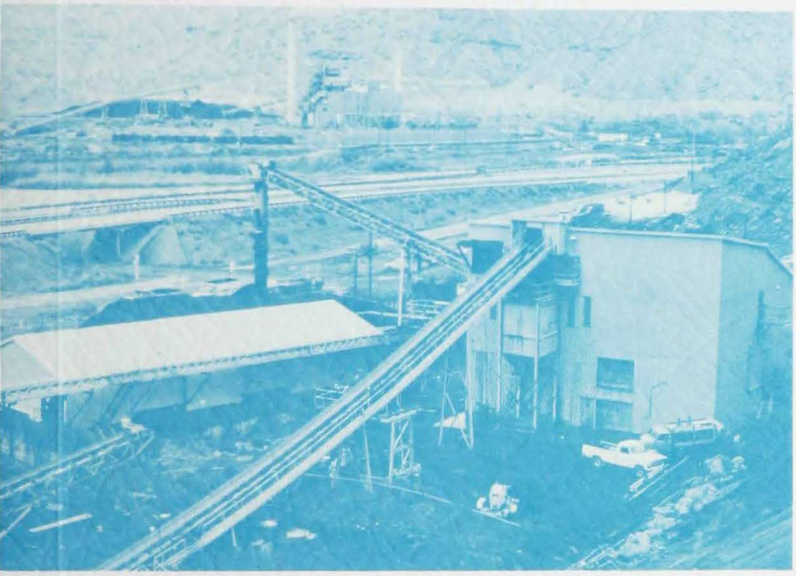
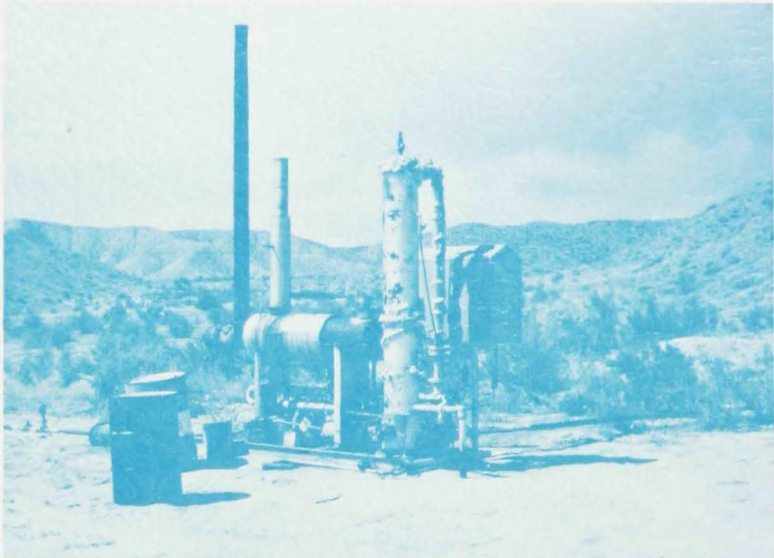
Resource Series 2

MINERAL RESOURCES SURVEY of
Mesa County
–A MODEL STUDY





by Stephen D. Schwochow
1978

COLORADO GEOLOGICAL SURVEY
DEPARTMENT OF NATURAL RESOURCES
DENVER, COLORADO

STATE OF COLORADO
1876

FRONT COVER (clockwise from top left):

The Principal Mineral Industries in Mesa County:

COAL--Tipple and washing plant at CMC (Roadside) Mine on the Colorado River near Cameo, Grand Mesa field, northeastern Mesa County)

NATURAL GAS--Typical gas well in Bar X field, northwestern Mesa County, Hancock East Bar X No. 1 in Prairie Canyon

URANIUM-VANADIUM--Ore-loading facility at Blue Creek Group mines, Gateway district of the Uravan mineral belt, southwestern Mesa County

GRAVEL--Plant site of Whitewater Building Materials Corporation on the Gunnison River at Whitewater, southeastern Mesa County

Mineral Resources Survey of

MESA COUNTY

A Model Study Prepared in Cooperation with the
Mesa County Development Department
Grand Junction, Colorado

compiled by
Stephen D. Schwochow

Colorado Geological Survey

RESOURCES SERIES 2

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INTRODUCTION

Mining and mineral resources have played significant roles in Colorado's history, culture, and economy for more than 100 years. For a long time the state enjoyed prominence as a major producer of gold, silver, and the base metals. Continued prominence in molybdenum and intensified development of its vast coal resources will maintain Colorado's position in the country's mining industry. In recent years both mining industry and state and local governments have realized that land-use coordination becomes a vital aspect of resource conservation, especially where mining, development, and political interests may conflict. This report is an outgrowth of that awareness.

History and Purpose of Project

In 1974 the Colorado legislature passed a controversial land-use law, House Bill 1041, which was designed to give local government control over such important land-use aspects as mineral resources, geologic hazards, flood plains, wildfire hazards, historical and archaeological resources, and key facilities. The bill first provided for the "identification" of such lands by the county and by several state agencies and secondly for the "designation" of the lands for control of development. In the area of mineral resources the law defined "mineral" as

> *"...an inanimate constituent of the earth, in either solid, liquid or gaseous state which when extracted from the earth, is usable in its natural form or is capable of conversion into usable form as a metal, metallic compound, a chemical, an energy source, a raw material for manufacturing, or construction material. This definition does not include surface or ground water subject to appropriation for domestic, agricultural, or industrial purposes, nor does it include geothermal resources."*

A "mineral resource area" was defined as

> *"...an area in which minerals are located in sufficient concentration in veins, deposits, bodies, beds, seams, fields, pools, or otherwise, as to be capable of economic recovery. The term includes but is not limited to any area in which there has been significant mining activity in the past, there is significant mining activity in the present, mining development is planned or in progress, or mineral rights are held by mineral patent or valid mining claim with the intention of mining."*

Other provisions regarding the designation of mineral resource areas (MRA) are listed in Appendix 1. The statutes include essentially all possible mineral resources with special exceptions for oil, gas, and geothermal resources. During the 4 years since the passage of this law, mineral resource inventories have been done in all or parts of 19 counties.

The involvement of the Colorado Geological Survey in mineral resource inventory dates from the time of the early Territorial Geologist and later State Geologist, who acted essentially in a consulting capacity to the state's budding mining industry. Most of the first Survey's published reports dealt with the geology and ore deposits in the metal-mining districts. Indeed, the creation of the Survey in 1907 included specific legislative charges-*"A study of the geological formations of the State with special reference to its economic mineral resources* and *"the preparation and publication of geologic and economic maps to illustrate the mineral resources of the State."*

Nearly all the reports of several interim agencies that succeeded the first Survey also were aimed at inventorying resources and assessing various sectors of the industry. When the Colorado Geological Survey was recreated in 1969, the legislature stated specific charges relating to mineral resources:

* promote economic development of mineral resources,

* inventory and analyze the state's mineral resources as to quantity, chemical composition, physical properties, location, and possible use,

* prepare, publish, and distribute reports, maps and bulletins when necessary to achieve these purposes.

Following the success of sand and gravel investigations for House Bill 1529 (1973), the Colorado Geological Survey, as a technical assistance agency, prepared several papers for the implementation of HB 1041. The first report, Special Publication 6 (1974), was a set of guidelines for the identification of MRA's and geologic hazard areas. This was followed by county mineral resource bibliographies (open-file report, 1975), a symposium proceedings (1977, Special Publication 8), and a model environmental geology study in the Redlands area near Grand Junction (1976, Map Series 5). A list of standardized mineral resource map symbols will follow the publication of this Mesa County study.

The purpose of the Mesa County mineral resources survey is twofold. First, as the hub of western slope development and energy activity, Mesa County and Grand Junction are in a favorable and timely position to incorporate basic resource information into their comprehensive land-use plans. The identification of resource areas and mining industry activities early in the land development cycle will help avert some of the problems that have plagued other growing metropolitan areas. Secondly, as the Survey's first model study on the county level, this inventory hopefully provides a format by which other counties may conduct their own surveys. In addition to covering a variety of mineral resources--metallics, nonmetallics, and mineral fuels--the inventory includes geologic structure, and exploration, mining, processing, and transportation facilities to round out the industrial picture. The mapping also is an experiment in the use of standardized map symbols and notation and in the use of the new 1:50,000-scale (1 inch = 0.8 mile) county format series topographic base maps being compiled for the State of Colorado by the U.S. Geological Survey.

This resource inventory evolved from the environmental study of the Redlands area (Hart, 1976), which included geology, geologic hazards, mineral resources, and relative permeability. The countywide study was initiated at the request of former Land Use Administrator, James Kyle. Most of the field work and office compilation was coordinated with County Land Use Administrator, W. James Clark. The county provided a fund of $1500 for drafting the six 1:50,000-scale resource maps.

Methods of Investigation

Much of this investigation is based on photogeologic interpretation of three sets of aerial photography: 1) AMS (1954-1955), scale approximately 1:63,000, 2) Mark Hurd quad-centered aerial photography (1972-1973), scale 1:80,000, and 3) Olympus Aerial Survey rectified air photos (1977). Basic geologic information, reports, maps, and analytical information were obtained primarily from literature published by Colorado Geological Survey, U.S. Geological Survey, and U.S. Bureau of Mines. Additional literature sources include technical journals, university periodicals and theses, and mining and geological association publications. Unpublished file information was obtained from Colorado Division of Mines, Colorado Oil and Gas Conservation Commission, Colorado Geological Survey, U.S. Bureau of Reclamation, Mesa County Development Department, and Colorado Division of Highways. Information compiled on the 1:24,000-scale basic-data maps was checked in the field during the summer and fall of 1977. At the same time a number of interviews were conducted with industry personnel, with state and local government agencies, and with many residents of Mesa County.

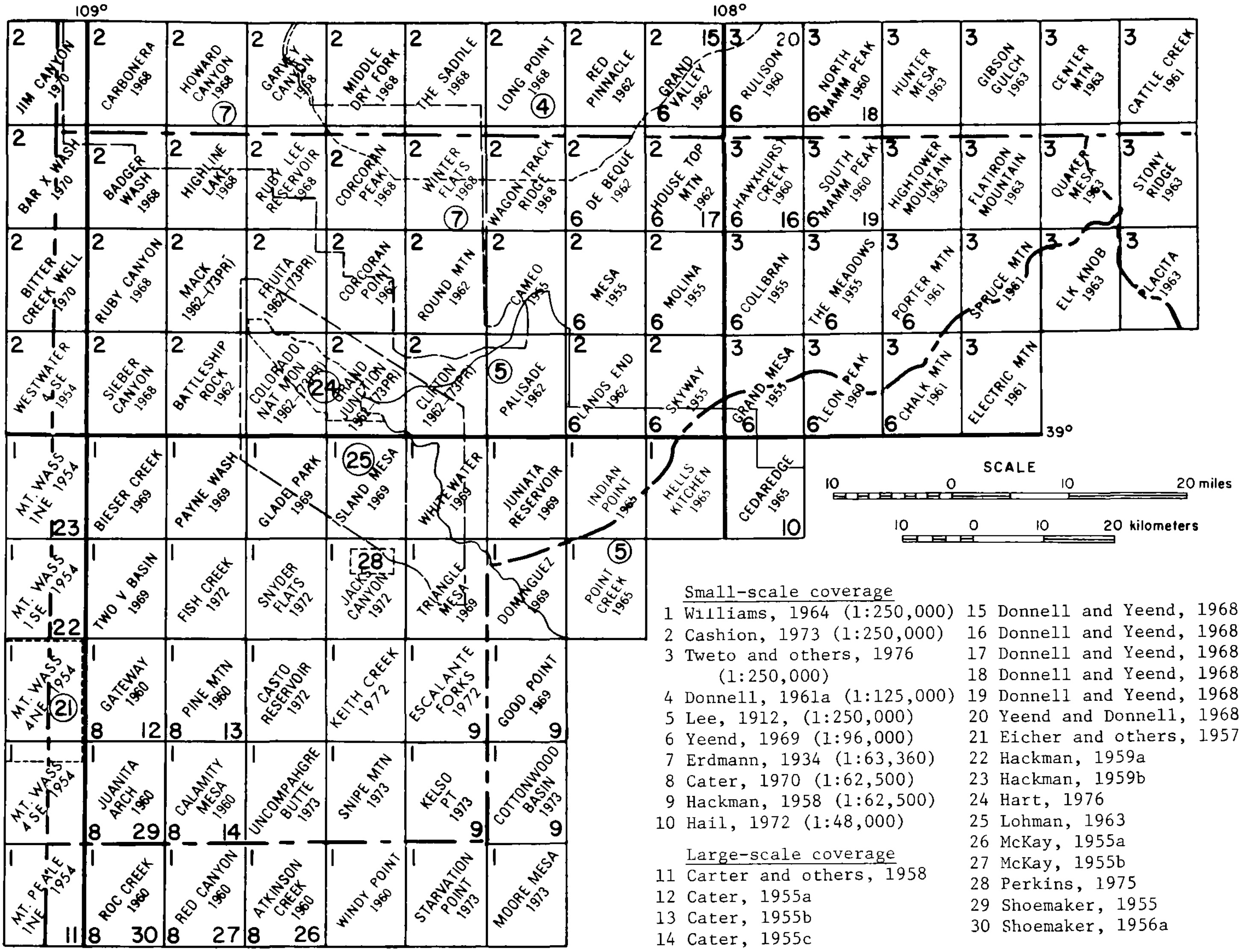
The principal products of this investigation include this formal report that accompanies the six 1:50,000-scale resource maps. Because these sheets are rather large and unwieldy, a 1:100,000-scale reduction (Plate 2) was prepared for publication with the text. Full-sized reproducibles of the six sheets will be kept on file at the Colorado Geological Survey in Denver and at the Mesa County Development Department office in Grand Junction.

Previous Studies

Until recently, no complete county mineral resource inventories had been done in Colorado. Although other state geological surveys have comprehensive, basic and economic geologic coverage at the county level, the early Colorado Geological Survey focused on detailed studies of specific mining districts and statewide inventories of particular commodities. Early federal government surveys of the western territories (Peale, 1876, 1877) were aimed at reconnaissance mapping, general stratigraphic correlation, and identification of important resource areas to be studied in detail later. On Figure 1, the index map of standard 7.5' topographic quadrangles, I have indicated the extent of important geologic mapping. The earliest detailed mapping evolved from the U.S. Geological Survey investigations of public coal lands (Lee, 1912; Erdmann, 1934) along the Book Cliffs and Grand Mesa. Interest in strategic uranium and vanadium in the 1940's and 1950's led to detailed geologic mapping in the Uravan mineral belt quadrangles in the southwestern corner of the county. Later areal studies focused on Tertiary oil-shale stratigraphy (Donnell, 1961; Donnell and Yeend, 1968), Quaternary geology (Yeend, 1969), and hydrologic preinvestigation (Lohman, 1963). The most recent studies have included a general structural and economic study (Cater, 1970), a graduate thesis study in the county's principal copper district (Perkins, 1975), and a model environmental geology study in Redlands (Hart, 1976). All of Mesa County is covered by three 1° x 2° AMS topographic sheets, the geology of which has been mapped by Williams (1964), Cashion (1973), and Tweto and others (1976). Reference to other reports will be cited in the appropriate commodity discussions.

Acknowledgments

In addition to all the people I have cited in the text, I would like to acknowledge contributions from the following: William L. Chenoweth, U.S. Department of Energy, Grand Junction; James Nelson-Moore and Donna B. Collins, Colorado Geological Survey; Robert Lucas, District 3, Colorado Division of Highways, Grand Junction; James Clark, Mesa County LUA; John Ballagh, Mesa Co. Development Dept.; Willard Phillips and Donald Clay, U.S. Bureau of Reclamation, Western Colorado Projects Office, Grand Junction; Ray Greb, Jr., Fruita Ready Mix Sand and Gravel; Thomas Baxter, Whitewater Building Materials Corporation; Frank Stivison, Continental Oil Co.; William Stanley, Rocky Mountain Natural Gas, Collbran; James Duckworth, Western Slope Gas Co.; J. William Fishback, Superior Oil Co., Englewood; Thomas Hess, Public Service Company, Cameo; and Thomas Ingwerson, Public Service Co., Grand Junction. I thank also the staff members of the Colorado Division of Mines and Colorado Oil and Gas Conservation Commission for their assistance in obtaining valuable file information. I wish to thank the following for their technical review of portions of the text: A. L. Hornbaker, Colorado Geological Survey; William L. Chenoweth, U.S. Department of Energy; William Tobey, Cotter Corporation, Lakewood; and Stanley B. Weil, Gary Western Refinery, Fruita. The final manuscript was prepared by Becky Andrews on the Wang mini-computer/word processor.



Small-scale coverage

1 Williams, 1964 (1:250,000)
2 Cashion, 1973 (1:250,000)
3 Tweto and others, 1976 (1:250,000)
4 Donnell, 1961a (1:125,000)
5 Lee, 1912, (1:250,000)
6 Yeend, 1969 (1:96,000)
7 Erdmann, 1934 (1:63,360)
8 Cater, 1970 (1:62,500)
9 Hackman, 1958 (1:62,500)
10 Hail, 1972 (1:48,000)

Large-scale coverage

11 Carter and others, 1958
12 Cater, 1955a
13 Cater, 1955b
14 Cater, 1955c
15 Donnell and Yeend, 1968a
16 Donnell and Yeend, 1968b
17 Donnell and Yeend, 1968c
18 Donnell and Yeend, 1968d
19 Donnell and Yeend, 1968e
20 Yeend and Donnell, 1968
21 Eicher and others, 1957
22 Hackman, 1959a
23 Hackman, 1959b
24 Hart, 1976
25 Lohman, 1963
26 McKay, 1955a
27 McKay, 1955b
28 Perkins, 1975
29 Shoemaker, 1955
30 Shoemaker, 1956a

FIGURE 1. Quadrangle index and status of geologic mapping in and around Mesa County. Numbers in quadrangles refer to the numbered list of abbreviated citations. See bibliography for complete references.

PART 1: MESA COUNTY OVERVIEW

GEOGRAPHY

Mesa County lies in the center of Colorado's westernmost tier of counties and takes its name from the high, rugged plateaus that characterize the western third of the state. Surprisingly, the county is fourth largest in the state in terms of its 3,312-sq-mi area, behind only Las Animas, Moffat, and Weld. Mesa ranks 10th in the state in population, as estimated for July 1, 1974 by the U.S. Department of Commerce. Colorado West Area Council of Governments estimated the 1977 county population at more than 66,800 and that of the seat, Grand Junction, at 25,400. The highest elevation in the county, 11,236 ft, is measured at Leon Peak, which lies at the eastern end of Grand Mesa, the county's most prominent and famous landmark. The lowest elevation, 4,300 ft, is measured on the Colorado River at Utahline siding, about 27 miles west of Grand Junction. Of the more than 2,000,000 acres of land, about 73 percent is public land controlled by the federal government, and the remainder private and municipal lands.

The Colorado River flows through the northwestern third of Mesa County and directly drains about 60 percent of the surface. The river's principal tributaries include Roan Creek, Plateau Creek, the Gunnison River, East Salt Creek, and West Salt Creek. The Gunnison River enters the county at the base of the panhandle and directly drains about 25 percent of the county's land. Its principal tributaries in this area include Escalante Creek, Big Dominguez Creek, Kannah Creek, East Creek, and Whitewater Creek. The Gunnison joins the Colorado River at Grand Junction, the city named for this prominent confluence at the time the Colorado was known as the Grand River. The Dolores River drains the remaining 15 percent of the county and joins the Colorado River about 25 miles northeast of Moab, Utah. The river's principal tributaries within the county include Blue Creek, Salt Creek, Maverick Creek, and West Creek.

Several major transportation routes provide convenient access into and through the county. Interstate 70 and U.S. 6 and 24 from Glenwood Springs enter the county at De Beque, pass through Grand Junction, and proceed westward into Utah. U.S. 50 comes northwestward from Delta and joins U.S. 6 in Grand Junction. Colorado 65 from Delta passes over Grand Mesa, through the town of Mesa, and westward to De Beque Canyon where it joins I-70. Colorado 139 traverses Douglas Pass and connects Loma with Rangley. Colorado 141 begins at Whitewater, traverses Unaweep Canyon to Gateway and south to Uravan, Nucla, Naturita, and Slick Rock. The Denver and Rio Grande Western Railroad also traverses the county, paralleling both the Colorado and Gunnison Rivers.

The semiarid climate, soils, and rainfall in the Grand Valley are conducive to a thriving fruit industry, one of the county's leading economies. In addition to tourism, farming and ranching, and manufacturing, the county also supports a prosperous mining industry, as we shall see in the following discussions.

GENERAL AND ECONOMIC GEOLOGY

The bedrock geology in Mesa County (Plate 1a) encompasses nearly the entire geologic time scale and includes representative rocks from the Precambrian and from the Late Paleozoic through the Late Cenozoic. Overlying the bedrock formations is a variety of interesting surficial, unconsolidated deposits of Quaternary or very latest geologic age. Much of the local stratigraphic section reflects well-known Colorado Plateau geology from the Upper Paleozoic continental clastic deposition flanking the Uncompahgre Plateau through the extensive Upper Jurassic and Lower Cretaceous coastal plain and shoreline deposits, into the Upper Cretaceous marine phase, and ultimately back to Upper Cretaceous and Lower Tertiary continental deposits.

Precambrian

The Precambrian or oldest rocks in the county are exposed entirely on the steep walls and valley floors along streams that dissect the Uncompahgre Plateau. This mass of ancient metamorphic and igneous rocks was eroded to an extensive plain when the ancestral Uncompahgre highland was uplifted in Late Paleozoic times. Upper Paleozoic and Triassic clastic sediments covered the erosional plain and progressively overlapped one another onto higher Precambrian slopes. The exhumation of this ancient surface is readily apparent in Colorado National Monument and Unaweep Canyon.

In addition to the complexly folded schists and gneisses that comprise the bulk of the Precambrian here, Perkins (1975) recognized younger granodiorite porphyry and granite that resemble similar rocks exposed in the Black Canyon of the Gunnison. Younger pegmatite and aplite dikes intrude the older rock masses.

Mineralized Precambrian veins in Unaweep Canyon, Big Dominguez Canyon, and the Coates Creek drainage have yielded copper, some silver, fluorite, and amethyst. The younger Curecanti-type granite in Unaweep Canyon has been quarried for dimension stone, and weathered coarse-grained granite elsewhere provides a usable road material.

Paleozoic

All the rocks of Late Paleozoic age (Pennsylvanian and Permian) exposed in Mesa County lie in Sinbad Valley and the Dolores River valley. The oldest sedimentary rocks, the Paradox Member of the Hermosa Formation, crop out on the floor of Sinbad Valley and consist of highly contorted gypsum, sandstone, limestone, and carbonaceous shale. A thick sequence of salt in this member lies at depth in the core of the Sinbad Valley anticline. The Paradox Member is a potential source of salt, potash, and oil and gas. The Late Pennsylvanian Rico Formation consists of red feldspathic sandstone, reddish-brown mudstone, and gray limestone but is exposed only in one small outcrop on the faulted eastern edge of Sinbad Valley.

The Permian Cutler Formation is well exposed on the lower slopes flanking the Dolores River around and below Gateway and up to 5 miles above Gateway along West Creek. In most places the formation dips gently to the southwest into the Dolores River syncline, but around the lower inner slopes of Sinbad Valley the beds dips away from the axis of the Sinbad Valley anticline. The colorful Cutler Formation consists of feldspathic sandstone, reddish-brown mudstone, and a maroon to purple conglomerate that contains pebbles of Precambrian lithologies derived from the adjacent Uncompahgre Plateau. The beds represent up to 8,000 ft of fanglomerate deposition that accompanied uplift of the ancestral Uncompahgre highland. The Cutler yields abundant coarse sand for road material.

Mesozoic

Formations of Mesozoic age crop out over most of the central, northeastern, and southern portions of the county and include some of the county's most colorful and scenic rocks. In the Dolores River valley the Lower to Middle(?) Triassic Moenkopi Formation overlies the Cutler and forms steep slopes and ledges south of Gateway, on the Palisade, and around Sinbad Valley. The lower member contains 200 to 220 ft of brick-red mudstone and sandstone; the middle member contains 100 to 250 ft of purple and reddish-brown conglomerate, feldspathic sandstone, and reddish-brown shale. The upper member, where present, attains a maximum thickness of 575 ft and consists of reddish-brown shale and sandstone. The only economic resource in the Moenkopi is a 6-ft gypsum bed at the base of the lower member.

The Chinle Formation, Late Triassic age, although widespread across the Plateau, is commonly obscured by talus from overlying sandstones. Over much of the Plateau the bright red shales, mudstones, siltstone, and sandstone rest directly on the eroded Precambrian and form a slope just below the base of the overlying Wingate Sandstone. The formation thickens from about 100 ft near Grand Junction to 120 to 300 ft at Gateway. In Unaweep Canyon the Chinle is mineralized with copper, fluorite, and gem-bearing veins.

The Triassic-Jurassic Glen Canyon Group includes, in ascending order, the Wingate Sandstone, Kayenta Formation, and Navajo Sandstone. Differential weathering of the massive Wingate and overlying thinner bedded Kayenta sandstones results in steep spires and ridges known as *monuments* the most spectacular of which are exposed in Colorado National Monument. The Wingate, a tan and gray, fine-grained sandstone ranges from 275 to 400 ft in thickness and, because of the sheerness of its cliffs, commonly forms reentrants and overhangs where large blocks have fallen away. In contrast, 90 to 300 ft of thin-bedded, flaggy Kayenta sandstone, siltstone, and shale overlie the Wingate and crop out over much of the northwestern end of the Uncompahgre Plateau. The Navajo Sandstone, a prominent, massively cross-bedded eolian sandstone, thickens to 260 ft southwestward from its featheredge exposures in Maverick Canyon east of the Dolores River. Both the Wingate and Kayenta have been quarried for building stone in Colorado National Monument and near Unaweep Canyon. In Sinbad Valley the lower Wingate contains copper mineralization.

The Carmel Formation, Entrada Sandstone, and Summerville Formation comprise the Middle to Late Jurassic San Rafael Group. The 10- to 90-ft-thick, tan and red Carmel siltstones, mudstones, and sandstones grade upward into eolian sandstones in the Entrada. Throughout the Colorado Plateau the orange, tan, and white Entrada Sandstone weathers into a picturesque, rounded but prominent ledge, commonly showing horizontal rows of pits on weathered surfaces. Variegated sand and silty shales in the 40- to 130-ft-thick Summerville Formation commonly form a steep, debris-littered slope just below the more resistant sandstones in the lower Morrison Formation. Regarding resource potential, the Entrada Sandstone hosts uranium and vanadium mineralization in some areas of the Colorado Plateau but is essentially barren in Mesa County.

The Morrison Formation crops out over a large percentage of the Uncompahgre Plateau and is especially important regionally within the Uravan mineral belt. The lower Morrison, known as the Salt Wash Member, stands out as a series of resistant ledges, consisting of tan, white, and gray sandstone with shale, mudstone, and locally some gray lenticular limestones. The most important uranium and vanadium deposits are found in the upper sandstone layers of this 100- to 350-ft-thick member. The upper or Brushy Basin Member contrasts the lower member with 320 to 450 ft of red, blue, and green bentonitic shale and mudstone and lenses of conglomerate, sandstone, and limestone. Brushy Basin exposures appear in subdued, rounded slopes, occasionally littered with debris from the overlying Burro Canyon and Dakota Formations. In addition to the valuable metallic deposits, the Morrison yields bentonitic clay, dinosaur bones, petrified wood, and fieldstone.

Formations of Cretaceous age comprise the thickest section of Mesozoic rocks in Mesa County. Resistant sandstone ledges in the Lower Cretaceous Burro Canyon Formation overlie the more easily erodible Brushy Basin Member and usually form long or broad dipslopes. The Burro Canyon's composite of sandstone, green and red shales and siltstones, and locally a basal conglomerate varies from a few to 200 ft in thickness. The Dakota Sandstone is the youngest sedimentary formation capping the Uncompahgre Plateau, and it, with the Burro Canyon, forms a prominent series of dipslope mesas extending along the northeastern flank and around the northwestern end of the uplift. From Orchard Mesas northeast to Devils Canyon, the Dakota and Burro Canyon cap a low bluff line where the Colorado River has eroded into the gently dipping strata near their contact with the overlying Mancos Shale. Young (1959, 1960) divided the Dakota Group into an inland and flood-plain facies (Cedar Mountain Formation) and a lowland and coastal plain facies (Naturita Formation). The basal conglomerate and channel sandstones of the Cedar Mountain grade laterally into the gray, carbonaceous shales, coals, and marine sandstones of the Naturita. Both the Burro Canyon and Dakota are sources of fieldstone in the Grand Junction area, but the Dakota has historically been a source of coal, natural gas, and road materials, and contains potentially economic clay beds.

Nearly 4,000 ft of Upper Cretaceous Mancos Shale underlies Grand Valley and is best exposed above Government Highline Canal and on the slopes of the Book Cliffs where it is upheld by Mesaverde sandstones. The Mancos essentially is an olive-gray to black marine shale with a few thin sandstones and yellow-brown concretionary zones. At its base the shale interfingers with upper Dakota lithologies and indicates the initial transgression of the great inland sea. At the top of the shale the regression of the sea is revealed by the interfingering with the lower Mesaverde. Economic products from the Mancos Shale include brick clay and natural gas.

Rocks of the Mesaverde Group, which includes the Mount Garfield and Hunter Canyon Formations, form the spectacular Book Cliffs that mark the southern boundary of the Roan Plateau. Prominent ledge-forming beach sandstones, coals, and lagoonal deposits in the Mount Garfield interfinger with the regressing Mancos Shale from west to east along the face of the cliff. Eventually the entire 970- to 1,100-ft-thick section becomes dominated by lower coastal plain sediments and finally the massive, cliff-forming continental sandstones of the Hunter Canyon Formation, which attains thicknesses between 375 and 1,400 ft. These two formations, as undivided Mesaverde, continue south of the Colorado River into Delta County and form steep slopes around the base of Grand Mesa. The lower and middle sections of the Mount Garfield Formation contain important bituminous and subbituminous coals in the Book Cliffs and Grand Mesa fields. Other portions of the Mesaverde Group are sources of natural gas in fields near De Beque and in the Plateau Creek valley.

Cenozoic

Paleocene and Eocene rocks overlie the Upper Cretaceous section over most of the county's eastern panhandle. Red, gray, and brown sandstones and siltstones, and variegated shales in the Paleocene-Eocene Wasatch Formation are well exposed in the upper Colorado River valley and Plateau Creek valley, and on highly erodible and failure-prone slopes around Battlement Mesa and Grand Mesa. Locally the 300- to 1,500-ft-thick Wasatch section includes a basal conglomerate known as the Ohio Creek Formation.

The Green River Formation covers a very large portion of northwestern Colorado, northeastern Utah, and southwestern Wyoming and represents fine-grained sediment deposition in great inland lakes that covered much of the area in early and middle Eocene times. The distinctive gray, brown, and yellowish-brown limestones, shales, marlstones, sandstones, and siltstones form steep slopes and prominent cliffs on the Roan Plateau and the higher slopes around Battlement Mesa and Grand Mesa. Toward the southern edge of the Piceance Creek Basin the Green River thins and eventually disappears on the west side of Grand Mesa. Up to 1,000 ft of siltstone, sandstone, and marlstone in the Uinta Formation (formerly a part of the Green River) are preserved on top of Battlement Mesa, but much less is preserved under the caprock on Grand Mesa.

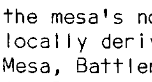
The Wasatch Formation is a source of natural gas and local road and borrow materials and has yielded important mammalian fossils useful in stratigraphic studies. The Green River Formation is best known for huge reserves of shale oil, mostly in Garfield and Rio Blanco Counties. Potentially economic oil shales underlie Battlement Mesa and part of Grand Mesa.

Thick Miocene to Pliocene basalt flows that cap Grand Mesa originated from east-west-trending feeder dikes in easternmost Mesa County and northwestern Gunnison County. Small remnants of the lava flows are preserved on top of Battlement Mesa. Presumably the Grand Mesa flows originally filled old stream valleys, but the softer sedimentary rocks have been eroded away, leaving the basalt preserved as a mesa. The 800-ft-thick sequence of flows is an excellent source of crushed stone, road material, and building and decorative stone. The vesicular zones of the flows also contain numerous zeolite minerals.

The youngest deposition in Mesa County is represented by many surficial sediments of Quaternary age. Glaciers that covered Grand Mesa during the Ice Ages deposited sand, gravel, silt, and clay in moraines on the mesa and in till and outwash across the mesa's northern slopes. Alluvial fans containing locally derived sediment flank the slopes of Grand Mesa, Battlement Mesa, and the Book Cliffs. Along the Dolores, Gunnison, and Colorado Rivers, floodplain and terrace gravels contain both local lithologies and igneous and metamorphic rocks carried in from the San Juan Mountains and from other headwater ranges in central Colorado. Quaternary sands and gravels are extensively used for concrete and bituminous aggregates, other road materials, and decorative stone.

PHYSIOGRAPHY AND STRUCTURE

The physiography or form of surface features in Mesa County directly reflects the geologic structure of the strata and the relative resistance of the beds to erosion and weathering. Plates 1b and 1c show the principal physiographic divisions and structural features in Mesa County. The names of a number of physiographic features correspond to well-known geographic names, but I have introduced other informal names to facilitate the discussions throughout the report.

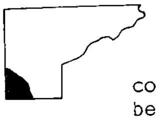


The most extensive single landform in the county is the Uncompahgre Plateau, a 3,500-sq-mi dome-shaped plateau extending from Grand County, Utah, over 100 miles southeast through Mesa and Montrose Counties, and into northwestern Ouray County. Paleozoic and Mesozoic sedimentary rocks that cover most of the plateau dip gently away from the main axis of the Uncompahgre Uplift, which parallels the Gunnison-Dolores drainage divide south of Unaweep Canyon and extends northwest to the Little

Dolores River near the state line. Along the southwestern and northeastern margins of the uplift, faulted monoclines parallel the main axis and locally steepen the strata. Several faults and monoclines in the brilliant red Triassic formations are magnificently exposed in deep canyons on the northeastern limb of the uplift in and near Colorado National Monument. The entire uplift appears somewhat asymmetrical in cross-section, with the Uncompahgre monocline (southwest) lying much closer to the main axis than the monoclines on the northeast.

The gradual domal uprising of the plateau is readily detectable from most places in Grand Valley and along U.S. 50 southeast of Grand Junction. The land rises to a high point elevation of about 9,760 ft on the Gunnison-Dolores divide and surprisingly exhibits a total relief of about 4,900 ft. Streams tributary to the Colorado, Gunnison, and Dolores have deeply dissected the uplifted surface of the plateau and created steep slopes, deep canyons, and rugged topography. In any one area, tributary streams that flow parallel to each other typically form long, interstream mesas and *flats*, which essentially are dipslopes of resistant Burro Canyon and Dakota Formations. Occasionally the action of ancestral streams and contemporaneous mass-wasting reduced an interstream-divide mesa to a long sharp ridge known as a *point*. Where several side canyons have penetrated a divide mesa, *breaks* have formed. A *bench* forms on long landslide complexes or where an intermediate step below the mesa top has developed at the expense of a more easily erodible rock layer, usually a shale. A *park* results when weak rock units are eroded away over a larger area at present stream level, usually on the obsequent slopes of a broad mesa. Parks often contain islands or remnants of more resistant overlying beds. Hogbacks in the Burro Canyon and Dakota can be seen wrapping around the northwestern end of the plateau where the dipping beds reflect the plunging anticlinal nose of the uplift. Other impressive features at this end of the plateau include Ruby and Horsethief Canyons that were deeply incised by the Colorado River along its course from Grand Valley into Utah.

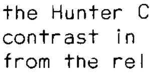
A spectacular topographic anomaly known as Unaweep Canyon crosses the Uncompahgre Plateau nearly at a right angle to the axis of the uplift. Most of the geologic section from Precambrian through Lower Cretaceous can be seen on the canyon walls that rise more than 2,500 ft above the valley floor. East Creek and West Creek drain the canyon in opposite directions away from a subtle drainage divide just below Snyder Flats. These two underfit streams, flowing in an apparently oversized canyon, and the composition of terrace gravel remnants support the theory that Unaweep Canyon actually was created by the ancestral Gunnison River, which later was diverted out of the canyon.



The Paradox Basin covers about 11,000 sq mi in the Four Corners region, and its northeasternmost component, the Paradox fold and fault belt, abuts the Uncompahgre Plateau a few miles northeast of Gateway. I have divided Mesa County's portion of the basin into the Dolores River valley and Sinbad Valley. The 1,000-ft-deep canyon of the Dolores River separates a series of deeply dissected mesas exhibiting as much as 2,000 ft of local relief. A topographic profile across the valley reveals three prominent and successively higher cliff lines. The lowest cliff, closest to the river, is upheld by the massive Wingate Sandstone. Proceeding away from the river, one encounters an intermediate cliff supported by the Entrada Sandstone and thick sandstones of the Salt Wash Member of the Morrison Formation. A third cliff line is formed by the Burro Canyon Formation, which caps most of the mesas flanking the river valley. North of Gateway at the edge of the plateau, nearly all the sedimentary section has been eroded away. Rising above the deeply dissected slopes of Cutler Formation, however, the precipitous topographic sentinel known as The Palisade towers to more than 2,400 ft above Gateway.

Structurally, the Dolores River crosses the Dolores River syncline, a shallow fold that trends from southeast to northwest parallel to the axis of the Uncompahgre Uplift. West of Gateway the Sagers Wash syncline extends into Utah along the same trend as the Dolores River syncline.

Gently dipping beds on the southwest limb of the Dolores River syncline become the northeast limb of the Sinbad Valley-Fisher Valley anticline, a salt anticline that reflects the overall northwestward trends of the Paradox fold and fault belt. Unlike the core of the Uncompahgre Plateau and Uplift, the Sinbad Valley anticlinal core is a topographic low--the more resistant capping formations have been eroded away to expose the complex evaporite beds in the Paradox Member. Triassic and lower Jurassic formations dip away from the fold axis in a spectacular 1,300- to 2,000-ft-high cliff sequence that completely encircles the valley. A complex system of normal faults also encircling the inner valley walls has downdropped large blocks of the cliff-forming strata. Salt Creek, which drains Sinbad Valley, breaches the northeastern wall of the valley and joins the Dolores River 4 miles downstream. Salt Creek itself flows down the center of the Salt Creek graben, a 3.5-mile-long downdropped block oriented normal (perpendicular) to the Sinbad Valley anticline.



The Colorado River flows through three contrasting terrains along its course between De Beque and the Utah state line. In the first stretch of the river valley, extending from the Garfield County line to the mouth of the canyon just east of Palisade, the river widened its valley at the expense of the relatively easily erodible Wasatch Formation. Upon entering De Beque Canyon the river crosses the Wasatch-Hunter Canyon contact where it has eroded a 500- to 800-ft-deep canyon in the Hunter Canyon's resistant sandstones.. Thus the contrast in valley width and form arises directly from the relative resistance of the different rock strata. The canyon at most attains a width of 2,500 ft, compared to a maximum width of 2 miles near De Beque.

At the mouth of the canyon east of Palisade the river enters Grand Valley, the most important area of the county in terms of development, agriculture, and economy. Grand Valley is bounded by the Book Cliffs on the northeast and by the Uncompahgre Plateau on the southwest and averages 12 miles in width. The entire valley is underlain by easily erodible Mancos Shale over which most of the valley development has taken place. Both valley boundaries mark the transition of the Mancos into more erosion-resistant sandstones that form the Book Cliffs (Mesaverde Group) and the low bluff line south of the river (Dakota Group).

Upper Grand Valley lies between the base of the Book Cliffs and Government Highline Canal. This strip of nonirrigated land is characterized by several levels of long, deeply dissected alluvial fans deposited by dry washes that drain the cliff front. Up to 200 ft of relief can be seen along the base of the cliffs. Along the fan edges the deeply weathered but resistant gravels uphold moderate to steep slopes in the underlying Mancos Shale.

The marked change in topography south of Government Highline Canal is due to an important change in geology that one cannot directly discern by looking at the surface. Well logs show that much of Lower Grand Valley is underlain by a thick fill of gravel deposited in ancient courses of the Colorado River and that now is covered by a very thick apron of silt and clay derived from erosion of the Mancos Shale in Upper Grand Valley. Both the original gravel deposition and later alluvial cover tended to subdue the topography, which in very latest times has been locally modified further by extensive farming. South of Loma the river leaves Lower Grand Valley and flows through deep canyons carved into the northwestern end of the Uncompahgre Plateau.

A fourth subdivision of the river valley, the Orchard Mesas, lies on the south bank of the river between Palisade and Grand Junction and supports many of the county's important fruit orchards. Several levels of river terraces on the 0.5- to 2-mile-wide belt are separated by irrigation canals or subtle topographic breaks.

The Roan Plateau lies south of the White River, covers most of Rio Blanco and Garfield Counties, and terminates along the Colorado River in Mesa County. The entire plateau forms an impressive skyline along the northern edge of Grand Valley in Colorado and Utah. The plateau abruptly terminates on an extraordinary escarpment known as the Book Cliffs. Much of the 1,300- to 1,600-ft-high cliff line is composed of Mancos Shale held up by massive resistant sandstones of the coal-bearing Mesaverde Group. Upon entering Grand Valley from the east, one immediately sees Mount Garfield, a 1,900-ft-high protuberance from the cliff. Behind Book Cliffs lies a series of ridges and flats formed in the Hunter Canyon, Wasatch, and Green River Formations. As much as 2,000 ft of total relief are exposed on South Shale Ridge, the southeasternmost of several ridges capped by the cliff-forming Green River Formation. Other high rugged cliffs, a southwestward continuation of the Roan Cliffs, lie north of Corcoran Wash and South Dry Fork.

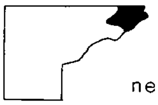
Structurally the beds at this end of the Roan Platau dip gently to the northeast into the Piceance Creek Basin and also reflect the northeast limb of the Uncompahgre Uplift. Mesaverde Group rocks locally steepen across the Book Cliffs monocline, and several other subsurface folds parallel the general northwest-to-southeast trends in the area.

Grand Mesa and Battlement Mesa, the highest landmarks in Mesa County, are situated between the Roan Plateau and the Elk and West Elk Mountains--all topographically high elements within the structural Piceance Creek Basin. Plateau Creek, which drains the county's eastern panhandle, separates the two mesa provinces. I have subdivided each of the provinces into an Upper Bench, Lower Bench, Lower Mesas, and in the case of Grand Mesa, Glaciated Valleys. The high elevations of the mesas are due to the thick accumulations of Tertiary sediments that are overlain and protected by thick basalt flows. Actually, at the time of its deposition, the basalt flowed into preexisting drainages. Since late Tertiary time the less resistant sedimentary rocks eroded away, leaving the basalt flows as a mesa top--Grand Mesa proper (Upper Bench). On the north side of Grand Mesa, the Lower Bench is principally a series of high landslides that occurred as the basalt oversteepened the slopes in the weaker underlying strata. At the east end of the mesa landsliding has reduced the flows to a high knife-edged ridge known as Crag Crest, a popular hiking site in Grand Mesa National Forest. Leon Peak, the highest point in the county, is a remnant of the flow that has become isolated by the extensive landslides in the Lower Bench. On the eastern side of Grand Mesa the Lower Bench is upheld primarily by the resistant Mesaverde Group sandstones, which are partly overlain by glacial debris and landslides (of Wasatch). In both cases the transition into the Lower Bench is marked by steep, thickly vegetated slopes and cliffs. The Lower Mesas around the west end of Grand Mesa are characterized by enormous alluvial fans on the west and southwest and by bedrock dipslopes on the northwest.

Glaciers formed on and moved across Grand Mesa during the Quaternary ice ages. Basaltic glacial debris was deposited in ridges known as *terminal* and *recessional moraines* that were left on the mesa top as the glaciers advanced and retreated. These 20- to 40-ft-high moraines pleasantly interrupt the rather monotonous flat topography on the mesa top. In the case of Kannah Creek, a glacier actually moved down over the cliff and left a continuous terminal moraine across both lobes of the mesa and the intervening Kannah Creek valley.

The northern slopes of Grand Mesa below the Lower Bench are characterized by broad till-filled valleys separated by ridges and rounded hills of Wasatch Formation. Glaciers that moved down these valleys disrupted preexisting drainage and often split the ancestral stream into two streams that ultimately developed at the outer margins of the glacial valley fill. The glacier that moved down the Park-Leon Creek valley actually dammed up Plateau Creek and created a lake on the present site of Vega Reservoir. This same glacier supposedly extended farther down Plateau Creek and formed The Peninsula, a long fingerlike body of glacial till and alluvium that separates Plateau Creek and Buzzard Creek.

The physiography of Battlement Mesa is similar to that of Grand Mesa but slightly less pronounced. The original basalt flow that capped the mesa has been reduced by landsliding to three or four pointed remnants, including North Mamm and South Mamm Peaks. Thus, the Upper Bench includes the basalt flow remants and most of the landslide topography. The Lower Bench consists of rugged, deeply eroded and oversteepened lower members of the Green River Formation. The Lower Mesas are confined to the northwestern and southwestern slopes and appear, respectively, as high, broad alluvial fans adjacent to the Colorado River and faulted Wasatch dipslopes above Plateau Creek.



Upper Plateau Creek, West Divide Creek, and East Divide Creek, which drain the extreme northeastern corner of the county, have developed a low mountainous topography in the Wasatch Formation, although Mesaverde Group rocks are exposed in a small anticlinal *range* extending from Little Rock Creek and Mosquito Mountain northwest to Uncle Bob Mountain (Garfield County). The stream valleys terminate at the county line on a sinuous divide that in a few places, such as Oil Well Mountain, exceeds 10,000 ft in elevation. The principal structures here, the Divide Creek anticline and an unnamed monocline parallel to West Divide Creek, generally reflect fold trends associated with the Elk Mountains and White River uplifts to the east and northeast, respectively.

To summarize, the physiography or land features in Mesa County directly reflect different rock types and structural attitudes. The varying degrees to which different lithologies resist the erosive forces of water, ice, and wind are manifested in the county's diverse and often dramatic landforms. Although certain geologic structures are invisible or, at best, subtle to the ground observer or photogeologist, they can profoundly affect both the physiography and more importantly the occurrence of certain mineral resources. To a certain extent, the intimate relationship among geology, structure, physiography, and processes can be used to predict some mineral occurrences and favorable exploration areas. In the commodity discussions that will follow, I will discuss in detail some of these interesting relationships.

MINERAL RESOURCES

Since the first reported production of 300 tons of coal in 1888, Mesa County has exported a variety of mineral products--from strategic metals such as uranium and vanadium, to such vital mineral fuels as coal and natural gas, to society's basic construction materials of gravel, stone, and clay. In addition to these principal commodities, other metal-bearing areas have yielded copper, silver, and gold and even reports of titanium, beryllium, and chromium. Mineral fuels, although dominated by natural gas and coal, include minor petroleum production and potential oil shale. The most important nonmetallics currently being produced include sand and gravel, crushed stone, decorative and building stone. In addition to brick clay, gypsum, and mica that were mined in previous years, the county contains potentially economic fluorspar, salt, and limestone. Other *popular* resources include gemstones, mineral specimens, and assorted fossils.

Processing facilities are important components of the county's mining industry, even though some of the materials processed do not themselves occur within the county. In addition to the local ready-mix and bituminous aggregate plants, and petroleum and gasoline storage sites, the county processes such imported commodities as crude oil, clay, insulation materials, and gilsonite. Several abandoned uranium-vanadium mills once received ore from the Uravan mineral belt. As will be shown, these diverse processing industries round out the total mineral industry picture for Mesa County.

The total value of mineral production from Mesa County (Table 1) has fluctuated greatly in recent years, reaching a 1967 peak of nearly $12 million, which ranked the county sixth in production value in the state. The low point of $2.5 million in 1972 has been followed by an increase of more than 100 percent, a rise that likely will continue in future years, based on renewed interest in coal, natural gas, and uranium. Although Mesa County's rank in terms of production value has dropped considerably since 1967, a reverse trend is indicated and shows that as its annual production increases, rank within the state also improves, meaning that Mesa County is more than holding its own compared to other counties.

In the next three sections of this report, I have attempted to structure the commodity discussions with detailed outlines of the physiography, structure, and geology of the occurrence areas, followed by production history and analysis (when valid), and mining and processing activities. For the more important resources I have given indications of the future mining development potential and certain land-use aspects that should be considered for county planning.

TABLE 1. Comparison of annual Mesa County mineral production value to Colorado total (values from Colorado Division of Mines annual reports).

Year	Mesa County	Colorado	Percent State Total	Rank in State
1963	$ 5,073,636	$340,878,270	1.5	15
1964	8,263,940	338,012,523	2.5	11
1965	9,134,828	345,377,001	2.6	9
1966	10,200,791	366,282,151	2.8	9
1967	11,949,588	371,210,704	3.3	6
1968	*11,739,883	376,736,257	3.1	7
1969	6,210,010	357,207,547	1.7	14
1970	5,867,032	371,883,497	1.6	18
1971	5,013,595	376,389,497	1.3	20
1972	2,536,116	406,297,848	0.6	30
1973	3,344,866	626,747,156	0.5	29
1974	4,016,176	697,993,220	0.6	29
1975	4,066,900	820,784,561	0.5	28
1976	5,767,588	981,889,648	0.6	25
1977	11,164,804	1,199,334,609	0.9	23

* includes reported $10,856,883 plus an estimated $883,000 from 6,403,817 Mcf natural gas production not reported in CDM 1968 annual report.

PART 2. METALLICS

INTRODUCTION

A surprising variety of metal-bearing minerals occurs in Mesa County, an area outside what is traditionally known as the Colorado mineral belt. Aside from the well-known uranium and vanadium district near Gateway, the county has produced other base and precious metals, among which copper dominates. Gold and silver round out the production picture, with reported occurrences of molybdenum, titanium, and beryllium. With only several exceptions, all the reported metallic production has come from three areas in the Colorado Plateau province (Plate 1b)--Unaweep Canyon, Dolores River Valley, and Sinbad Valley, all of which differ greatly in physiography, geology, and structure.

Table 2 gives the reported production of copper, silver, gold, and lead in the county. Copper heads the list with a cumulative production of nearly 57,000 lb. Silver follows with 6,265 oz and gold with 387 oz. These three metals account for a cumulative value of slightly over $17,000.

COPPER

Unaweep District

A. C. Peale noticed copper-bearing veins in Unaweep Canyon over 100 years ago during the government's early geological surveys of the western territories (Peale, 1877). Corregan and Lingane (1883) noted "new" copper discoveries there and briefly described claims that showed copper, silver, and gold. Although a brief note on the Unaweep ores was given by Emmons (1905), B. S. Butler (1915) made the first detailed description of the district's geology and ore deposits. The most recent work is a thesis by Perkins (1975), on which most of this discussion is based.

Geology and Geography

Unaweep mining district (Plate 2) lies 10 to 14 miles southwest of Whitewater on Colorado 141 near the east end of Unaweep Canyon, which was once an ancient course of the Gunnison River. Precambrian schists and granite form the prominent lower bench that rises 240 to 360 ft above the alluvium-covered valley floor of East Creek. The top of the bench closely approximates the contact between the Precambrian and the Triassic Chinle Formation and represents reexcavation of an ancient erosion surface. The base of the second bench, located back from the lower bench, consists of Chinle Formation overlain by the massive Wingate Sandstone, rising an additional 300 ft above the valley bottom.

Four rock types comprise the Precambrian in Unaweep Canyon. The oldest rocks in this sequence consist of schist and gneiss, complexly folded metamorphic rocks that are found mostly as large inclusions within younger intrusive igneous rocks. The next younger rock type, the Vernal Mesa-type granodiorite porphyry, consists of conspicuous microcline-feldspar phenocrysts in a medium-grained groundmass of quartz, feldspar, and biotite. The Curecanti-type granite is a light-gray medium-grained granite containing inclusions of older rocks. The Vernal Mesa- and Curecanti-type igneous rocks resemble their namesakes exposed in the Black Canyon of the Gunnison. The fourth type are pegmatite and aplite dikes that transect the older igneous rocks in a west-northwest direction. Pegmatites consist of distinctly coarse-grained quartz, muscovite, microcline, and plagioclase; aplites are similar in composition but much finer grained than the pegmatites.

Rocks of Cambrian or Ordovician age include diabase dikes--dark greenish-black, dense, fine-grained igneous rocks composed of plagioclase feldspar and hypersthene, with some magnetite and quartz. The vertical dikes trend from N60°W to N65°W and vary from a few feet up to 200 ft in width. They too resemble Cambro-Ordovician dikes exposed in the Black Canyon.

The ancient Uncompahgre highland was exposed to erosion during Pennsylvanian and Permian times, and part of the Precambrian and any younger sedimentary rocks overlying it were removed. During Triassic times, the bright red siltstones of the Chinle and the thick massive Wingate sands were deposited on the eroded Precambrian surface that is now being exhumed as the top of the lower bench.

Structurally the Unaweep district lies on the northeastern flank of the Uncompahgre Uplift and just south of the northeastern monocline belt. The Chinle and other sedimentary rocks dip gently to the northeast. Prominent vertical faults and fractures, some traceable for several miles, cross the district at N55°W to N65°W and cut both the Precambrian and younger sedimentary rocks. A second system of faults and fractures south of the district trends about N45°E to N60°E. The character of the principal faults changes from a narrow, brecciated and silicified zone at Taylor Ranch to a 100-ft-wide brecciated zone in the fault northeast of the Grant Ranch.

Mineral Deposits

Mineral deposits in the Unaweep district are found under two different structural and stratigraphic conditions. In the first, mineralized veins lie between diabase dikes and the intruded granite. Principal vein minerals include malachite [$Cu_2(OH)_2CO_3$] and azurite [$CU_3(OH)_2(CO_3)_2$], which are secondary copper carbonate minerals, quartz and calcite, with lesser amounts of chalcopyrite [$CuFeS_2$], galena [PbS], fluorite [CaF_2], barite [$BaSO_4$], and hematite [Fe_2O_3]. Perkins believes that most of these veins are not important economically. Below the Last Chance Mine he reports mineralized gneiss and schist that assayed 1.4 percent lead, 1.3 percent copper, with traces of zinc, molybdenum, gold, and silver.

Colorless and light green fluorite and quartz comprise many of the veins in the sedimentary rocks. A conspicuous intergrowth and zonation of these two minerals normal to the vein walls was seen in a fracture on the hillside east of the Nancy Hanks shafts. In addition to the major veins, the quartz, with traces of amethyst and smoky quartz, also fills small veins and vugs and often replaces vein breccia fragments.

Development

Copper veins in the Unaweep district were first noted in the 1870's, and the first development probably

TABLE 2. Mesa County metals production (exclusive of uranium and vanadium)

	Gold				Silver				Copper					Cumul.
		Cumul.	Value	Cumul.		Cumul.	Value	Cumul.		Cumul.	Value	Cumul.	Total	Total
Year	oz	oz	$	$	oz	oz	$	$	lb	lb.	$	$	$	$
1897	-	41.6	859	859	-	7	4	4	-	-	-	-	-	863
1898	8	49.6	165.36	1024.36	20	27	11.65	15.65	-	-	-	-	177.01	1,040.01
1899	6	55.6	124.02	1148.38	4120	4147	2454.70	2470.35	4650	4650	818.87	818.87	3397.59	4,437.60
1900	6	61.6	124.02	1272.40	511	4658	313.80	2784.15	2150	6800	355.18	1174.05	793.00	5,230.60
1901	99	160.6	2046.33	3318.77	155	4813	91.37	2875.52	7795	14,595	1290.46	2464.51	3428.16	8,658.76
1902	26	186.6	537.42	3856.19	32	4845	16.69	2892.21	15,000	29,595	1783.05	4247.56	2337.16	10,995.92
1903	17	203.6	351.39	4207.58	8	4853	4.28	2896.49	-	29,595	-	4247.56	355.67	11,351.59
1904	12	215.6	248.04	4455.62	9	4862	5.15	2901.64	-	29,595	-	4247.56	253.19	11,604.78
1905	25	240.6	516.75	4972.37	11	4873	6.64	2908.28	-	29,595	-	4247.56	523.39	12,128.17
1906	103	343.6	2129.01	7101.38	697	5570	465.53	3373.81	6000	35,595	1156.68	5404.24	3751.22	12,479.39
1912	0.43	344.03	8.89	7110.27	257.46	5827.46	156.63	3530.44	7287	42,882	1185.30	6589.54	1351.71[3]	13,831.10
1913	31.38	347.168	64.86	7175.13	1.39	5828.85	0.83	3531.27	-	42,882	-	6589.54	65.69	13,896.79
1927	-	347.168	-	7175.13	81	5809.85	46	3577.27	893	43,775	117	6706.54	163	14,059.79
1928	-	347.168	-	7175.13	29	5938.85	17	3604.27	1202	44,977	173	6879.54	190	14,249.79
1932	1.98	349.148	41	7216.13	-	5938.85	-	3604.27	-	44,977	-	6879.54	41	14,290.79
1933	1.74	350.888	36	7252.13	-	5938.85	-	3604.27	-	44,977	-	6879.54	36	14,326.79
1934	15.02	365.908	525	7777.13	164	6102.85	106	3710.27	5000	49,977	400	7279.54	1031	15,357.79
1935	17	382.908	595	8372.13	4	6106.85	3	3713.27	-	49,977	-	7279.54	598	15,955.79
1936	4	386.908	140	8512.13	14	6120.85	11	3724.27	1000	50,977	92	7371.54	243	16,198.79
1937	-	386.908	-	8512.13	40	6160.85	31	3755.27	1400	51,377	169	7540.54	200	16,398.79
1940	-	386.908	-	8512.13	45[1]	6205.85	32	3787.27	3200[2]	54,577	384	7924.54	416	16,814.79
1942	-	386.908	-	8512.13	59	6264.85	42	3829.27	2100	56,677	254	8178.54	296	17,110.79

[1] estimated at $0.71/oz

[2] estimated at $0.12/lb

[3] includes 20 lb of lead valued at $0.89

took place around 1880. More attention was given to the district in the 1890's. The "boom" in 1897-1898 led to the first reported production of 4,650 lb of copper in 1899. At the same time, Copper City was established at the north end of the district, and a small matte smelter operated for a few years. The remains of the village and the smelter are still visible on the south side of the highway. The failure to discover large ore bodies after the initial boom probably led to the district's quick decline. The Colorado Division of Mines biennial report for 1917-1918 suggests only intermittent activity at that time.

Perkins' (1975) map shows more than 50 mines and prospects in the district, but information on individual mines is lacking. Corregan and Lingane (1883) and Butler (1915) described some of the shafts but gave no locations. For example, the Joe Dandy and Pioneer shafts were reported to be 10 ft and 45 ft deep, respectively. Butler states that the Bell claim shaft was 120 ft deep and that the McKinley Mine, the deepest in the district, reached a depth of 600 ft. The Nancy Hanks mines at the northern end of the district were developed by a 300-ft-long tunnel and two shafts each over 100 ft deep. A Colorado Division of Mines mine manager's report for 1900 (pt. 2, p. 441) states that the Nancy Hanks, Hobo, Jessie May, and Jack Pot claims were operated by Western Slope Mining and Smelting Company of Grand Junction. At that time a 100-ft shaft was developed by drifts at the 20-ft, 60-ft, and 85-ft levels. The Chance [Last Chance?] claim supposedly was developed by a 700-ft-long tunnel and a shaft more than 300 ft deep.

Rohrig and Brown Associates of Grand Junction have shown recent interest in the district by requesting a conditional-use permit for mining and prospecting on 10 claims, the Crystal Queen and Blue Bird groups, located in the S/2 sec. 9, T14S, R100W on the northwest side of the district. Chances are questionable for further development in the district as Butler (1915) saw no evidence of large or richer deposits at greater depths than had already been prospected. Instead of yielding copper though, the veins may be sources of collectors' and rock shop specimens of fluorite, quartz, amethyst, and malachite.

Land Use

Although Plate 2 shows numerous mines and prospects in this district, actual development and land disturbance have been minimal. Many mines are located on the upper bench and, therefore, are not visible from Colorado 141. Of greater importance here is the fact that many adits and shafts remain open. Only a few of the shafts that I examined were fenced, rather inadequately. Several open shafts lie immediately next to Colorado 141 and Divide Road. These openings can pose a danger to hikers, rock hounds, cattle, and even to other prospectors.

Dominguez District

This small copper district lies in Dominguez Canyon 3 to 4 miles from Bridgeport and about 6 miles southeast of the Unaweep district (Plate 2). The geology and structure of the district are similar to the Unaweep district with the exception that Dominguez Creek has not deepened its valley to the same extent as East Creek and the ancient Gunnison River. Precambrian rocks, although incised, are exposed only on the narrow valley floor, and the "lower bench" here is formed by Chinle and Wingate. Through airphoto interpretation, several structural trends were extended into the south end of the district southeastward from Unaweep. One prominent fault on the same trend extends even farther southeast across Little Dominguez Creek to Escalante Creek in Delta County.

Several prospects and one shaft were developed on the valley floor in mineralized veins in the Precambrian. Active work in 1976 consisted of recovering malachite, azurite, quartz, and amethyst specimens. Although the Colorado Division of Mines noted some prospecting there in its 1901-1902 biennial report, I could find no other details of the district's history. Apparently no production was ever recorded. Although no major discoveries have been made or likely will be made, the projected structural trends in the southern part of the district do warrant prospecting.

For the purposes of mineral resource area identification, I have shown two map units in the Unaweep and Dominguez districts: 1) *Cu-1*, which is the outcrop area of Precambrian rocks, and 2) *Cu-2*, which is the outcrop area of the Chinle Formation and Wingate Sandstone. These geologic units have been mapped, openended, 0.5 to 1 mile beyond the mines, prospects, and favorable structures.

Other Uncompahgre Plateau Occurrences

Structural trends similar to those in the Unaweep and Dominguez districts were mapped in the southeastern corner of the county (Plate 2). Although no occurrences have been reported in this area, the structure affecting the Precambrian and lower Triassic rocks would warrant prospecting on Wildhorse Draw, the No Mans Mesa area on Little Dominguez Creek, Kelso Creek, and the North, Middle, and East Forks of Escalante Creek.

One other known copper deposit at this end of the plateau, the Missouri Girl Mine, occurs on Hill Creek, a tributary of Coates Creek near the western edge of the county. In the Coates Creek and Little Dolores River drainages, as in the Unaweep and Dominguez districts, Precambrian rocks are exposed on the lower slopes and on valley bottoms of a number of tributary streams. The principal difference between the Hill Creek and Unaweep areas can be seen in the structure, which at Hill Creek reflects numerous northeast-trending faults and fractures associated with the Sandflat Graben and the Ryan Creek fault zone. A Colorado Division of Mines file report from 1966 describes the Missouri Girl Mine as 65- and 75-ft-deep shafts in a 4-ft-wide north-south-trending Precambrian fault zone, containing both copper and silver values. The mine, last active in 1966, supposedly operated in 1912 and again in 1935.

Sinbad Valley

Several peculiar copper and silver deposits occur in the Sinbad Valley of Mesa and Montrose Counties, in the Paradox Valley of Montrose County, and in Lisbon

Valley, Utah. Upon entering Sinbad Valley along Salt Creek, one can see a 2,000-ft-high series of cliff lines encircling the oval anticlinal valley. The stratigraphic interval exposed here embraces a great span of geologic time, starting with the Pennsylvanian Hermosa Formation on the valley floor and continuing through the Cretaceous Burro Canyon Formation, which caps John Brown Mesa and Sinbad Ridge. The rather complicated structure of the valley will be discussed in detail in the section dealing with gypsum and halite.

In a paper about copper occurrences on the Colorado Plateau, Emmons (1905) described several western Colorado localities visited in 1899. Later, Fischer (1936) gave a more detailed view of the geology, mineralogy, and origin of these vein-type copper occurrences on the Plateau. Geology and structure of Sinbad Valley are shown by Williams (1964), Shoemaker (1955), and Cater (1970).

The Pyramid claims were among the first staked in Sinbad Valley in 1908. Surface excavations accounted for most of the production between 1908 and 1916. During this same time, the Copper Rivet Mine opened but apparently did not produce much ore. A 4.9-ton shipment in 1942 reportedly contained 8.25 oz of silver and 20.65 percent copper. Early in 1942 the Colorado Copper Company acquired the Pyramid workings and later added 6 more claims. The following descriptions of the Sinbad Valley operations are taken from Holmes and Harrer (1952).

On the east side of the valley, copper mineralization in the lower Wingate Sandstone occurs at the Copper Rivet Mine in the form of chalcopyrite, luzonite [Cu_3AsS_4], and some chalcocite [Cu_2S]. Fischer (1936) describes the mineralization along a northeast-trending fault associated with the Salt Creek Graben. Holmes and Harrer's (1952) plan of the mine shows that the upper (southwestern) adit leads into a tunnel at a bearing of about N50°E. Near the end of the 430-ft-long tunnel, a raise connects it to a lower tunnel leading from the lower adit (Figure 2). Ore deposits were found in the upper tunnel just above the base of the Wingate. Assays of nine channel samples from the upper tunnel (Table 3) ranged from a low of 0.5 percent copper to a high of over 10 percent and overall averaged 2.07 percent, with a trace of chromium.

Other properties of the old Colorado Copper Company include Colorado No. 3 claim, Claim No. 9, and the Pyramid group, whose locations on Plate 2 were approximated from airphoto examination. Original hillside development of the Colorado No. 3, located at the north end of the valley, consisted of several small open cuts and a 105-ft tunnel heading N7°E. In its investigation of the site, the U.S. Bureau of Mines dug seven surface trenches and analyzed more than 140 channel samples from these trenches and from the adit. Mineralization was found associated with fault and fracture zones in sandstones and conglomerates of the Cutler Formation. I have summarized the results of chemical analyses in Table 4. The highest copper values were found in the adit along the main ore body close to the northern end of the tunnel.

The Pyramid group was developed by 215-ft and 120-ft tunnels and several open cuts in altered Dolores

FIGURE 2. Lower (southeastern) adit of Copper Rivet Mine, Sinbad Valley. This tunnel leads to an upper tunnel and copper mineralization near the base of the massive faulted Wingate Sandstone.

TABLE 3. Ore assays from Copper Rivet Mine, Sinbad Valley (from Holmes and Harrer, 1952).

Sample No.	Sample length (ft)	Cu (%)	Cr_2O_3 (%)
186	9.0	2.10	-
187	5.9	0.05	<0.20
188	4.6	2.78	-
189	9.8	0.29	-
190	9.9	10.24	-
191	6.6	0.04	-
192	9.8	1.86	-
193	14.7	1.08	<0.20
194	15.6	0.47	<0.20

TABLE 4. Ore assays from Colorado No. 3 and Pyramid claims, Sinbad Valley (from Holmes and Harrer, 1952, Tables 2, 3, and 4).

Sample site	No. Samples	Sample length (ft)	% Cu range	% Cu ave.
Colo. #3				
trench 1	47	1.3-10.8	<0.02-2.51	0.37
trench 3	36	1.7-12.3	<0.02-1.20	0.11
trench 4	32	1.3-15.9	<0.02-0.60	0.06
trench 7	10	1.8-8.0	<0.02-0.45	0.11
adit	21	1.7-6.5	<0.02-4.46	1.32
Pyramid claim	15	0.7-8.9	0.10-8.52	2.66

[Chinle] Formation and Wingate Sandstone. Mineralization occurs in faulted Wingate in the main tunnel and along fractures exposed in the hillside above the portal. Results of 15 analyses are included in Table 4. Excluding the one anomalously low value reported, the Pyramid group averages 2.84 percent copper. Seven of the fifteen analyses had Cr_2O_3 contents less than 0.02 percent. Weak mineralization in the Wingate was noted at Colorado No. 9 claim, about 0.75 mile southeast of Copper Rivet Mine, but was not sampled.

PLACER GOLD

Parker's (1974a) summary of Colorado placer deposits described considerable activity along the Dolores River in the 1870's up to 1910. Hydraulic mining below Uravan took place at a time when extensive ditches were constructed to bring water up to the mesa tops to work sandstone deposits. The most impressive of these engineering structures is the famous "Hanging Flume" built in the Dolores River canyon by the Montrose Placer Mining Co. The flume was actually suspended from the cliff edges for a distance of more than 4 miles in its reported 10- to 13-mile length.

In Mesa County Corregan and Lingane (1883) described several placers located in 1882 on the Dolores River. The Claude R., Washington, Lady Elgin, and Little Giant placers comprised 160 acres along the river 8 miles below the San Miguel River confluence. At that time the claims were developed by 100 ft of ditching and four 30-ft shafts. The 160-acre Little Gem placer was situated 9 miles below the San Miguel River and was developed by more than 1,500 ft of ditching.

Parker (1974b) mentions panning operations in Unaweep Canyon and along Buzzard Creek, presumably in the Plateau Creek valley. Activity in the latter seems to be documented by Mining and Scientific Press (1913) which reported a "rush" to Clover Gulch and Kimball Creek northwest of Collbran. The interesting article is here reproduced in its entirety:

> *"A rush to the recent gold discoveries near Collbran has started from all parts of the state. Scores of men are coming in from De Beque on every stage and the mining camp in Clover Gulch is taking on the appearance of a tented city. Over 150 claims have already been staked, and the claims extend for 14 miles up and down Clover Gulch, while prospectors are now staking other claims on Kimball Creek. The advance prospectors from the Eagle district report that they will be followed by scores of other prospectors if early reports of discoveries are borne out. Additional assays of ore have been made and show from $138 to $150 per ton, with indications of a streak of uranium. Merchants of Collbran have ordered large quantities of tents and other camp supplies."*

Apparently the early reports exaggerated any discoveries that might have been made.

Table 2 shows that a total of 387 oz of gold was produced in the county intermittently through 1936. The source of all the production is uncertain but credited to the Colorado and Gunnison Rivers.

MOLYBDENUM

Molybdenum has been reported in two localities in Mesa County. Worcester (1919) described the Gavette and Collinson claims in Unaweep Canyon near Unaweep Divide. The U.S. Geological Survey (1971) map approximates the Collinson and Gavette claims in secs. 26 and 34, T14S, R10W, respectively. On the Gavette claim mineralization in the Precambrian schist is associated with a 2- to 5-ft-thick, coarse-grained granite dike that trends at approximately right angles to the general east-west trend of the pegmatites. Molybdenite [MoS_2], found at the contact between the dike and country rock, occurs as isolated crystals and as small masses 1/4 to 1/2 in. in diameter. According to Worcester, the vein had been prospected to a depth of 4 ft.

The Collinson claim, located about 2 miles northeast of the Gavette claim, also lies on Precambrian schist and granite on the north side of the canyon. The 12- to 18-in.-wide vertical vein strikes N30°W and is composed of coarsely granulated quartz with occasional flakes of molybdenite. Neither of the claims was located in the field and so do not appear on Plate 2.

The Colorado Division of Mines annual report for 1922 cites another molybdenum occurrence 7 miles west of Grand Junction, which would indicate some site within the Colorado National Monument. The Silver Bell group (Silver Bell 1 and 2, Rex 1 and 2, Alaskan 1, and Log Cabin) consists of six unpatented claims covering 140 acres. A 3-ft vein in Precambrian granite reportedly showed molybdenum, pyrite, and a high gold content. Within the monument, Precambrian rocks are exposed on the lower slopes of several deeply incised canyons, the most likely of which include No Thoroughfare, Ute, and Red Canyons.

In my field examination of lower No Thoroughfare Canyon, the most likely site of these claims, I found remnants of an old road grade, one definite prospect, and one probable prospect. At the southern prospect, southwest of Devils Kitchen, the mineralized vein trends N10°E. The mineralized samples collected apparently consist of specular hematite (Fe_2O_3), characterized by shiny black aggregates of platy crystals, the largest of which measured 0.6 in. in diameter. Some of the masses contain dark reddish-brown and yellow alteration, indicating the presence of limonite. The second prospect along the same trend about 550 ft to the northeast showed conspicuous red and green alteration halos around inclusions in the schist. Quartz blebs, pods, lenses, and thin dikes trend about N85°W and are cut by prominent fractures trending N10°E. No metallic mineralization was seen.

I could not confirm molybdenum mineralization at either of these prospects. It is possible that the claims lie in Red Canyon or Ute Canyon, but neither are as readily accessible.

BERYLLIUM AND TITANIUM

The U.S. Geological Survey (1971) reports a beryllium occurrence in sec. 7, T15S, R101W at Thimble Rock Point in Unaweep Canyon. Although unverified, the occurrence could be the mineral beryl [$Be_3Al_2(SiO_3)_6$] associated with the east-west trending pegmatites in the canyon.

Titanium-bearing sandstones in the Mesaverde Group have been reported in Utah, Wyoming, New Mexico, Colorado, and Montana since 1914. Geologists have shown that titanium minerals were deposited in the beach environments of regressive marine sequences. In this area lower flood-plain and beach environments of the basal Mesaverde moved eastward and gradually replaced the marine environment that prevailed during the deposition of the Mancos Shale.

Murphy and Houston (1955) described Wyoming *black sands* containing up to 16.5 percent TiO_2, chiefly in the form of ilmenite [$FeTiO_3$] and anatase TiO_2], with accessory monazite [(Ce, La, Y, Th)PO_5], columbium-bearing minerals, and uranium. Dow and Batty (1961) analyzed black sandstones in the Menefee Formation, the basal Mesaverde in Montezuma County, and found the following:

	range	Palmer Mesa
TiO_2	ave. 0.2-0.5%; high 5.5%	2.8%
ZrO_2	0.05%	0.42
Fe	2.2-11.6%	12.8
$eThO_2$	0.01-0.06%	0.03

For southwestern Colorado they estimated 253,000 tons of mineralized rock at the following grade: 0.89 percent TiO_2, 0.08 percent ZrO_2, 7.35 percent Fe, and 0.03 percent $eThO_2$. Although the mineralized sands could be separated into constituent mineral products, they did not believe the deposits could be economically worked.

Houston and Murphy (1977) described a titaniferous sandstone in the Lower Mesaverde at Lands End on Grand Mesa, but neither an exact location nor chemical analysis was given; thus, no inference can be made regarding the deposit's potential.

URANIUM AND VANADIUM

The production of uranium and vanadium represents a most significant portion of the total mining industry in Mesa County. Because of the intimate nature of their occurrence and production histories, this chapter will examine both metals together. An incredibly large amount of literature has been written on the uranium and vanadium geology of the Colorado Plateau, but I have selected only a few detailed references for this summary of geology, ore occurrences, and production. Many of the references listed in the bibliography were taken from a pre-publication printout of the Colorado Geological Survey's Bulletin 40, *Radioactive Mineral Occurrences of Colorado, with Bibliography* by James L. Nelson-Moore, Donna Bishop Collins, and A. L. Hornbaker. Undoubtedly I have overlooked some references for the Colorado Plateau that contain information about Mesa County, but those listed will suffice for additional inquiries. Other government reports still classified as company confidential neither could be inspected nor referenced.

We have long recognized the importance of uranium as a fuel for nuclear reactors, but the utility of vanadium often is overlooked. Most vanadium is used in the manufacture of high-strength, low-alloy steel and nonferrous aluminum and titanium alloys. Other industrial uses include petroleum refining and the manufacture of sulfuric acid, colored glass, ceramic glazes, and paint and varnish driers. In the future, vanadium may find potential use as a construction material for fast-breeder nuclear reactors.

Geography and General Geology

One of the country's principal uranium-vanadium areas occurs in western Colorado and eastern Utah and is known as the *Uravan mineral belt* (URAnium-VANadium). The deposits form an arcuate belt extending through Mesa, Montrose, and San Miguel Counties, Colorado, and into Grand and San Juan Counties, Utah. The northwest-flowing Dolores River and 11 principal tributaries, including West Creek and Salt Creek, drain the Mesa County portion of the belt, commonly known as the Gateway district. Broad mesas and rugged canyons in the district characterize the Dolores River valley (Plate 1b).

The area is accessible on Colorado 141 through Unaweep Canyon southwest from Whitewater and northwest from Uravan and Naturita. The only road into Beaver Mesa, the western part of the district, follows John Brown Canyon southwestward from Gateway. The eastern part of the district is accessible by a dirt road up Casto Draw southeast from West Creek or via Uranium Road and Divide Road southwest from the Unaweep mining district.

In this area of the Colorado Plateau one can see most of the sedimentary formations described earlier in this report. The oldest sedimentary rocks, the Cutler Formation, crop out on the lower slopes next to the Dolores River. The three prominent cliff lines visible on the mesas' profiles are formed by the Wingate Sandstone (lowest), Entrada Sandstone and Salt Wash Member of the Morrison Formation (intermediate), and Burro Canyon Formation (highest). The youngest sedimentary rocks, the Dakota Sandstone, form remnants on the tops of Long Mesa, Beaver Mesa, Dolores Point, and John Brown Mesa.

Both the Uncompahgre Uplift and Sinbad Valley incline have influenced the structure of the district (Plate 1c). The Uncompahgre Monocline borders the belt on the northeast and has tilted the strata 9° to 18° to the southwest. The Dolores River syncline trends northwestward through the center of the Gateway district and extends into Utah as the Sagers Wash syncline in the higher formations. Strata on the southwestern flank of the Dolores River syncline become the northeastern flank of the Sinbad Valley-Fisher Valley anticline.

Geology of the Ore Deposits

Uranium host rocks on the Colorado Plateau span a large stratigraphic interval and include the Hermosa, Cutler, Chinle, Wingate, Entrada, Morrison, and Burro Canyon sequences. This discussion will focus on the Salt Wash and Brushy Basin Members of the Morrison Formation, the principal ore-bearing rocks in this area of the Plateau. The lithologic descriptions are based on those by Fischer and Hilpert (1952), Cater (1955a, 1955b, 1955c), and Shoemaker (1955).

Geologists have interpreted the Salt Wash Member in the Four Corners area as a large northeast-spreading alluvial fan whose apex lies in southern Utah and northern Arizona. The fan consists of four major textural facies (from southwest to northeast): 1) conglomerate-sandstone (south-central Utah), 2) sandstone-mudstone (northeastward as far as Grand Junction), 3) claystone-lenticular sandstone (northeastern Utah and northwestern Colorado), and 4) claystone-limestone. The last facies lies east of the limit of recognizable Salt Wash and is not strictly a facies of the member. The Salt Wash Member in the Gateway district is dominantly the sandstone-mudstone facies.

Salt Wash beds crop out as a series of resistant ledges above the slope-forming Summerville Formation. The predominantly sandstone sequence is interbedded with red shale, mudstone, and a few gray limestones. The fairly continuous sandstone strata consist of highly lenticular and cross-bedded sets commonly containing fossilized wood, carbonaceous matter, and dinosaur bones. In the Gateway district the member ranges from 240 to 360 ft in thickness. A fluvial origin of the sandstones is indicated by a variety of sedimentary structures such as festoon and torrential cross-bedding, ripple and rill marks, and current lineations.

The Brushy Basin Member contrasts sharply with the Salt Wash in lithology and topographic expression, but the change between the two is gradational. Above the ledge-forming Salt Wash, the Brushy Basin forms smooth slopes littered with float from the overlying Burro Canyon. Lithologically the member consists of bentonitic shales and mudstones with beds and lenses of dark rusty-red, chert-pebble conglomerate and conglomeratic sandstone. Geologists interpret the coarser-grained lenses as stream channels that crossed finer grained flood-plain deposits. The Brushy Basin ranges from 300 to 450 ft in thickness in the Gateway district. Plate 2 shows the outcrop of the Salt Wash (*UV-1*) and Brushy Basin (*UV-2*) Members. The third unit (*UV-3*) is the outcrop of Burro Canyon and Dakota, which, although not ore-bearing, can be considered as overburden to possible buried deposits in the Morrison.

Ore Occurrence

Fischer and Hilpert (1952) describe the Uravan mineral belt as a long, narrow, arcuate band concave to the west (Figure 3). Ore deposits within the belt historically are larger, better defined, and more productive than those found outside. Here in the Gateway district the northern end of the belt varies from 1.5 to 3.5 miles in width and bends abruptly westward across the eastern side of Outlaw Mesa and extends across Calamity, Tenderfoot, and Beaver Mesas into Utah. Uranium-vanadium ore bodies appear as irregularly tabular layers 2 to 4 ft thick and a few feet to several hundred feet wide. They tend to be clustered in patches 1,000 to several thousand feet wide and several thousand feet long. Both the ore bodies and the clusters are elongated normal (perpendicular) to the trend of the belt, although they do not necessarily extend the width of the belt. Craig and others (1955) recognized three general quantitative relationships between ore occurrences and the Salt Wash Member. First, most deposits occur where the

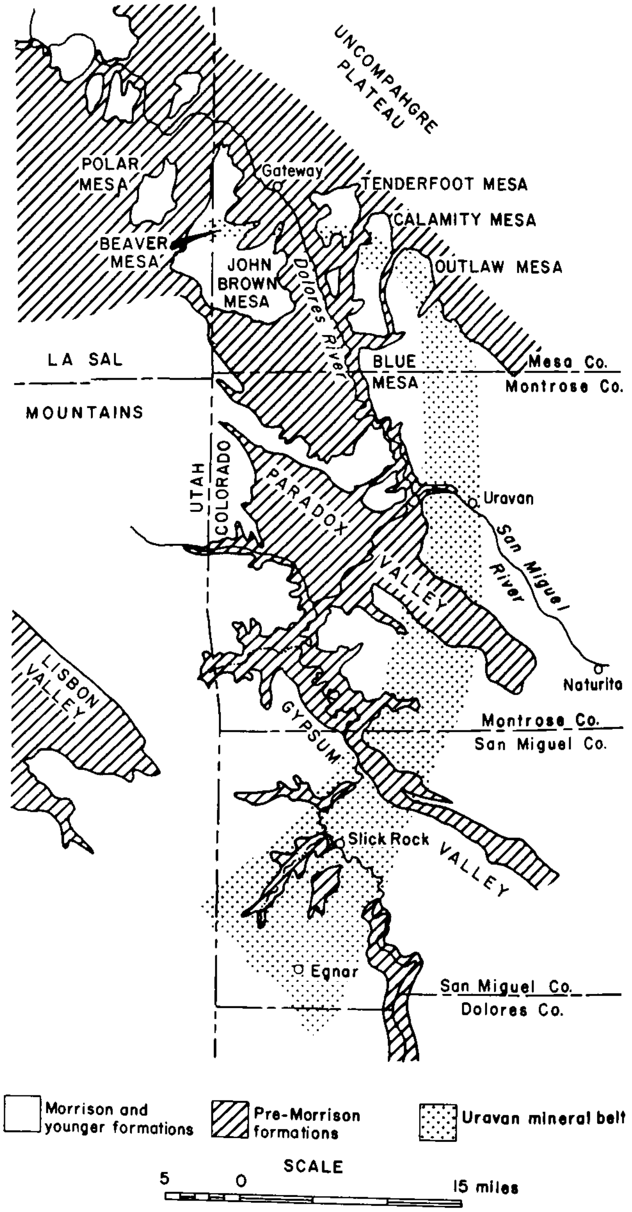


FIGURE 3. General geography and geology of the Uravan mineral belt, Colorado and Utah (modified from Fischer and Hilpert, 1952).

member exceeds 240 ft in thickness. Second, most occur where stream deposits comprise 40 to 55 percent of the member. Third, most occur where stream deposits vary from 90 to 200 ft in thickness.

Ore deposits commonly contain fossil tree trunks and branches that were rafted by the ancient streams and oriented parallel to the stream-flow direction. *Ore rolls* are 10- to 100-ft-long concretionary structures that are elongated parallel to the logs. Orientation of the logs, rolls, and ores in that general direction suggests a widespread geologic control of ores within the belt.

The origin and peculiar localization of these ores have long been a controversy among geologists. Craig and others (1955) have disproved three proposed sources--sedimentary rocks in the source area of the Salt Wash, a post-Salt Wash hydrothermal source in the Colorado Plateau, and post-Salt Wash sedimentary rocks near the present ore deposits. Another theory states that uranium minerals originally deposited with the sediments were later precipitated by percolating ground waters.

Regardless of the minerals' exact origin, of more immediate concern is why the ores occur as they do in long fingers within the belt. Shawe (1962) believes that the belt shape reflects the toe of a small alluvial fan superposed on the larger Salt Wash fan at the time of deposition. The smaller fan formed when part of the area subsided into a large basin that overlapped the Paradox Basin and part of the ancient Uncompahgre highland. Fluvial deposits in and west of the belt then are the result of deflection of distributary streams from the main fan. This theory would support a strong relationship between orientation of the ores and sedimentary structures in the smaller fan. Craig and others (1955) do not, however, believe that the sedimentary structures exerted that much control over mineralization because, despite the radial orientations, the ore rolls cut across bedding and laminations.

Shawe's (1956) theory of ore-roll formation begins with the observation that the cross-sectional arcuate, C- and S-shaped rolls commonly terminate against thin mudstone layers. Although usually sinuous, the rolls' long axes generally coincide with current lineations and channel trends. Warm groundwater solutions, which contained uranium, vanadium, and other elements leached from other sedimentary rocks, moved through the permeable sand-filled channels. These warm waters met cooler connate waters and established an essentially static interface along which the various ions were precipitated. Slight oscillations of the interface account for the concentric layering of the ores and layering of such other minor elements as selenium, iron, and calcium. Ore roll also were localized where many thin mudstones divided the sheet of moving warm water into a number of sheets, thus causing a sinuous roll front and fingers. The presence of carbonized logs also modified the shape of the roll front. This theory then depends on highly permeable sand channels as conduits for the mineralizing solutions. At the Calamity and Outlaw mines, Phoenix (1956) found a close correlation between the most productive deposits and highest sandstone transmissivities in the upper Salt Wash, in trends normal to the belt. He believed that if the mineralizing solutions moved laterally after Salt Wash deposition, then mineral deposition could have responded to changes in ground-water velocity, hydrostatic pressure, and possibly temperature.

Ore Mineralogy

Over the years a wide variety of major and minor uranium and vanadium minerals have been discovered and described in the Uravan mineral belt. Botinelly and Weeks (1957) classify Colorado Plateau deposits into eight types based on the V:U ratio and atomic valence states of the elements. Those in the Gateway district are classified as Group 1, Type 1—high-valence oxidized ores with V:U ratios of 3:1 to 15:1. Dominant ore minerals include carnotite $[(K_2(UO_2)_2(VO_4)_2\cdot 3H_2O]$, tyuyamunite $[Ca(UO_2)_2(VO_4)_2\cdot 7\text{-}10.5\ H_2O]$, hewettite $[CaV_6O_{16}\cdot 9H_2O]$, and vanadium clay. The minor ore minerals include:

high valence:

fervanite	$Fe_4V_4O_{16}\cdot 5H_2O$
hummerite	$K_2Mg_2V_{10}O_{28}\cdot 16H_2O$
navajoite	$V_2O_5\cdot 3H_2O$
pascoite	$Ca_2V_6O_{17}\cdot 11H_2O$
rossite	$CaV_2O_6\cdot 4H_2O$
sodium vanadate	

middle-valence:

corvusite	$V_2O_4\cdot 6V_2O_5\cdot nH_2O$?
fernandite	$CaO\cdot V_2O_4\cdot 5V_2O_5\cdot 14H_2O$
melanovanadite	$2CaO\cdot 2V_2O_4\cdot 3V_2O_5\cdot H_2O$?
rauvite	$CaO\cdot 2UO_3\cdot 5V_2O_5\cdot 16H_2O$?

low-valence:

paramontroseite	VO_2
uraninite (with coffinite)	UO_2

Descriptions and identification criteria of these complex minerals are given in Weeks and Thompson (1954).

History of Uranium and Vanadium Production and Processing

Before the last turn of the century, no one could foresee that the discovery of radium, uranium, and vanadium on the Colorado Plateau would evolve into one of this country's most fascinating stories of mining and processing technology. Because of the interdependence of these metals, all three must be discussed together. This summary is based on historical sketches presented in Wright and Everhart (1960), Bruÿn (1955), Seidel and Kuhn (1961), and Dare and others (1955).

The first interest in this area of Colorado came in 1881 when Thomas Talbert, a local prospector in the Roc Creek area, sent several ore samples to Leadville for copper assay. After a mere trace of gold and silver were found, Talbert abandoned his claim. Later, the diligent research of Pierre and Marie Curie in Paris led to their discovery of the element radium in December 1898. The pitchblende used in their experiments was discovered by a colleague rather accidentally on the dump of the Wood Mine near Central City, Colorado. The isolation of radium from this ore immediately caused a great demand for Colorado pitchblende.

About this same time, a Michigan copper company, interested in building a mill at the Cashin Mine in western Colorado, sent Charles Poulot, a French chemist, to Cashin to investigate the area. In this small Montrose County village, Poulot met Thomas M. McKee, a local photographer and rock hound who had noticed a peculiar mineral on some of the nearby mining claims. Poulot analyzed the mineral as a vanadate but sent it to his former professors in Paris for verification. Poulot was later in Denver where he met Gordan Kimball, a Ouray businessman. Kimball sent Poulot some mineral samples that were identified as uranium-bearing. In 1898 Kimball secured a lease presumably in the Roc Creek area and made the first ore shipment--10 tons of hand-sacked ore assayed in France at 21.5 percent U_3O_8 and 15 percent V_2O_5. Kimball received $2600 for the ore. The next year, 1899, the results of McKee's samples were publicized. French assayers Charles Friedel and E. Cumenge announced the discovery of *carnotite*, a new mineral that they named for the prominent French physicist Adolphe Carnot. The announcement expectedly caused prospectors to flock to Colorado in search of uranium and radium.

Just after 1900, several plants were constructed to recover uranium and vanadium oxides. Not until 1911 were radium slimes shipped out, relegating vanadium and uranium to by-product status. From 1910 to 1923 nearly all the world's radium came from western Colorado. In 1912 newly discovered radium pitchblende from the Belgian Congo entered the world market and all but ended activity in Colorado. Domestic vanadium requirements were obtained from Peru and from the deposits at Rifle, Colorado. By the mid-1930's the growing need for vanadium renewed interest in Colorado carnotite, and many mines reopened. World War II stimulated production of strategic vanadium, and the development of the atomic bomb brought about an intensive search for new uranium deposits in western Colorado. In 1947 the Atomic Energy Commission (AEC) was created to control the production, ownership, and use of fissionable materials. This government buying program, which created the mining boom of the 1950's, was discontinued in 1970.

The processing of uranium actually follows the historical development of vanadium milling on the Plateau. The metal now known as vanadium was discovered in 1801 by Andres Manuel del Rio in Mexico City. His experiments were, however, disputed, and the metal was rediscovered by Nils Sefstrom in 1830 in Swedish iron ores. Because of the brightly colored compounds formed in the laboratory, *vanadium* was named after Freya Vanadis, the Scandinavian goddess of beauty. As a result of H. E. Roscoe's work in the 1860's, the metal was classified into Group VA with arsenic, antimony, and bismuth. Not until the first isolation of pure vanadium in 1927 were its true properties known, resulting in its reclassification into Group VB with tantalum.

Early mills on the Colorado Plateau were designed for vanadium recovery. The three mills that operated in Mesa County include Gateway Alloys Co. (Gateway, 1939-1945, Figure 4), Loma mill (Loma, 1940-1941(?)), and U.S. Vanadium Co. (Grand Junction, Manhattan Project, 1943-1946). Other principal mills operated at Uravan, Rifle, Naturita, Slick Rock and Newmire, Colorado, and at Dry Valley and Blanding, Utah. From 1910 to 1924, vanadium concentrate was produced by a process known as *salt roasting*, which was introduced to the Colorado Plateau at Newmire. In this procedure vanadium ore is mixed with salt, ground to -20 mesh, and roasted to form soluble sodium vanadate. After the calcine is water leached, the slurry is treated with ferrous sulfate, $FeSO_4$, to precipitate iron vanadate, which is then filtered, dried, and packed. All the salt used in this roasting process came from Salt Lake Valley in Utah, although unsuccessful attempts were made to recover salt from brine wells in Paradox Valley.

FIGURE 4. Abandoned vanadium mill of Gateway Alloys Company, Gateway. This plant processed Uravan belt vanadium ores between 1939 and 1945. In right background, massive Wingate Sandstone overlies Chinle and Moenkopi Formations.

From 1924 to 1940, processing circuits increased in complexity, adding acid-leach and alkaline-leach steps to the basic salt-roast step. The addition of the acid-leach circuit in the late 1930's facilitated the recovery of uranium concentrate. Two events in the 1940's greatly affected vanadium production on the Plateau. First, to meet the demand for vanadium, the government financed the construction of two new mills, at Durango, Colorado, and at Monticello, Utah. Second, the Army Corps of Engineers began the recovery of uranium for the Manhattan Project.

By 1943, leach plants to recover uranium from the Uravan and Durango salt-roast tailings were in operation. The concentrates were shipped to a U.S. Vanadium Company mill built on the present site of the U.S. Department of Energy complex in Grand Junction. Figure 5 is a process flowsheet of that mill. At the leach plants, salt-roast tailings were digested in sulfuric acid and treated with Na_2CO_3 or NaOH to precipitate uranium-vanadium *green sludge* that was then dried and shipped to the Grand Junction mill. Here the sludge was treated with Na_2CO_3 and roasted to produce a water-soluble sodium-vanadate calcine. Following water leaching and an alumina-cake precipitation step, a *red cake* vanadium concentrate was precipitated. The remaining water-leached residue, containing the uranium values, was dried and shipped to eastern plants for purification.

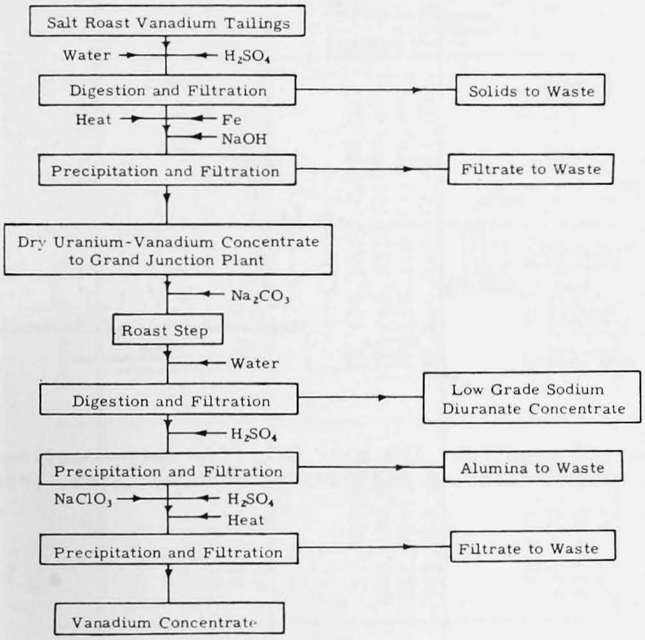


FIGURE 5. Process flowsheet of the U.S. Vanadium Company tailings treatment plant, Grand Junction. This plant produced vanadium and uranium concentrates during the Manhattan Project, 1943-1946 (from Seidel and Kuhn, 1961).

At the end of World War II, most vanadium plants closed down, but some were reopened in 1948 by the newly created AEC, which guaranteed minimum prices for uranium ore and encouraged exploration and development. The Climax Uranium Company mill (Figure 6), built in Grand Junction in 1951, was the first mill designed specifically to recover uranium. As shown in the process flowsheet (Figure 7) the mill used a complex salt-roast, water-leach, acid-leach, solvent-extraction process that recovers both uranium and vanadium. Minus-14-mesh rod-mill product enters conditioning and neutralizing tanks where the metallic slimes are precipitated. After a salt-roast cycle, the water-leached calcine is pumped to a red-cake precipitator where sodium hexavanadate is recovered. The remaining calcine enters the hot acid-leach cycle and is treated with sulfuric acid. Uranium and any remaining vanadium in the resulting liquors are separated by di-2-ethylhexylphosphoric acid (DEPHA). A sodium carbonate solution is then added to strip the uranium from the DEPHA solvent. After a second sulfuric acid treatment, sodium uranate is precipitated by ammonia, and the resulting *yellow cake* is filtered, washed, and dried. After 19 years of operation, the Climax facility was shut down. The main mill buildings still stand but are owned by another company.

FIGURE 6. Main mill buildings of the Climax Uranium Company, Grand Junction. This complex mill, the first in the country designed specifically to recover uranium, operated from 1951 to 1970.

The only operating uranium facility in Mesa County now is a crushing and sampling plant built at Whitewater last year by Cotter Corporation (Figure 8). At the south end of the plant, incoming ore is weighed, crushed, sampled for moisture, and classified into one of six stockpiles by a semicircular conveyor-stacker. Stockpiled ore will be conveyed into the sampling building where it will be crushed and split four times to achieve a final 100-lb sample of 3/16-in. material that will be used for chemical analysis. To ensure accuracy and quality control, two baghouses collect dust from the crushers and return it to the cycle. Rejected ore is conveyed to a loading bin and trucked to stockpiles (Paul Blanchette, 1978, pers. comm.). Later this year, a covered conveyor and walkway will be built to span the Gunnison River and convey the ore from the plant to a loading site on the D&RGW Railroad from which the ore will be shipped to Cotter's mill in Canon City (William Tobey, 1977, pers. comm.).

Production

This analysis of Mesa County uranium and vanadium production can be based only on cumulative figures for certain periods of time. Annual county figures are not yet available. Table 5 compares Mesa County vanadium and uranium production with that of the Uravan mineral belt and Colorado for the time up to 1947, from 1948 to 1971, and from 1948 to 1976. The pre-1946 figures are Webber's (1947, fig. 59) estimates of the total amount of ore that had been produced since the turn of the century, using all available records. Figures in the rest of the table are unpublished DOE statistics from Chenoweth (1977; 1978, pers. comm.). From 1946 to 1948 the industry was so depressed that very little if any ore was produced; therefore, the omission of these two years will not affect the to-

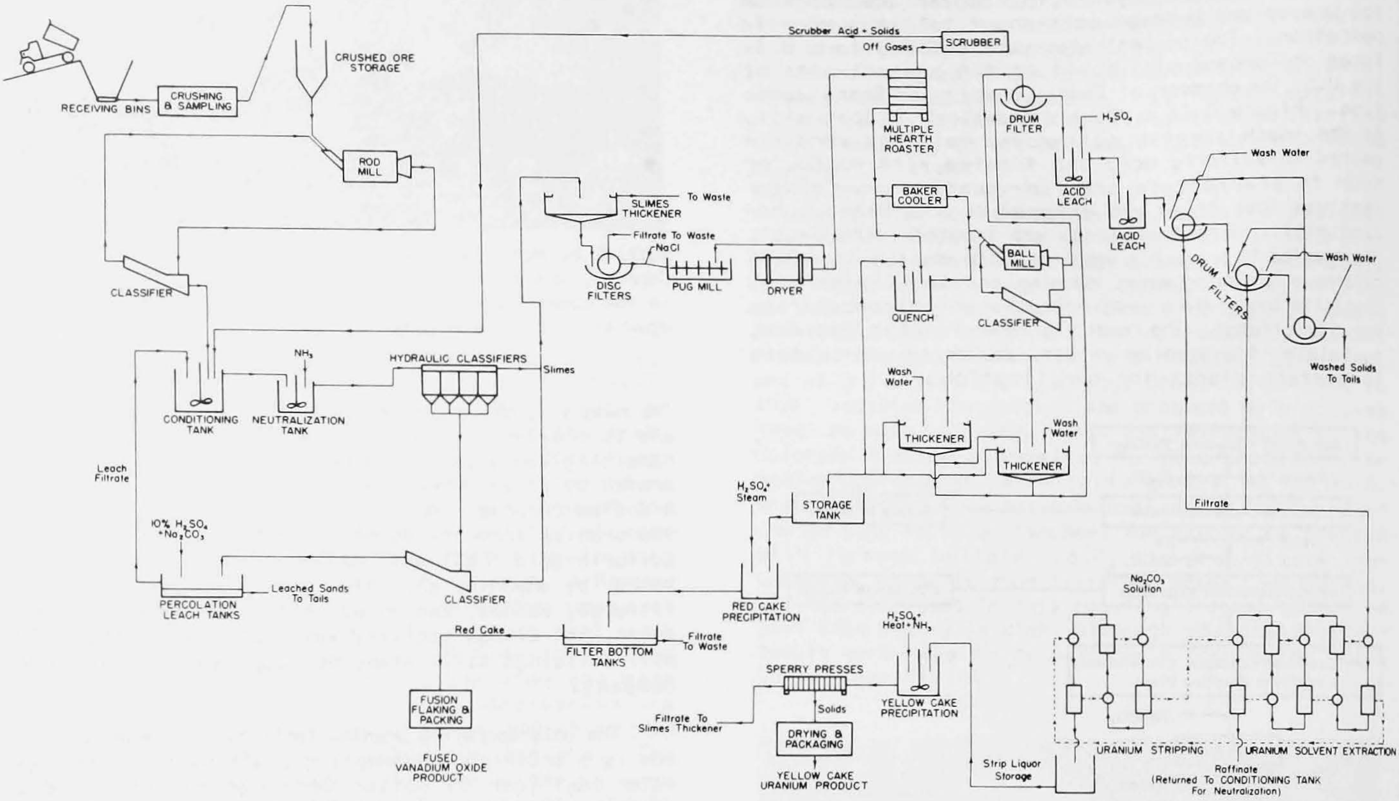


FIGURE 7. Process flowsheet of the Climax Uranium Company mill at Grand Junction. The mill utilized salt-roasting, water-leaching, acid-leaching, and solvent extraction to recover uranium and vanadium concentrates (from Seidel and Kuhn, 1961).

FIGURE 8. Cotter Corporation's new crushing and sampling plant at Whitewater. The facility consists (from right to left) of weighing station, crusher (covered), semicircular conveyor-stacker, ore stockpile bins, fine crushing and sampling plant. Grand Mesa looms in the background beyond the Gunnison River valley. View is to the east-northeast.

TABLE 5. Vanadium and uranium production in Mesa County compared with Uravan mineral belt and State of Colorado.

	V_2O_5				U_3O_8			
	tons ore	grade %	lb	Cumulative lb	tons ore	grade %	lb	Cumulative lb
PRE-1946[1]								
Mesa County	28,920	1.93	1,114,960	1,114,960	28,920	0.17	100,544	100,544
Colorado Uravan	637,543	1.89	24,190,252	24,190,252	637,543	0.28	3,630,612	3,630,612
Colo.-Utah Uravan	648,103	1.92	24,845,140	24,845,140	648,103	0.29	3,723,594	3,723,594
Colorado	1,247,477	1.85	46,102,039	46,102,039	1,247,777	0.17	4,258,436	4,258,436
1948-1970[2]								
Mesa County	1,911,000	0.99	37,986,000	39,100,960	2,026,000	0.29	11,941,000	12,041,544
Colorado Uravan	10,798,000	1.34	290,986,000	314,263,252	10,964,000	0.25	55,736,000	59,366,612
Colo.-Utah Uravan	11,307,000[3]	1.34	302,794,000[3]	327,639,140	11,479,000[3]	0.25	58,233,000[3]	61,956,594
Colorado	11,996,000	1.27	305,098,000	351,200,039	13,971,000	0.28	78,368,000	82,626,436
1948-1976[4]								
Mesa County	2,107,000	0.97	40,871,000	41,985,960	2,223,000	0.29	12,950,000	13,050,544
Colorado Uravan	12,574,000	1.32	331,778,000	355,968,252	12,742,000	0.25	63,326,400	66,957,012
Colo.-Utah Uravan	13,172,200[3]	1.33	347,609,000[3]	372,454,140	13,345,000[3]	0.25	66,077,400[3]	69,800,994
Colorado	15,139,000	1.17	352,795,000	398,897,039	16,665,000	0.25	82,385,500	86,643,936

[1] estimated figures from Webber (1947)

[2] from U.S. Atomic Energy Comm. files

[3] does not include La Sal, Utah, area

[4] from Chenoweth (1977; pers. comm., 1978)

tals. In the center of the table the January 1, 1971, cutoff marks the end of government ore purchases; thus, some comparisons can be made during that buying program.

For the period up to 1946, Mesa County contributed 4.6 percent of the Colorado Uravan mineral belt (UMB) V_2O_5 production and 2.4 percent of the total state production. In U_3O_8 the county produced 2.75 percent of the Colorado UMB total and 2.35 percent of the state total. Through the time of the government buying program, 1948 to 1971, Mesa County accounted for 13.1 percent of the Colorado UMB V_2O_5 production and 21.4 percent of the U_3O_8. The county also contributed just over 15 percent of the state's U_3O_8 production. For the period 1948-1976 the county's contribution of V_2O_5 and U_3O_8 averaged somewhat less, indicating that the county has not kept pace with other producing counties. Compared to cumulative total production, Mesa County accounts for slightly more than one-ninth of the UMB V_2O_5 and about one-fifth of the U_3O_8; the fractional contributions to state totals are slightly less.

Table 6 (Appendix 2) lists the cumulative production to 1/1/71 of individual mines and properties. In addition to these mines, two other sources of production may be noted. First, the Loma mill and buying station, operated at Loma in 1940 and 1941, processed ores from the Yellow Cat or Thompson district in Utah. Many years after the mill's abandonment, leftover material was collected from the site and shipped to the Rifle mill. Similarly, at the Climax Mill fine-grained material was periodically collected from the mill machinery and processed at one time. The *Silver Moon* and *Drum Dust* statistics are as follows:

	tons ore	U_3O_8		V_2O_5	
		grade	lb	grade	lb
Silver Moon (Loma)	4	0.09	7	0.57	46
Drum Dust (Climax)	121	4.04	9769	-	0
Total	125	3.91	9776		46

One can see from the following list of the 15 most productive mines and properties that the largest uranium producers also were the largest vanadium producers with only three exceptions.

U_3O_8 (lb)		V_2O_5 (lb)	
Rajah 30	1,484,991	Rajah 30	4,538,721
Bonanza 2	981,486	Rajah 67&68	2,555,105
AT-05-1-36	733,479	Hubbard Home	2,269,086
Rajah 67&68	598,010	New Verde	1,951,777
Incline 101	591,783	Zee-Rajah 49	1,765,306
Mark 2	537,893	Mark 2	1,653,150
Hubbard Home	532,183	Bonanza 2	1,469,879
Zee-Rajah 49	510,499	Pack Rat 1&2	1,373,280
New Verde	465,920	Lumsden 2&6	1,325,897
Lumsden 2&6	336,008	La Sal Group	1,309,922
October Adit	331,194	Lost Dutch 17	1,293,825
Lost Dutch 17	322,250	Mesa 8	1,053,868
Pack Rat 1&2	300,994	October Adit	970,686
Bonanza 3	238,404	Rajah 11 63	728,209
Mesa 8	216,548	Bonanza #2	693,005

These top-producing mines together account for about 68 percent and 66 percent of the U_3O_8 and V_2O_5 production, respectively.

Further analysis of Mesa County production can be made with the aid of histograms that show the relative distribution of mines for given intervals of production. Figure 9a shows that one-fourth of all the mines produced between 10,000 and 100,000 lb of combined concentrate. Half of all mines produced between 1,000 and 100,000 lb of U_3O_8, and 47 percent produced V_2O_5 in the same range. Less than 7 percent of all mines produced combined concentrate in excess of 1,000,000 lb. Figure 9b indicates that nearly one-third of all the mines produced ore with V:U ratios between 4:1 and 5:1, and nearly three-fourths of the mines had V:U ratios between 3:1 and 6:1.

Mines and Mining Methods

Although the Uravan mineral belt is obviously the most heavily mined area in the county, information on the mines is somewhat incomplete. Exact locations were determined for only about one-third of all the properties in Table 6. Except for Cater (1955a, 1955b, 1955c), Shoemaker (1955), Hague and others (1966), and Eicher and others (1957), no other sources cited mine locations more accurately than by section. Where space permitted, I have labeled on Plate 2 mines and prospects whose locations could be determined from the above cited maps. Colorado Division of Mines annual reports list a number of mines that presumably began after 1971. No correlation could be found between names in the cumulative list (Table 6) and those below.

Mine	Location	Area
Winfield-McCormick	33, T51N, R19W	Dolores Point
The Cave	....	Beaver Mesa
Palisade #1	....	Gateway
Stafford #5	1, [15S, 104W]	north of Gateway
Black Jack	NE31, T51N, R18W	Tenderfoot Mesa
Bujan	NE31, T51N, R18W	Tenderfoot Mesa
B-Chitty-U	18, T50N, R18W	Flat Top Mesa
Outlaw 23	....	Outlaw Mesa
Wedge	12, T50N, R18W	Outlaw Mesa
Maw	4, T49N, R17W	Mesa Creek

Some of the above listed mines may have been included in the cumulative production table but under different names.

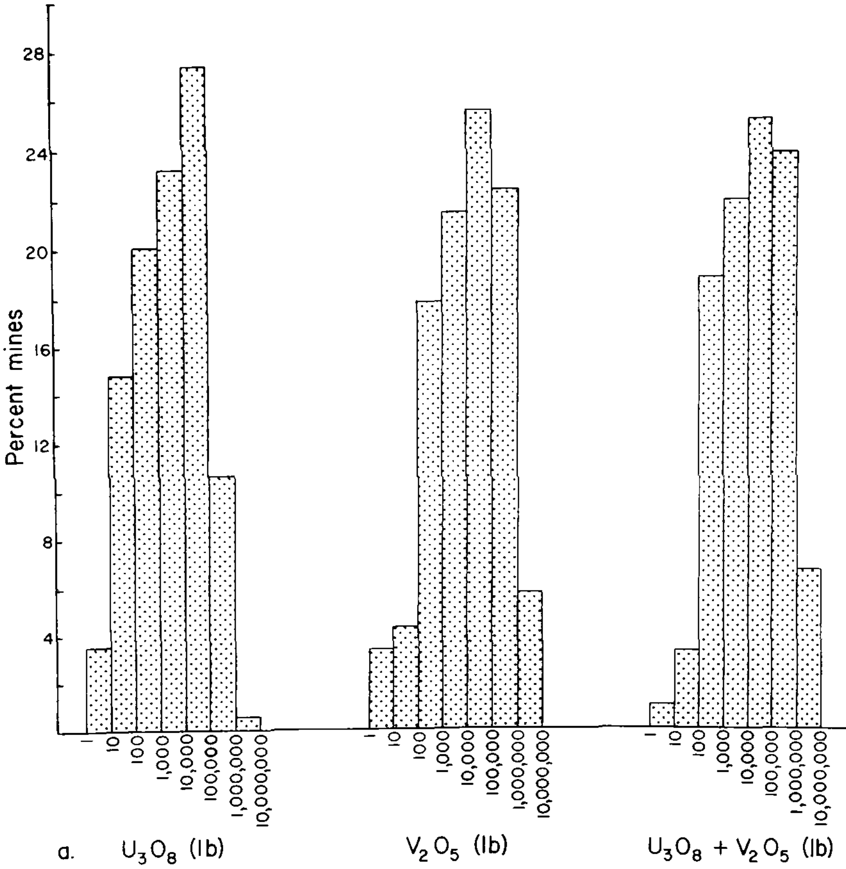


FIGURE 9a. Distribution of mines vs. cumulative U_3O_8 and V_2O_5 production.

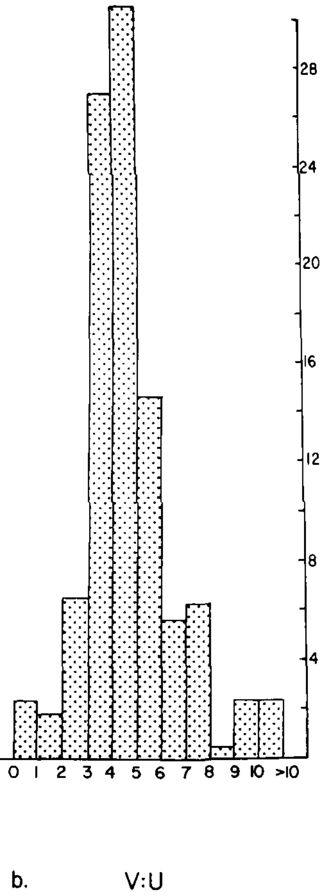


FIGURE 9b. Distribution of mines vs. V:U ratio.

Uranium and vanadium in western Colorado were first discovered in mineralized exposures along the rims of the mesas. Consequently, because of easy access and low cost, the first mines were developed also on the rims by *adits* and horizontal or near-horizontal workings. Once the rim areas had been thoroughly prospected, it became necessary to explore the tops of the mesas. Mines then were developed by vertical and inclined *shafts*, *incline adit*, (slope-entry) and *open cut* (Figure 10). Before a newly discovered deposit could be developed, a miner had to evaluate factors relating to the type and location of a mine opening--topography; depth, thickness, shape, size, center, and lowest point of the ore body; condition of the rock and overburden; utility of any existing workings; property boundaries; and comparative costs of alternate methods of entry. For ore deposits greater than 150 to 200 ft deep, shaft methods were preferred in which the ore was removed either by open stopes without support or by open stopes with pillar and timber supports. Open-cut mining depends on type and thickness of overburden; thickness, size, and grade of ore; mining costs compared to those of the cheapest underground method; and completeness of extraction compared to underground methods. Most of the mines in Mesa County are developed by adit and slope-entry, followed by open cut and lastly by shaft (Figure 11). For details on methods and costs of an example mine, the La Salle, the reader is referred to Dare (1961).

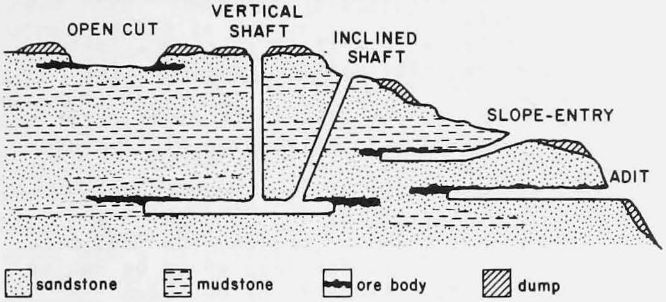


FIGURE 10. Diagrammatic cross-section of basic mining methods in the Uravan mineral belt. Tunnels are most commonly driven inward from the edge of the mesa. Shafts and open cuts are developed on top of the mesa.

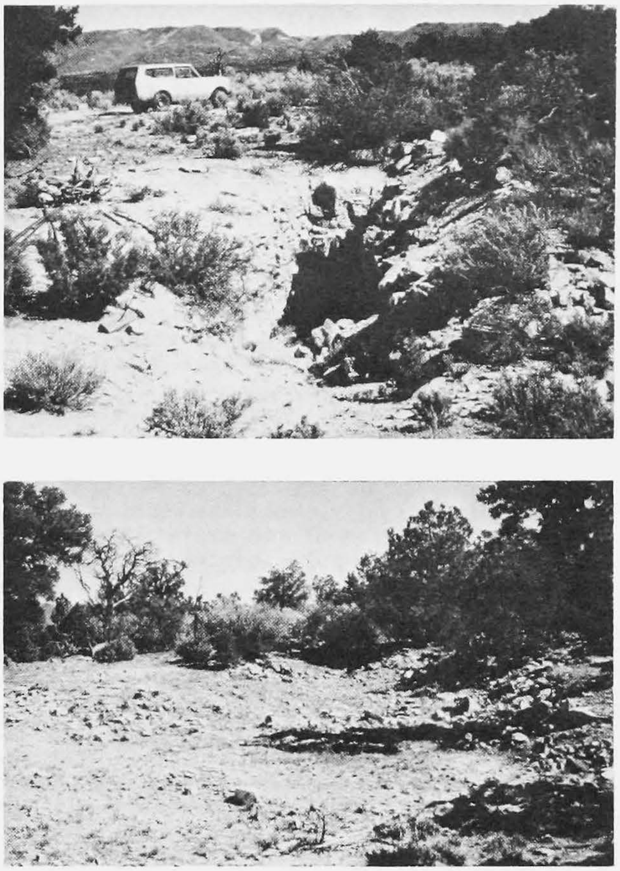


FIGURE 11. Typical mine adit (top) and open cut (bottom) in the Gateway district. These mines, located in the Outlaw group, produced ore from sandstones in the upper Salt Wash Member of the Morrison Formation.

Future Potential

The development of new mines in recent years demonstrates industry's renewed interest in the Uravan mineral belt. Increased yellow cake prices brought on by the demand for fuel in nuclear generating plants has stimulated exploration on all levels, from core drilling to airborne radiometric surveying.

The many years of geological study in the area have pointed out several exploration criteria that may be used on a small scale (McKay, 1955). First, near large ore deposits, ore-bearing sandstones usually exceed 40 ft in thickness. Second, near ore deposits, sandstones appear light brown in color, but turn reddish away from the ores. Third, mudstones in and below ore-bearing sandstones are altered from red to greenish-gray. Fourth, sandstones near the ore deposits contain abundant carbonaceous woody matter.

One also may use several large-scale geologic relations. First, sandstones within the Salt Wash Member are dominantly lenticular and lithologically similar. Sedimentary structures trend, with local divergences, toward the eastnortheast. Second, scour-fill bedding, fossil wood, and altered mudstone are associated with ores in the upper Salt Wash strata. Third, altered mudstone is 6 to 18 in. thick beneath lenticular sands and is less than 5 ft thick beneath channel-fill sands in the upper stratum. Fourth, ore-body size is proportional to the thickness of sandstone lenses in the upper stratum. Sandstones 15 to 35 ft thick yield small ore deposits; thicker strata yield both small and large deposits. U.S. Geological Survey (1968a, 1968b, 1969) core holes on Outlaw, Blue, and Moon Mesas also show where ore and weak mineralization have been encountered.

Land Use

Historically, very few people have occupied this part of the county, and most of the permanent residents live in or near Gateway (about one percent of the county's population). Actual mining has been confined to the outcrop of the Morrison Formation, and recent discoveries show that future exploration and development will lie within the same area. Although access is very limited and somewhat difficult, ore eventually reaches Colorado 141 for convenient transport to Uravan, Naturita, or Whitewater. This road will become more vital to the industry as new mines develop and as such new processing facilities as Cotter Corporation's sampling plant reach full capacity.

Even though the mining district is isolated, one obvious problem involves the scores of unreclaimed mines and prospects. At the time of the mines' development, no laws required reclamation of the properties. Legally, new mines would be subject to the latest revision of the state's reclamation law, but such efforts would scarcely be noticeable in this area.

Another vital concern that has arisen in the last few years is the radiation hazard of uranium mill tailings. In 1974 ERDA undertook an inventory of 21 tailings sites in eight western states (nine sites in Colorado) for which remedial measures were deemed necessary. Ford, Bacon, and Davis Utah Inc. studied the Climax Mill tailings, and their reports of 1977 give the following information.

During its 19-year operation from 1951 to 1970, the Climax Mill generated 2.2 million tons of tailings, 1.9 million tons of which remain on the site. The original ore averaged 0.28 percent U_3O_8 and 1.41 percent V_2O_5, but tests show that the tailings average 0.017 percent U_3O_8. Presently the pile covers about 59 acres and is stabilized by a 6-in.-thick grassed earth cover (Figure 12) and by an earthen dike along the Colorado River. Major health concerns arise about exposure to gamma radiation and about inhalation and ingestion of radionuclides (^{230}Th, ^{226}Ra, and ^{222}Rn and its daughter products) released from the pile.

FIGURE 12. Uranium mill tailings near the Climax Uranium Company mill at Grand Junction. The 1.9-million-ton pile, although stabilized with a 6-in. grassed earth cover, is one of several Colorado sites that pose major disposal problems.

Ford, Bacon, and Davis Utah presented eight options and cost alternatives for remedial work on the tailings. One solution not considered was the feasibility of secondary recovery of uranium. The original mill process was so efficient that the 0.017 percent U_3O_8 left in the pile cannot economically be recovered at current prices. The eight options include decontamination and stabilization of the present site or removal of the tailings to one of five other sites:

1) on-site decontamination; maintenance and security
2) stabilize with 2-ft earth cover, revegetate, decontaminate; strengthen river dike with riprap
3) same as (2) but with 13-ft earth cover
4) move tailings to Whitewater Hill; other steps as in (1)
5) same as (4) but at East Orchard Mesa site
6) same as (4) but at Indian Wash site
7) same as (4) but at Grasso Mine Road site
8) same as (4) but tailings would be hauled by rail to site north of De Beque

Estimated costs rise from $470,000 for option 1 to $18,130,000 for option 8, and potential adverse effects decrease from options 1 to 8.

The first three options do not involve transport of the tailings. Wind and water erosion can be controlled more effectively, and 13 ft of soil cover theoretically would reduce radon gas escape by 95 percent. As to the options for removal, the Whitewater Hill site, the closest, would either incorporate the existing landfill there or utilize a side canyon too steep for a normal landfill. The Indian Wash and Grasso Mine Road sites, on otherwise unusable land, have the advantage of isolation but the disadvantage of a haul route through populated areas. The most remote site, East Orchard Mesa, involves haulage through a much less populated area. The site north of De Beque would be large enough to accommodate tailings from both Grand Junction and Rifle. Its location on the railroad also facilitates rail transport from both towns.

At this point in the study, potential social impacts and the implementation, maintenance, and monitoring costs for each option should be evaluated. After this evaluation and the selection of the desired option, Ford, Bacon, and Davis Utah will prepare plans and specifications for the remedial action.

PART 3: MINERAL FUELS

INTRODUCTION

Mesa County is fortunate to possess, in addition to metallic resources, a variety of mineral fuel resources, among which coal and natural gas predominate. Petroleum has been produced in small quantities only in the last 4 years. Battlement Mesa and Grand Mesa contain substantial amounts of oil shale, but their potential remains essentially unevaluated. The recent production picture is dominated by wells in eight gas fields and two coal mines. Increased demand for these vital commodities will intensify exploration and development of the county's resources.

NATURAL GAS AND PETROLEUM

Scattered across the northern one-third of the county are 25 gas fields that, although having produced from a relatively restricted portion of the geologic column, extend across varied physiographic terrains, from the Upper Grand Valley on the west through the Roan Plateau and into the Battlement and Grand Mesas regions. Structurally the gas resources are related to northwest-to-southeast-trending anticlines associated with the Uncompahgre Uplift and with subsurface folding in the Piceance Creek Basin.

History of Development

Development of oil and gas resources in Mesa County began just after the turn of the century with the discovery of oil near De Beque (Woodruff, 1913). In 1902 the De Beque No. 1 well encountered oil at depths of 614 ft and 790 ft. At the time of Woodruff's investigation in 1910, nearly all the gas from the well was used at a single residence. This initial discovery led to the drilling of ten more wells in the next two years. The locations of the early wells in the De Beque field (Plate 2) were approximated from Woodruff's (1913) geologic map. Most of the early wells produced gas, and several yielded a few barrels of oil. In addition to these occurrences, Arthur Lakes (1902) reported natural gas seeping from springs in the bed of the Colorado River just below De Beque.

In 1925 the Garmesa field came into production, but only the Garfield County portion of the field has reported gas production. Following the Asbury Creek discovery in 1949, eleven other fields came into production in the 1950's, and eight more followed in the 1960's. The latest discovery in the county is the Vega field, located southeast of Vega Reservoir State Recreation Area in the Plateau Creek valley.

On Plate 2, gas fields have been denoted by pattern, some reflecting known subsurface structures and others encompassing a general area of influence.

Production and Reserves

Table 7 summarizes the geologic characteristics and production statistics of the named fields in the county. Divide Creek heads the list in terms of cumulative production, followed by Plateau, Buzzard Creek, Bar X, Asbury Creek, Hunter Canyon, and Buzzard, all exceeding 1,000,000 Mcf. Together these seven fields account for 97 percent of the county's cumulative production; Divide Creek alone accounts for 65 percent of the total. Two-thirds of all the fields produced from the Mesaverde Group. The remainder produced from the Mancos, Dakota, Buckhorn, Morrison, and Entrada Formations, and one from the Wasatch. Mesa County's production as a percentage of the state total has been rather minimal, ranging from a low of 0.47 percent in 1960 to a peak of 6.1 percent in 1967 and back down to about 1 percent in 1976.

The county has produced a negligible amount of oil compared to the state total. Significant production first came in 1974 from the Gipson-Kelley well in the Bar X field. Table 8 shows that the cumulative oil production through 1977 slightly exceeds 17,500 bbl.

Table 8. Mesa County petroleum production.

Bar X field	Oil (bbl)	Cumulative oil (bbl)
1974	3,284	3,284
1975	10,186	13,470
1976	2,548	16,018
1977	1,510	17,528

Gas production histories of the individual fields are shown graphically in Figures 13, 14, and 15. Most curves show a distinct decline 1 to 3 years after initial production. Only the Bar X and Plateau fields have shown marked increases within the last 4 years. The total county production curve shown in Figure 15 generally reflects the Divide Creek field curve from 1965 to 1975, when the bulk of that field's production was realized. During 1966 the county attained its peak production of 8,622,924 Mcf and for the last 4 years has fluctuated around 1,880,000 Mcf.

Haun and others (1976) have estimated Mesa County gas reserves as of 1/1/75 to be 21,961,905 Mcf, which is the product of the 1974 production and a constant decline factor. This factor was calculated from a geometric progression based on a 6-percent annual production decline for a period of 20 years in several west slope counties whose gas production largely is not associated with oil production. This 6-percent average decline may, however, not accurately reflect the conditions specifically in Mesa County, as will be seen in the production-decline scale below.

TABLE 7. Mesa County gas field statistics.

Field	Years Producing	Cumulative Production 1/1/78 (Mcf)	Producing horizon	Thickness (ft)	Specific Gravity	Btu	Porosity %	Type of Trap
De Beque	'02		Kmv					
Garmesa	'25		Kd	25	-	715	-	struct.
			Kbh	25	-	884	-	
			Je	15	-	435	-	
Asbury Creek	'49-'65	2,406,841	Kd	29	0.715	866	-	strat.-struct.
			Kbh	28	0.704	890	-	
Highline Canal	'51-'61	184,129	Kd	14	0.651	889	11.3	
			Jms	20	0.783	729	12	
Bar X	'53-	4,030,372	Kd	40	0.065	1045	13.5	strat.
			Kbh	19	0.065	1045	13.0	strat.
			Jms	22	0.070	1005	13.0	struct.
			Je	40	0.095	486	22.5	struct.
Buzzard Creek	'55-	4,197,664	Kmv	40	0.66	1050	9	strat.
			Km	27	0.59	975	7	strat.
Hunter Canyon	'55-	1,879,115	Kmvz	18	-	1074	-	strat.
Divide Creek	'56-	41,139,702	Kmv	60	-	897	11.9	struct.
Mack Creek	'57-'69	251,198	Jm					
Plateau	'58-	6,240,602	Kmvc	78	0.584	1034	7.5-10	strat.
			Kmvz	43				
Sneep Creek	'58-'72	66,710	Km					
Buzzard	'58-	1,407,732	Kmv					
Coon Hollow	'58	SI	Kmv	53	-	-	-	strat.-struct.
			Kd	22	-	-	-	
Grand Mesa	'58-'66	741	Kmv	145	0.663	1144	13-20	strat.
Shire Gulch	'60-'65	29,936	Kmvc	40	0.584	1034	7.5-10	strat.
Roberts Canyon	'60-'72	375,773	Km	13				
			Kd	12				
Leon Creek	'61		Kmv	38				
Cameo	'61	29,238	Kd	13	0.615	985	17	strat.-struct.
			Kbh	13	0.595	983		
Fruita	'61-'70	607,228	Kbh	6				
Hells Gulch	'64-	150,397	Kmv					
Horsethief Creek	'64-'70	141,282	Tw	10				
Coal Gulch	'66-	110,614	Kmv					
Vega	'77-	13,263	Kmv	50				
		Total 63,327,813						

Tw - Wasatch
Kmv - Mesaverde
Kmvc - Corcoran
Kmvz - Cozzette

Km - Mancos
Kd - Dakota
Kbh - Buckhorn
Jm - Morrison
Je - Entrada

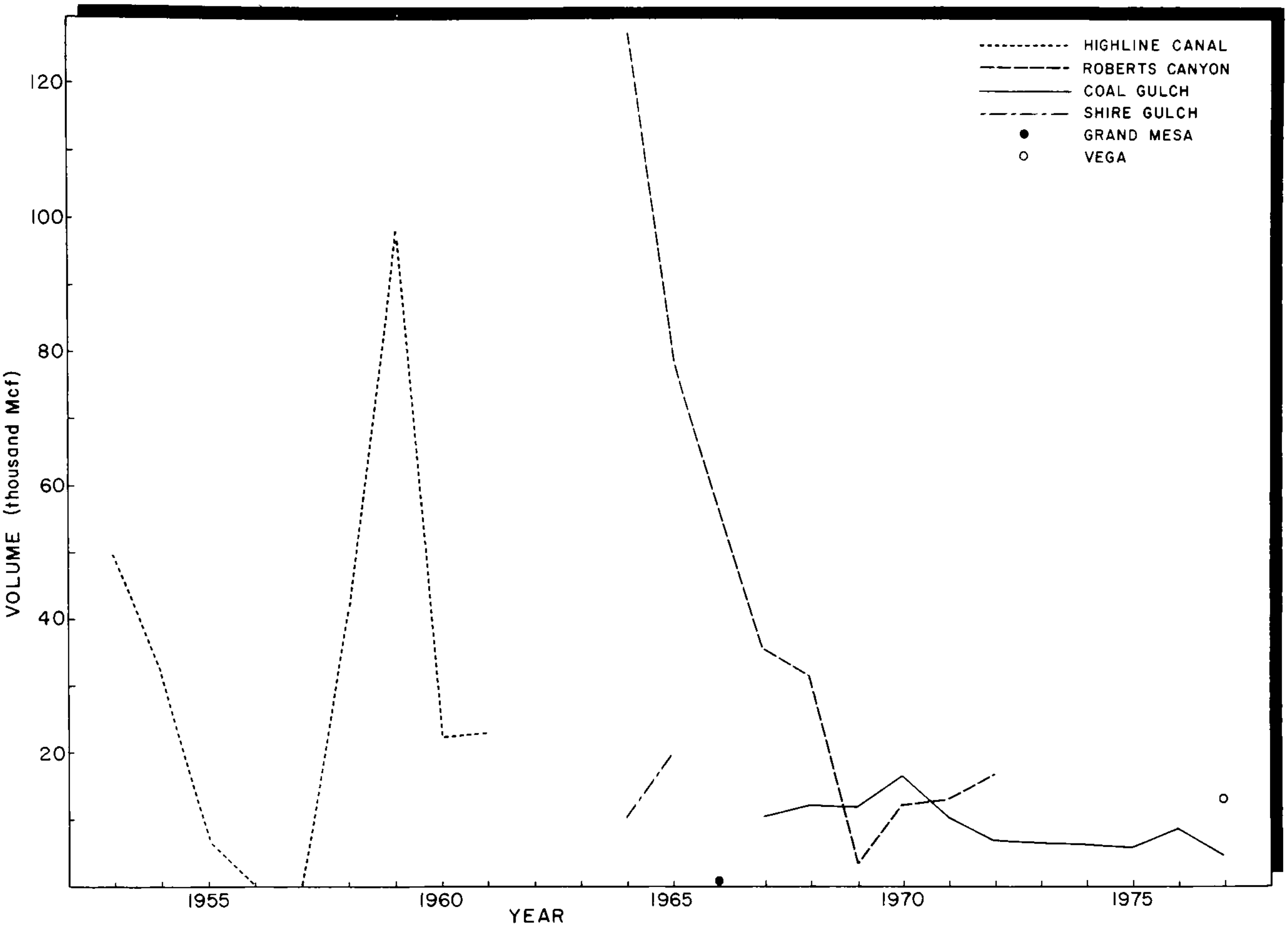


FIGURE 13a. Mesa County gas field production histories (low-volume fields).

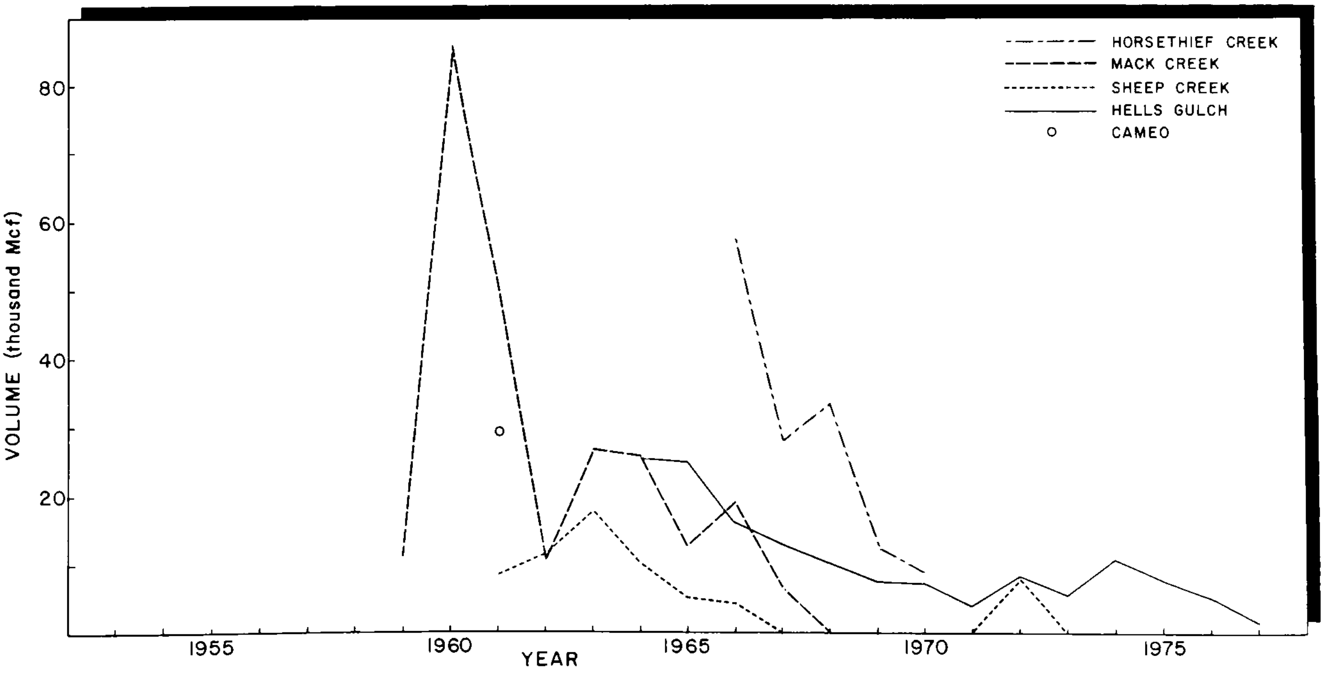


FIGURE 13b. Mesa County gas field production histories (low-volume fields).

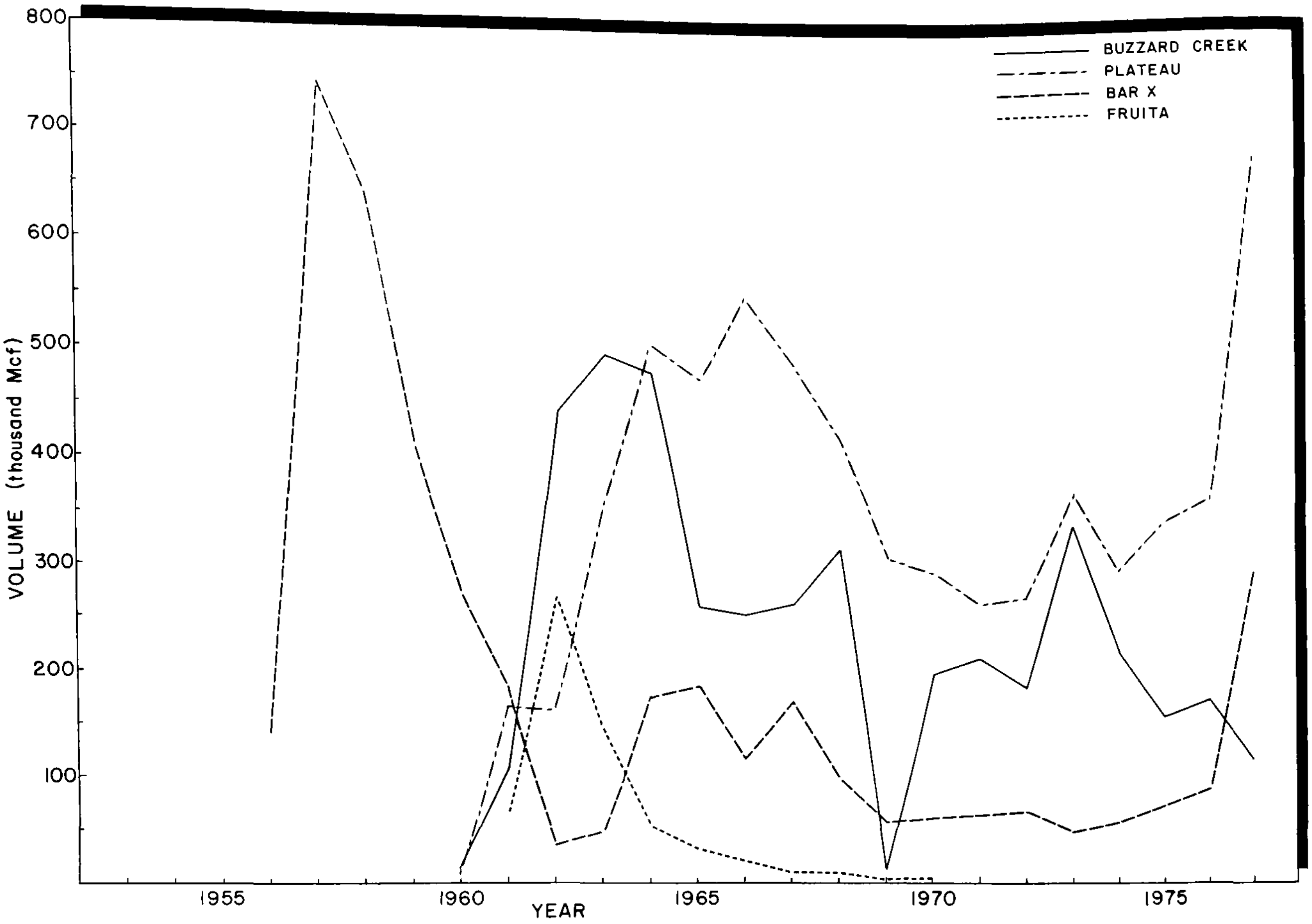


FIGURE 14a. Mesa County gas field production histories (moderate-volume fields).

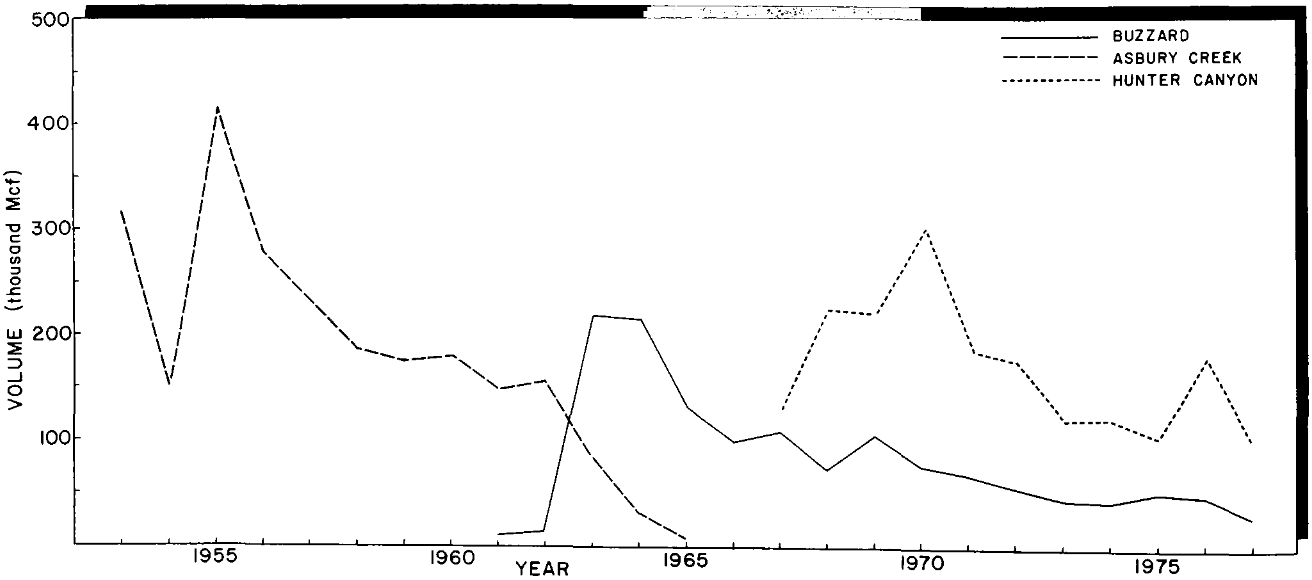


FIGURE 14b. Mesa County gas field production histories (moderate-volume fields).

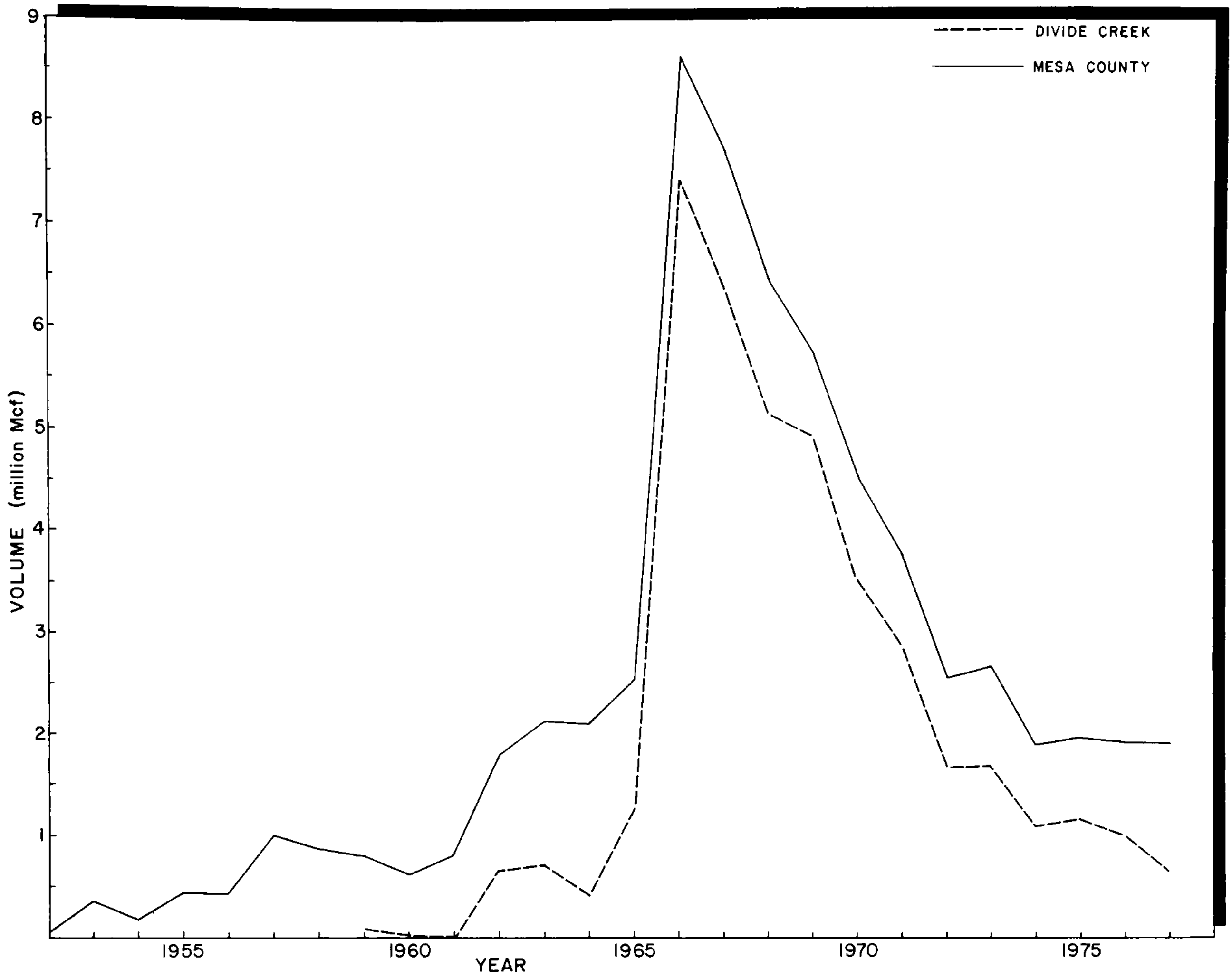


FIGURE 15. Mesa County gas field production histories (high-volume fields) and total natural gas production in Mesa County.

Year	Prod. (Mcf)	Decline (Mcf)	% Decline
1966	8,622,924		
1967	7,657,768	965,156	11.2
1968	6,403,817	1,253,951	16.4
1969	5,708,831	694,986	10.0
1970	4,495,774	1,213,057	21.3
1971	3,731,679	764,095	17.0
1972	2,514,936	1,216,743	32.6
1973	2,635,207	-120,271	-4.8
1974	1,857,118	778,089	29.6
1975	1,924,824	-67,706	-3.7
1976	1,884,891	39,933	2.1
1977	1,876,444	8,447	0.5

Since the peak year of 1966, production has declined somewhat erratically. During two different years, production increased slightly, giving a negative decline.

To calculate the county reserves from this production record, one may begin with Haun and others' method of geometric progression, given by the formula

$$S = a\frac{1-r^n}{1-r} \quad , \qquad \text{(Eq. 1)}$$

where S = reserves, a = production for last year of record, r = percent of previous year's production, and n = time base in years. The multiplier f is given by

$$f = \frac{1-r^n}{1-r} \quad . \qquad \text{(Eq. 2)}$$

Haun and others used a 6-percent basis for calculating r, apparently an average value for several western slope counties. A new r value may be calculated specifically for Mesa County. A straight arithmetic average of the decline percentages listed above gives a 12.1-percent annual decline for the 11-year post-peak period. A more accurate percent decline can be calculated by averaging the sum of compounded average ratios of annual production to peak production. This procedure gives an annual decline of 14.7 percent and a corresponding r value of 0.853 (100%-14.7%). To determine the time base n, I have selected the time at which the annual production equals 1 percent of the peak. Selecting such a figure assumes no effects from new discovery wells or from secondary and tertiary recovery. At 1-percent cutoff,

$$\begin{aligned} r^n &= 0.01 \\ 0.853^n &= 0.01 \\ n &= 29 \text{ yr.} \end{aligned}$$

With values of r and n determined, the multiplication factor f is found by

$$f = \frac{1-r^n}{1-r}$$

$$= \frac{1-0.853^{29}}{1-0.853}$$

$$f = 6.74$$

This factor is considerably less than the 11.83 used by Haun and others (1976).

A check on the accuracy of this procedure can be made by constructing a semilog plot of years after peak production against reported production. Because the theoretical production curve declines logarithmically after the peak year, a straight line was fitted through the points on the semilog plot and extrapolated to a point in time in which production becomes negligible. Here again, such an extrapolation assumes no new discoveries or additional recovery. At an ultimate production level of 1 percent of peak, the extrapolated line reaches the production level of 86,229 Mcf (8,622,924x0.01) at a time of 27 years after peak, which agrees closely with the 29 years calculated by the equations. A second extrapolated line that more nearly approximates the n value of 29 years was drawn to reflect the spread of the 1976 and 1977 data points, which themselves include new discovery wells. The effect of those new discoveries is to shift the production line to the right, thereby extending the total life of the reserves and increasing ultimate production.

Returning to equation 1 for the calculation of reserves,

$$\begin{aligned} S &= (8{,}622{,}924 \text{ Mcf})f \\ &= 58{,}118{,}508 \text{ Mcf.} \end{aligned}$$

This figure represents the total reserves at the end of 1966, the peak year. Adding this to the cumulative production through 1966 gives an estimated ultimate recovery of 80,750,845 Mcf. Subtracting each successive year's production from the 1966 reserves gives the reserves at the end of any particular year. At the end of 1977, estimated reserves total 17,427,319 Mcf, or 30 percent of the 1966 reserves. Reserves after 1974 total 23,113,478 Mcf, which is 5.25 percent higher than the 21,961,905 Mcf estimated by Haun and others.

Because only 4 years of records exist for oil production in the county, no detailed analysis can be made. However, Haun and others estimate only 30,000 bbl of reserves after 1974. The reserves left after successive years are as follows:

TABLE 9

	Prod. (bbl)	Cumulative Prod. (bbl)	Reserves (bbl)	Ultimate Recovery (bbl)
1974	3,284	3,284	30,000	33,284
1975	10,816	13,470	19,914	
1976	2,548	16,018	17,366	
1977	1,510	17,528	15,856	

Again the reserve estimates after 1975, 1976, and 1977 are based on a straight-line production-decline curve as it would appear on a semilog plot. After 1977 only 53 percent of the estimated reserves remain. Assuming no new discoveries or recovery enhancement, production and reserves could be reduced to trivial amounts in only a few more years.

Processing and Transportation

Operations attendant to gas and oil production shown on Plate 2 include pipeline systems and compressor stations for transportation, two plants for processing, and a number of storage and distribution facilities for petroleum products (Figure 16).

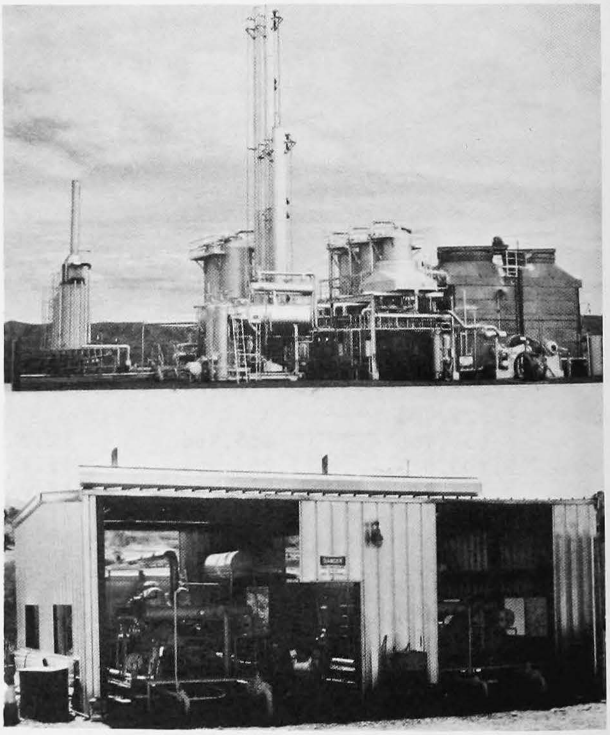


FIGURE 16. Mesa County natural gas processing facilities. On top, Continental Oil Company's plant on Little Salt Wash processes several natural gas products for consumption in Grand Junction. At bottom, the compressor station of Rocky Mountain Natural Gas Company, one of four such stations in the county, maintains the flow of natural gas through an intricate network of pipelines.

Pipelines have been labelled with company name and pipe diameter. The following compressor stations and facilities were located:

⊙ Asbury (Western Slope Gas Co.)
NE/4 sec. 34, T9S, R101W, 6th P.M.

⊙ Western Slope Gas Co.
NE/4 SW/4 sec. 30, T8S, R100W

⊙ Rocky Mtn. Natural Gas Co.
NE/4 SE/4 sec. 35, T9S, R95W

⊙ Northwest Pipeline Corp.
NE/4 SE/4 sec. 21, T9S, R104W

CONOCO gas processing plant
NE/4 sec. 34, T9S, R101W

Gary Western refinery
sec. 11, T1N, R3W, Ute P.M.

Continental Oil Company operates a gas processing plant south of the Asbury Creek gas field on Little Salt Wash about 7 miles northeast of Fruita. The adsorption-type plant has a design capacity of 20 Mcf/day and processes propane, butane, and natural gasoline (Frank Stivison, 1977, pers. comm.).

Perhaps one of the most well-known facilities in western Colorado is the oil refinery now operated by Gary Western Co. and located on U. S. 6 and 50 three miles northwest of Fruita. The facility is unique from three standpoints. First, the original feed pipeline was the first slurry pipeline constructed in the country. Second, the refinery was the first privately financed system in the United States to manufacture conventional petroleum products from a nonpetroleum source. Third, the plant's by-product coke is both manufactured *and* calcined there, whereas other companies required two different locations for the process. The history of the slurry pipeline and the refinery will be discussed in detail in the section about bitumens.

Land Use

Most of the county's gas fields lie in nonirrigable, unpopulated areas such as Upper Grand Valley and the Roan Plateau, or in unpopulated but vegetated lands such as upper Plateau Creek Valley and parts of Grand Mesa and Battlement Mesa. This geographic aspect and the fact that the wells and fields involve minimum surface disturbance greatly lessen the land-use impacts of this type of mineral resource development.

Surface facilities generally include several small structures at the well site, pipeline terminals, and an occasional compressor station, meter, or collection terminal. Most pipelines are buried, and both the buried and small-diameter surface lines follow existing road and canal rights-of-way. Buried facilities and a minimum surface involvement enable the land over the gas fields to support a variety of other uses, from agricultural to residential.

A potential land-use conflict may, however, arise in the Plateau field where most of the county's current gas production is taking place. It appears to me that both exploratory drilling and residential development compete to some extent with the area's farming and ranching. Although both well sites and home sites are relatively small, they do involve a certain amount of land modification because of the hilly topography. Where flat sites cannot be obtained, cuts and leveling must be done. Drilling sites may at first be rather objectionable to some, but once the well is brought in, a certain amount of site rehabilitation is done, and the site structures become less noticeable.

Some drilling allegedly is done indiscriminantly, but a new Mesa County permit resolution, adopted January 10, 1978, should help to ease the situation by requiring a readily obtainable special-use permit for gas and oil wells and their attendant roads and sites. The resolution and a sample application form appear in Appendix 1.

The Plateau Creek valley contains a variety of mineral, agricultural, and recreational resources, and I believe that the land is capable of supporting development associated with each. Regarding natural gas exploration and development, such county actions as the special-use permit and especially the input of the several communities involved should enable a systematic and satisfactory development of the Plateau field's reserves.

OIL SHALE

The Piceance Creek Basin in western Colorado contains an estimated 1,370 billion barrels of oil in shale with a grade of 15 gal/ton or better, making the basin one of the world's largest reserves. Federal Oil Shale Tracts C-a and C-b in Rio Blanco County alone contain nearly 9 billion barrels of oil. The eastern panhandle of Mesa County lies on the southern end of the Piceance Creek Basin and contains oil-shale deposits worthy of discussion.

A. C. Peale (1878) compiled probably the first geologic map of the Green River Formation during the early surveys of the territories. The oil-bearing nature of the rocks was described by Eldridge (1901), and mapping was done later by Woodruff and Day (1915), Winchester (1923), and George (1921). Donnell (1961a) provides detailed stratigraphy of the Green River Formation.

Development of the basin's oil shale resources has seen a long and controversial history beginning in the early 1900's and emerging periodically through the present. Seventy years of research by numerous agencies and investments of hundreds of millions of dollars by oil companies have, so far, failed to achieve shale-oil production on a commercial basis. However, substantial strides have been made in retort technology, mining, and reclamation.

In Mesa County, oil shales in the Green River Formation underlie Battlement Mesa and part of Grand Mesa. The prominent layers form one of the higher cliff lines in the lower benches of both mesas. Donnell (1961a) recognized four members in the Green River Formation, from oldest to youngest: Douglas Creek, Garden Gulch, Parachute Creek, and Evacuation Creek. He refers to the Anvil Points Member as a southwestward lateral equivalent of the Douglas Creek Garden Gulch, and lower Parachute Creek members. The Parachute Creek Member contains the thickest and richest oil-shale zones in the basin. Actually the term *oil shale* is a misnomer--the *shale* is mostly marlstone, and the *oil* is an organic material known as kerogen. At its type locality along Parachute Creek in Garfield County, the member exceeds 1,000 ft in thickness and is composed almost entirely of marlstone and shale. Of the three recognizable oil-shale zones in the member, the 300- to 680-ft-thick uppermost zone is most important economically. The rich basal unit of this zone, known as the Mahogany, yields an average 41.2 gal/ton, although it has assayed as high as 79 gal/ton.

The outcrop of the Parachute Creek Member and the Mahogany zone around Battlement Mesa, as shown on Plate 2, was modified after Donnell and Yeend (1968b, 1968c, 1968e). Outcrops of the member on the northern slopes of Grand Mesa were approximated by airphoto interpretation from Cashion (1973) and Tweto and others (1976). Glacial debris and landsliding prevented showing more than just a few isolated outcrops on the steeper slopes and knobs between Plateau Ridge and Skyway. West and southwest of Skyway, the entire Green River Formation under the mesa thins rapidly, and the validity of identifying a specific member becomes questionable.

Grand Mesa and Battlement Mesa shale-oil resources are difficult to evaluate because of the lack of detailed geology and analytical information. The oil yield of the shales logically decreases away from the deep central part of the basin toward the margins where individual members thin and become indistinguishable. Table 10 lists the available oil yields from several sites on the two mesas. The sample localities shown on Plate 2 were approximated from Winchester (1923) and Donnell (1972). One can readily see the decrease in average yield just from Battlement Mesa southward to Grand Mesa. Winchester's analyses from Battlement Mesa give a 30-gal/ton thickness-weighted average, and those from Grand Mesa average 14 gal/ton (W-2) and 27 gal/ton (W-3). Donnell's Grand Mesa analyses average 10 to 20 gal/ton with an overall average of 16 gal/ton. With so few data points and so little detailed geology, one cannot practicably calculate the resource potential, much less the reserves.

In addition to the somewhat low yields, two other aspects of the deposits also detract from their viability. First, access to the Battlement Mesa shales is limited to a few trails from Plateau Creek, Buzzard Creek, Mamm Creek, and the Colorado River. Access to Grand Mesa's isolated remnants is restricted to three roads and trails. Second, and probably more importantly is the fact that nearly all the outcrops lie within the Grand Mesa National Forest. It seems unlikely that the resources could ever be utilized under these conditions when larger, higher-yield, and more readily accessible reserves lie to the north in Garfield and Rio Blanco Counties.

TABLE 10. Oil shale analyses from Battlement and Grand Mesas.

Map Ref.*	Sample Number	Location	Sampled Thickness	Yield gal/ton
W-1	362	sec. 5, T9S,R95W (BM, Durant Gulch)	4'6"	47
	363	do.	6'10"	21
	364	do.	4'8"	22
	365	do.	1'10"	36
	365A	do.	4'8"	33
	366	do.	3'	27
W-2	367	sec. 29,T10S,R93W (GM, Park Creek)	4'4"	13
	368	do.	1'2"	28
	369	do.	2'6"	6
	370	do.	8'3"	14
W-3	371	sec. 31,T10S,R94W (GM, Big Creek)	3'2"	36
	372	do.	1'8"	24
	373	do.	9"	15
	374	do.	3'10"	37
	375	do.	2'	13
	376	do.	2'1"	13

			Core Thickness	Yield gal/ton Ave	Max
D-1	1	sec. 29,T10S,R93W (Park Creek)	21'	14	40
D-2	2	sec. 5,T11S,R94W (Collbran Road)	30'	19	55
D-3	3	sec. 27,T11S,R96W (Mesa Road)	16'	20	40
D-4	4	sec. 10,T12S,R97W (Lands End)	8'	10	15

* W-location approximated from Winchester (1923)
D-location approximated from Donnell (1972)

Apparently some interest in these deposits was shown in the early years of oil shale investigations. Colorado Division of Mines annual reports of the 1920's state that several oil shale companies headquartered in De Beque and Collbran managed properties presumably located within the county. The only apparent use of oil shale in the county was reported in an early journal article by L. W. Thiele (1882) about coal potential near the Book Cliffs:

> *"Grand [Colorado] River has cut in some portion of its course through an extensive stratum of oil-bearing shale or slate, the debris of which, rounded and flattened by the ceaseless action of the turbulent current, densely cover the bottom of the river for some distance below the mouth of the Gunnison. During the past summer, it was ascertained by prospectors and hunters that these shales would burn with a bright flame, and throw out a reasonable quantity of heat, sufficient for camping and cooking purposes. To some extent, these oil-bearing shales are utilized by the inhabitants of Grand Junction, who haul them up into town from the river-bed by the wagon-*

> *load and use them in their stoves. From the accompanying specimen the editor of the Engineering and Mining Journal will be able to judge whether its occurrence is an indication of paying petroleum deposits in that country or not."*

In effect, the Grand Junction residents hand-picked cobbles and boulders of oil shale that originated 35 to 55 miles upstream and subsequently were moved by the river and incorporated into the flood-plain gravel deposits. Despite recent energy shortages, however, it is difficult to imagine the revival of such a novel practice.

COAL

Mesa County's position in the regional coal picture can be seen in Figure 17. All the county's coal resources lie in the southeastern part of the Uinta Region, a 23,000-sq-mi basin extending from east-central Utah into northwestern Colorado. Twelve fields have been developed around the margin of the region, three of which are partly contained in Mesa County--the Book Cliffs, Grand Mesa, and Gunnison River fields. The coals lie in a relatively narrow stratigraphic interval but cross three physiographic divisions--the Uncompahgre Plateau, Book Cliffs, and Lower Mesas of Grand Mesa (Plate 1b).

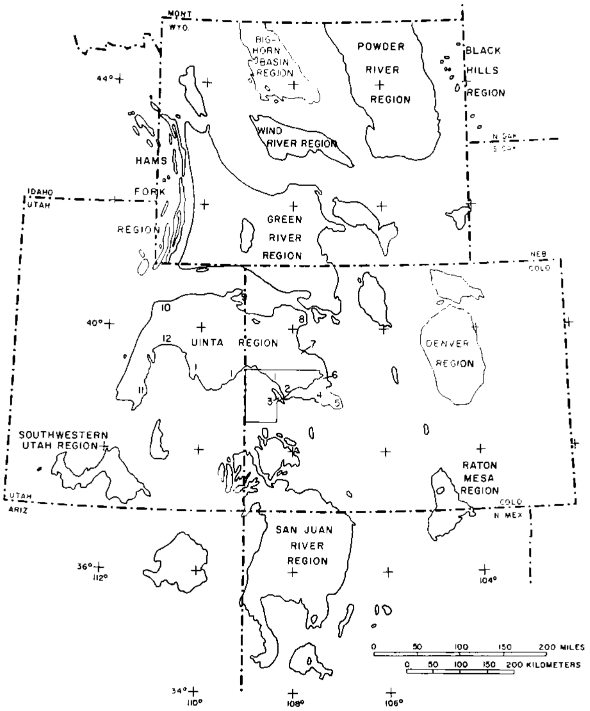
The earliest geological descriptions of the Book Cliffs area were made by Peale (1878) for the Hayden Survey. Later more detailed geology and coal development appeared in reports by Eldridge (1901), Richardson (1907, 1909), and Erdmann (1934). Descriptions of the Grand Mesa and Gunnison River coals appear in Lee (1909, 1912) and Woodruff (1912).

The following sections about each of the fields will include the geology and coal occurrences, coal quality, and the criteria for identifying the MRA's shown on Plate 2. Coal production and development potential will be treated in a final section.

Book Cliffs Field

Physiography and General Geology

The prominent skyline north of Grand Junction is the Book Cliffs, an impressive escarpment that separates the Grand Valley from the Roan Plateau (Plate 1b). The 1300- to 1600-ft-high cliff line starts at the Colorado River near Palisade and extends for more than 150 miles through Mesa and Garfield Counties into Emery County, Utah. From the Colorado River to Indian Creek, the cliff line is relatively undissected and interrupted only by the Mount Garfield prominence northwest of Palisade. Northwest of Indian Creek, the cliff line takes on a jagged appearance because of the short but steep-walled canyons that have been eroded. In Mesa County only a few canyons completely transect the cliffs, and only two of these, Coal Gulch and Hunter Canyon, are traversable by road. Most of the mines are accessible by a few dirt roads that climb northward from Grand Valley atop the gravel-capped mesas and terminate at the base of the cliffs.



1 Book Cliffs
2 Grand Mesa
3 Gunnison River
4 Somerset
5 Crested Butte
6 Carbondale
7 Grand Hogback
8 Danforth Hills
9 Vernal
10 Black Tail
11 Emery
12 Castlegate

FIGURE 17. Coal basins in the Southern Rocky Mountains. Mesa County's resources lie in the southern Uinta Basin, which includes 12 fields in parts of Colorado and Utah (listed above). Redrawn from Averitt (1972).

The geology exposed along the cliff line can briefly be described as a complex interfingering between the marine and nonmarine environments of the Lower Mesaverde Group, manifested here in the Mount Garfield Formation. The rocks reflect a general eastward regression of the Late Cretaceous inland sea that once covered much of Colorado. Structurally the Book Cliffs rock sequence dips gently to the northeast away from the Uncompahgre Uplift and into the Piceance Creek Basin. The Book Cliffs monocline, associated with the Uncompahgre Uplift, parallels the cliff line and locally steepens the bedding.

As an interesting historical note, Erdmann (1934) traced the origin of the name *Book Cliffs* and believed that the term first appeared in Beckwith (1854) in the narrative of Captain Gunnison. Through the years, various explorers and geologists used the terms *Book Cliffs* and *Roan Cliffs* to describe the Mesaverde escarpment in this region. The titles were even used in reference to the escarpment of the Tertiary Green River Formation near Rifle. Another name, the *Little Book Cliffs*, was once proposed for the section of the cliffs between Palisade and East Salt Creek. Whether or not the term was used correctly, early observers were impressed by what they saw and analogized the alternation of shales and sandstones to a stack of books lying on a table. Gannett (1877) and Campbell (1922) cited the origin of the name from the resemblance of the sandstone cap over the curved shale slope to the edge of a bound book. Regardless of which theory is correct, one should note that both claims arise directly from the geology.

Detailed Geology

To fully understand the complex intertonguing of the Mancos and Mesaverde, one really must start in Utah where the basal Mesaverde units begin their transformation eastward. An inherent problem in this discussion is the inconsistency of stratigraphic terminology. Through the years many geologists have studied this sequence but have applied a variety of local names from both Colorado and Utah in working the units eastward. The following discussion is based on the work of Erdmann (1934), Young (1955, 1959, 1960b, 1966), Fisher and others (1960), and Gill and Hail (1975).

The intertonguing of the Mancos-Mesaverde contact represents a shift in depositional environments through space and time. We see nonmarine environments (coastal plain, lagoon, beach) moving from northwest to southeast and replacing a dominantly marine environment, with periodic westward reinvasions of the sea. The cyclic nature of this process begins in Utah where the nonmarine environments move farther eastward after each marine transgression.

The discussion of the Book Cliffs geology can be facilitated with a correlation chart of terminology used by Young and by Fisher and others. On the left side of the chart below, Young's classification of the Price River Formation in Utah consists of two facies--the inland Farrer grading eastward into the coal-bearing Neslen. Fisher and others classification in the eastern Book Cliffs (western Colorado) consists of the Sego Sandstone at the base of the Mesaverde overlain by the coal measures and barren measures of the Mount Garfield Formation.

In the Price River Formation the basal Castlegate Sandstone is prominent in the northern Uinta Basin of Moffat and Rio Blanco Counties, but disappears just a few miles into Garfield County. Where the member is persistent, Mancos Shale above it is termed the Buck Tongue. East and southeast of the farthest extent of the Castlegate, the Buck Tongue becomes indistinguishable from the main body of the Mancos Shale. The next youngest member, the Sego, begins as one sandstone unit, but by the time it reaches Mesa County, it has split into two sandstones separated by another Mancos marine shale called the Anchor Mine Tongue. Thus, the lower Sego represents the base of the Price River Formation in northern Mesa County. As with the Castlegate, the lower Sego thins southeastward and disappears between Anchor #1 Mine and Hunter Canyon. Likewise, the Anchor Mine Tongue passes into Mancos Shale. At Hunter Canyon the upper Sego becomes the base of the Mesaverde Group.

At East Salt Creek, the lower Sego consists of 110 ft of lenticular sandstone and sandy shale grading upward into two massive sandstones separated by thin-bedded sandstone (Fisher and others, 1960). The 115-ft-thick Anchor Mine Tongue at East Salt Creek consists of a lower sandstone that grades into a gray sandy shale containing carbonaceous layers and thin coals. Young showed that the coal seams Erdmann had called the "Anchor" coal were really in beds above the upper Sego and not in the Anchor Mine Tongue at all.

A third tongue of Mancos Shale lies above the upper Sego and persists northwestward to somewhere between the Corcoran Mine and Adobe Creek. Above this shale tongue lies the basal littoral sandstone of Young's Corcoran Member. Beginning near Big Salt Wash the member extends eastward probably as far as

Young		Fisher and others	
Price River Formation			
Inland facies (non-coal)	Lagoonal facies (coal-bearing)	Central Book Cliffs	Eastern Book Cliffs
		Tuscher Formation	Hunter Canyon Formation
Farrer facies		Farrer Formation	Mount Garfield Formation: barren measures
	Neslen facies: Unnamed member Cameo Member Cozzette Member Corcoran Member	Neslen Formation	coal measures
	Sego Buck Tongue (Mancos) Castlegate	Sego Sandstone Buck Tongue (Mancos) Castlegate Sandstone	Sego Sandstone: upper Anchor Mine Tongue lower
Mancos Shale		Mancos Shale	Mancos Shale

the Watson Creek area southeast of Palisade. This member supposedly contained Erdmann's "Palisade" coal bed. The Cozzette Member, named for exposures at the old Cozzette Mine north of Palisade, is bounded by tongues of Mancos Shale. Young begins this member near Hunter Canyon, although Gill and Hail extend it farther northwestward to the Farmer-Nearing Mine.

The uppermost coal-bearer in Young's Price River Formation, the Cameo Member, appears at Hunter Canyon and extends eastward, capping Mount Garfield. The Cameo coal lies directly on the basal sandstone and consists of two beds separated by a thick parting. The Carbonera coal lies about 60 ft above the base of the Cameo and attains a maximum thickness of 10 ft. Young uses the term Farrer facies for a sequence of noncoal-bearing rocks that represent dominantly inland or terrestrial environments during the last stages of the marine regression.

Much of the confusion arises when comparing Young's terminology with that of Erdmann and Fisher and others. Erdmann's Mount Garfield Formation, lying directly on the Sego, consisted of a lower coal-bearing part 305 to 666 ft thick and an upper barren part 405 to 665 ft thick. His coal measures and "barren" measures correspond roughly but not precisely to Young's Neslen and Farrer facies, respectively. Another prominent unit introduced into the sequence is the Rollins Sandstone, which Lee (1912) used as the base of the Mesaverde in the Grand Mesa area, although other workers placed it stratigraphically much higher. The Rollins probably lies within or just above Young's Cameo Member. Gill and Hail place the Rollins at the base of a sequence above the Mancos Shale tongue atop the Cozzette Member. Fisher and others show it as a thick sequence between the Palisade and Cameo coals. Although not critical to the Book Cliffs discussion, the Rollins will be treated more fully in the Grand Mesa field summary.

Map Boundary

On Plate 2 the lower boundary of the Book Cliffs coal MRA from the Garfield County line to the vicinity of the Anchor #1 Mine represents the lower Sego Sandstone. From the Anchor #1 Mine to the Book Cliffs Mine, the line represents the sandstone of the upper Sego. From the Book Cliffs Mine to the Colorado River, the boundary corresponds to the base of Fisher and others' Mount Garfield Formation (Young's Corcoran Member).

The upper boundary of the map unit at the Book Cliffs Mine is the base of Fisher and others' (1960, p. 74) *barren measures*, described in a measured section as a sequence of five equally spaced, massive sandstones lying below the sandstones of the Hunter Canyon Formation. Although I could not precisely identify this interval on the airphotos elsewhere, the boundary approximates the top of the last dominantly shale sequence in the Mount Garfield Formation, thus including the *barren measures* and probably some of the *coal measures*. For the purposes of this project, however, a difference stratigraphically of 200 or 300 ft will not materially affect the position of the line.

Book Cliffs Coal Seams

Four coal seams are generally recognized in this part of the field--Anchor (oldest), Palisade, Cameo, and Carbonera. Erdmann (1934) originally placed the Anchor Coal in the Anchor Mine Tongue, but both Young and Gill and Hail showed that the bed lay above the Sego. Erdmann noticed the 5-ft seam near the Anchor #1 Mine and traced it 9 miles westward to a point near Mack Wash just inside Garfield County. Hornbaker and others (1976) note a 6.2-ft-thick seam at the Farmer-Nearing Mine.

The Palisade coal consists of several seams from 2.7 to 9.3 ft in thickness (Hornbaker and others, 1976), increasing eastward in economic importance. Usually only one minable seam occurs in any one locality. Erdmann recognized at least seven seams, no more than three of which were represented in any one vertical section. Although he mapped a long workable outcrop, the bed was considered useless in the western area because of difficult access and burned zones. The fresh coal has a dull to subbrilliant luster, and mineral charcoal is common on bedding surfaces. Erdmann characterized most seams by local irregularities in thickness due to nondeposition, rolling of the bed floor, and "horsebacks".

The Cameo coal, 3.5 to 10.4 ft thick, is the most economically important seam, accounting for more than two thirds of the field's production. The Cameo coal occupies a relatively high position on the cliffs, but few outcrops are visible because of burned zones. Between Hunter Canyon and the Book Cliffs Mine the clean upper coal bench is separated from the lower bony bench by a thick parting of shaly sandstone. The lower impure seams contain numerous carbonaceous shales. Sandstone dikes (Figure 18) are peculiar features that have been observed

FIGURE 18. Sandstone dike in coal seam at the McGinley Mine. Note the irregular but sharp boundaries between the dike and the coal. The sand was most likely intruded upward before the organic material above it had consolidated.

at the Hunter, Book Cliffs, McGinley, Coal Canyon Strip, and Palisade Mines. These tabular bodies trend nearly perpendicular to the bedding and are known to exceed 20 ft in length. Lakes (1904a) believed that the dikes formed when sand filled fissures that had opened up in the coal and shale. A more recent theory states that such dikes are formed by the liquefaction of sand after shallow burial by cohesive sediments such as clay or mud. The sand essentially is intruded *upward* into the overlying strata, as opposed to *downward* movement in the fracture-filling theory.

The uppermost coal seams, the Carbonera, vary from 7.5 to 8.5 ft in thickness and occur as discontinuous lenses about 60 ft above the base of the Cameo zone. Erdmann cites development of these coals mainly in the western part of the field, especially around Carbonera and in Stove Canyon in Garfield County. The detached seams decrease in number, thickness, and extent from west to east.

Coal Quality

Coals in the Book Cliffs field are ranked as bituminous, mostly high-volatile C but with some high-volatile B. The low-sulfur coals show a general decrease in average heat value from oldest (Anchor) to youngest (Carbonera) and an increase in ash content (Table 11). Table 12a contains proximate and ultimate analyses from Erdmann (1934) and Richardson (1909). Erdmann's average heat values (as-received) for the four coal seams are

TABLE 11. Book Cliffs field coal analyses, as-received basis (from Hornbaker and others, 1976).

Seam	Moisture %	Ash %	Sulfur %	Btu/lb	Fusion Temp. °F
Carbonera	9.3-11.4	7.2-14.4	0.4-0.6	10,470-11,150	2,850
Cameo	5.4-11.5	5.2-15.5	0.5-1.3	10,410-12,460	2,520-2,960
Palisade	3.3-14.0	4.9-17.4	0.5-1.6	10,950-13,560	2,130-2,910+
Anchor	8.2-9.8	5.9-9.8	1.0-1.7	11,910-12,330	2,190-2,790

Carbonera	11,000 Btu/lb
Cameo	11,920
Palisade	12,040
Anchor	12,100

Both fixed carbon and sulfur decrease upward through the section. As-received heat values and sulfur contents range according to the following:

	Btu/lb	Sulfur, %
Cameo	11,639-12,017	0.56-0.7
Palisade	11,500-12,240	0.6-0.8
Anchor	12,120-12,256	0.9-1.3

Erdmann also compared heat values of the Book Cliffs coals with those of other fields and found them generally higher than Walsenburg and Canon City coals, and Thompson, Utah, and Rock Springs, Wyoming. The values were generally less than those in Crested Butte, Somerset, New Castle, Durango, and Trinidad, and Castlegate, Utah.

Grand Mesa Field

Physiography and Geography

The geology and coal occurrences of the Book Cliffs field continue south of the Colorado River, although in a different physiographic setting. The northern part of the field immediately south of the river lies in the Lower Mesa sequence of Grand Mesa, which is characterized by gently dipping cliff-forming sandstones eroded into sharp ridges and points with 500 to 800 ft of local relief and up to 2,500 ft of total relief. The remainder of the field to the south marks the transition between the Lower Mesas and Lower Bench of Grand Mesa (Plate 1b). The outcrops along the steep, heavily vegetated slopes are obscured in many places by extensive colluvium, earthflow, and landslide debris. Most of the field is accessible only by a few trails and dirt roads. Principal access to the center of the field includes Lands End Road and GS Road up Kannah Creek.

Geology

The most detailed work done in the field are the reports by Lee (1909, 1912). Regional stratigraphy has been done by Fisher and others (1960) and Gill and Hail (1975).

Lee (1912) recognized the Rollins Sandstone as the base of the Mesaverde in the Grand Mesa and West Elk Mountains region. Named for its exposure at the Rollins Mine in Delta County, the marine Rollins appears as a white cliff-former 60 to 125 ft thick, thinning eastward. Lee subdivided the Mesaverde above the Rollins into the Bowie Shale and Paonia Shale Members. He mapped the Bowie Shale between the Colorado River and Whitewater Creek and in a second band that reappeared several miles northwest of Paonia. This marine-brackish-water facies consists of a maximum 425 ft of shales, massive sandstones, and one coal bed. The fresh-water facies, the Paonia Shale, extends the entire length of the field, lying unconformably on the Bowie Shale at the northern end and lying on the Rollins south of Whitewater Creek. The member attains thicknesses of 200 to 475 ft and consists principally of shale, some sandstones, and coals. Above the Paonia, Lee neither saw important coal beds nor subdivided the 1,500-ft-thick section of interbedded sandstones, and shales left in the Mesaverde.

Later geological studies showed that Lee misidentified the Rollins in Mesa County--the massive sandstone is actually the second or third ledge above the base of the Mesaverde. This observation also was confirmed in my airphoto study of the area. Gill and Hail's correlation shows both the Corcoran and Cozzette Members beneath the Rollins Sandstone at Watson Creek. They note one coal between the

TABLE 12a. Book Cliffs field coal analyses (proximate and ultimate). Samples 28917 through A40971 are from Erdmann (1934); samples 3550 through 3584 are from Richardson (1909); samples 840-D through A73711 are from U.S. Bureau of Mines (1937).

		Proximate			as-recd air-dried		% Loss on Air-	Ultimate				as-recd air-dried	
Sample	Location	Moist.	Volatiles	Fixed Carbon	Ash	Sulfur	Dry	H	C	N	O	Heat value cal	Heat value Btu
28917	Cameo Mine	7.34	36.15	46.97	9.54	0.58	1.9	-	-	-	-	6453	11,777
	sec. 34, T10S, R98W	-	39.01	50.69	10.30	0.63		-	-	-	-	7061	12,710
28918	Cameo Mine	7.20	36.89	47.70	8.21	0.59	1.9	-	-	-	-	6676	12,017
		-	39.75	51.40	8.85	0.63		-	-	-	-	7194	12,949
28919	composite of 28917 and	7.15	36.76	47.20	8.89	0.57	1.9	5.42	67.64	1.40	16.08	6608	11,891
	28918	-	39.59	50.84	9.57	0.61		4.99	72.85	1.51	10.47	7115	12,807
A24794	Farmers Mine	9.4	36.9	47.8	5.9	1.1	5.6	-	-	-	-	6733	12,120
	Anchor coal	-	40.7	52.8	6.5	1.3		-	-	-	-	7428	13,370
A23542	Boyer Mine	7.0	38.1	47.9	7.0	0.7	1.8	5.6	68.4	1.6	16.7	6761	12,170
	Palisade coal	-	41.0	51.4	7.6	0.8		5.2	73.6	1.7	11.1	7272	13,090
A23543	Williams Mine	7.9	37.2	48.4	6.5	0.7	1.0	5.7	68.9	1.6	16.6	6800	12,240
	Palisade coal	-	40.4	52.5	7.1	0.7		5.2	74.8	1.8	10.4	7389	13,300
A24792	McGinley Mine	7.8	35.1	50.1	7.0	0.7	4.3	-	-	-	-	6633	11,940
	Cameo coal	-	38.1	54.3	7.6	0.7		-	-	-	-	7194	12,950
A24793	Service Mine	7.0	36.4	48.2	8.4	0.7	3.1	-	-	-	-	6550	11,790
	Palisade coal	-	39.1	51.9	9.0	0.8		-	-	-	-	7040	12,680
A24791	Hidden Treasure Mine	9.6	35.1	49.7	5.6	0.6	7.0	-	-	-	-	6783	12,210
	Palisade coal		38.9	54.9	6.2	0.7		-	-	-	-	7506	13,510
A40971	Hidden Treasure Mine	7.5	34.1	53.2	5.2	0.7	6.4	5.7	70.9	1.7	15.8	7072	12,730
		-	36.8	57.5	5.7	0.8		5.3	76.7	1.9	9.6	7644	13,760
A40970	Peacock Mine	9.5	36.4	47.5	6.6	0.7	7.7	6.0	67.1	1.7	17.9	6694	12,050
	Palisade(?) coal	-	40.3	52.4	7.3	0.8		5.4	74.2	1.8	10.5	7400	13,320
A23189	Gearhart prospect	12.1	35.0	46.5	6.4	0.6	2.7	5.8	65.4	1.7	20.1	6278	11,300
	Palisade coal	-	39.8	53.0	7.2	0.7		5.1	74.4	1.9	10.7	7144	12,860
	sec. 1, T11S, R99W												
3550	Cameo Mine	8.42	33.32	47.53	10.73	0.6	4.3	5.45	65.52	1.20	16.50	6466	11,639
	sec. 34, T105S, R98W	4.30	34.82	49.67	11.21	0.63		5.19	68.46	1.26	13.25	6757	12,162
3547	Cameo Mine	8.17	33.69	53.42	4.72	0.57	2.8	-	-	-	-	-	-
		5.52	34.66	54.96	4.86	0.59		-	-	-	-	-	-
3542	Cameo Mine	7.55	31.07	48.27	13.11	0.57	2.6	-	-	-	-	-	-
		5.08	31.90	49.56	13.46	0.59		-	-	-	-	-	-
3540	Riverside-Farmers Mine	4.71	34.68	52.66	7.95	0.56	0.1	-	-	-	-	-	-
	upper coal	4.61	34.72	52.71	7.96	0.56		-	-	-	-	-	-
	sec. 3, T11S, R98W												
3546	Mt. Lincoln Mine(?)	7.57	33.56	52.91	5.96	0.72	2.2	5.50	69.47	1.56	16.79	6913	12,433
	lower coal	5.49	34.32	54.10	6.09	0.74		5.38	71.03	1.60	15.16	7069	12,723
	sec. 3, T11S, R98W												
3541	lower coal	7.52	36.03	50.46	5.99	0.85	2.0	5.26	68.43	1.55	17.92	6838	12,308
	sec. 3, T11S, R98W	5.63	36.77	51.49	6.11	0.87		5.14	69.83	1.58	16.47	6978	12,559
3549	lower coal	8.77	36.55	48.72	5.96	0.83	2.5	5.82	62.19	1.40	23.95	6034	10,861
	sec. 3, T11S, R98W	6.43	37.49	49.97	6.11	0.85		5.58	65.05	1.47	20.96	6312	11,361
3539	lower coal	9.02	34.51	50.89	5.58	0.67	3.1	-	-	-	-	-	-
	sec. 3, T11S, R98W	6.11	35.61	52.52	5.76	0.69		-	-	-	-	-	-
3545	Garfield Mine	13.96	31.30	48.73	6.01	0.63	4.4	-	-	-	-	-	-
	sec. 6, T11S, R98W	10.00	32.74	50.98	6.28	0.66		-	-	-	-	-	-

TABLE 12a, continued

3490	Book Cliff Mine	11.42	34.25	44.49	9.84	0.84	5.6	5.46	61.84	1.07	20.95	6166	11,099
	upper coal	6.17	36.28	47.13	10.42	0.89		5.13	65.51	1.13	16.92	6532	11,757
	sec. 8, T10S, R99W												
3496	Book Cliff Mine	10.75	34.83	47.58	6.84	0.55	3.5	-	-	-	-	-	-
	upper coal	7.51	36.09	49.31	7.09	0.57		-	-	-	-	-	-
3581	Book Cliff Mine	11.03	35.90	46.35	6.72	0.68	5.8	-	-	-	-	-	-
	1st coal below upper coal	5.55	38.11	49.21	7.13	0.72		-	-	-	-	-	-
3495		9.54	34.49	46.33	9.64	0.78	3.1	-	-	-	-	-	-
	sec. 7, T10S, R99W	6.65	35.59	47.81	9.95	0.80		-	-	-	-	-	-
3493	(weathered sample)	15.39	32.57	45.69	6.35	0.62	7.2	-	-	-	-	-	-
	sec. 1, T10S, R100W	8.83	35.10	49.23	6.84	0.67		-	-	-	-	-	-
3489		6.86	34.20	43.90	15.04	0.62	1.8	-	-	-	-	-	-
	sec. 36, T9S, R100W	5.15	34.83	44.70	15.32	0.63		-	-	-	-	-	-
3488	(weathered sample)	6.52	35.75	48.37	9.36	0.67	0.6	-	-	-	-	-	-
	sec. 35, T9S, R100W	5.96	35.96	48.66	9.42	0.67		-	-	-	-	-	-
3640	Hunter Mine	5.40	33.30	55.57	5.73	0.49	0.2	5.39	70.18	1.20	17.01	6894	12,409
	sec. 5, T9S, R100W	5.21	33.36	55.69	5.74	0.49		5.38	70.32	1.20	16.87	6908	12,434
3587	Anchor No. 1 Mine(?)	9.44	35.51	49.33	5.72	1.02	5.5	5.94	68.47	1.56	17.29	6811	12,260
	sec. 27, T8S, R101W	4.17	37.58	52.20	6.05	1.08		5.64	72.46	1.65	13.12	7207	12,973
3585	Anchor No. 2 Mine(?)	9.73	35.27	49.95	5.05	1.30	5.2	5.81	68.84	1.55	17.45	6809	12,256
	sec. 29, T8S, R101W	4.78	37.20	52.69	5.33	1.37		5.52	72.62	1.63	13.53	7182	12,928
3586	Farmers-Nearing Mine(?)	8.27	36.90	48.67	6.16	1.26	3.6	5.54	67.48	1.57	17.99	6771	12,188
	sec. 30, T8S, R101W	4.84	38.28	50.49	6.39	1.31		5.53	70.00	1.63	15.34	7024	12,643
3584	Coal Gulch	5.55	36.01	52.75	5.69	0.93	1.6	-	-	-	-	-	-
	sec. 18, T8S, R101W	4.01	36.60	53.61	5.78	0.95		-	-	-	-	-	-
840-D	Cameo Mine	7.4	36.2	48.6	7.8	0.6	2.1	-	-	-	-	6772	12,190
	west entry	-	-	-	-	-		-	-	-	-	-	-
A72853	Hidden Treasure Mine	7.0	35.7	51.2	6.1	0.7	1.6	5.8	70.7	1.7	15.0	6978	12,350
	face of 2d entry	-	-	-	-	-		5.4	76.1	1.8	9.3	7506	13,510
A81053	Hidden Treasure Mine	8.1	33.7	51.6	6.6	0.5	2.6	-	-	-	-	6831	12,350
		-	36.7	56.1	7.2	0.5		-	-	-	-	7461	13,430
A81054	Hidden Treasure Mine	8.7	34.1	50.9	6.3	0.5	3.0	-	-	-	-	6828	12,290
		-	37.4	55.7	6.9	0.5		-	-	-	-	7472	13,450
A73711	Grasso Mine	5.6	38.0	48.3	8.1	2.3	1.0	-	-	-	-	6878	12,380
		-	40.2	51.2	8.6	2.4		-	-	-	-	7283	13,110

TABLE 12b. Grand Mesa field coal analyses (from Lee, 1909, 1912).

			Proximate as-recd air-dried				% Loss on Air-Dry	Ultimate				as-recd air-dried Heat Value	
Sample	Location	Moist.	Vola-tiles	Fixed Carbon	Ash	Sulfur		H	C	N	O	cal	Btu
5724	Bailey Mine	7.18	32.97	50.98	8.87	0.58		5.53	67.54	1.24	16.24	6649	11,968
	SE/4 sec. 34, T10S, R98W	4.89	33.78	52.24	9.09	0.59	2.40	5.39	69.20	1.27	14.46	6813	12,262
5535	Patterson Mine												
	Midway Mine	11.51	32.60	45.53	10.36	0.93		-	-	-	-	5782	10,408
	SE/4 sec. 17, T12S, R97W	9.05	33.51	46.79	10.65	0.96	2.70	-	-	-	-	5942	10,696
5541	Kuhnley Mine, Delta Co.	17.2	30.7	41.4	10.7	0.70		-	-	-	-	5200	9360
	SE/4 sec. 34, T13S, R96W	12.8	32.3	43.6	11.3	0.74	5.0	-	-	-	-	5475	9860
5542	Rollins Mine, Delta Co.	19.2	31.2	41.7	7.93	0.75		6.06	55.11	1.10	29.05	5320	9580
	NW/4 sec. 35, T13S, R96W	14.1	33.2	44.3	8.43	0.80	5.9	5.74	58.56	1.17	25.30	5655	10,180
5540	Fairview Mine, Delta Co.	16.4	29.8	45.4	8.45	0.45		5.87	56.64	1.13	27.36	5615	10,110
	NE/4 sec. 19, T13S, R95W	12.6	31.1	47.5	18.83	0.47	4.3	5.63	59.29	1.18	24.60	5870	10,560
95458	Midwest Mine	6.6	36.7	48.6	8.1	1.1		-	-	-	-	6828	12,290
		-	39.3	52.0	8.7	1.2	4.0	-	-	-	-	7311	13,160

TABLE 12c. Gunnison River district coal analyses (from Woodruff, 1912).

Sample	Location	Proximate as-recd / air-dried: Moist.	Vola- tiles	Fixed Carbon	Ash	Sulfur	% Loss on Air-Dry	Ultimate: H	C	N	O	Heat Value as recd / air-dried: cal	Btu
5530	Grand Junction sec. 26, T1S, R1W	5.96 3.94	26.41 26.98	41.21 42.09	26.42 26.99	0.80 0.82	2.10	- -	- -	- -	- -	4697 4798	8455 8636
11108	Grand Junction sec. 26, T1S, R1W	5.1 3.3	27.9 28.5	38.8 39.5	28.2 28.7	1.14 1.16	1.9	- -	- -	- -	- -	5145 5245	9260 9440
11109	Grand Junction sec. 26, T1S, R1W	5.7 3.7	26.3 26.9	34.2 34.9	33.8 34.5	0.80 0.82	2.1	- -	- -	- -	- -	4650 4750	8370 8550
11104	Southwest of Whitewater Hill sec. 5, T2S, R1E	3.5 2.8	39.2 39.5	51.3 51.7	6.0 6.0	1.67 1.68	0.7	- -	- -	- -	- -	5840 7300	10,510 13,140
11105	Southwest of Whitewater Hill	3.2 2.5	29.1 29.3	45.3 45.6	22.4 22.6	1.19 1.20	0.7	- -	- -	- -	- -	5840 5880	10,510 10,590
5534	Wells Gulch, Delta Co. sec. 18, T4S, R3E	6.53 4.52	33.85 34.58	50.95 52.04	8.67 8.86	1.11 1.13	2.10	- -	- -	- -	- -	6078 6208	10,940 11,175
11106	Wells Gulch	3.4 3.0	38.8 39.0	51.8 52.0	6.0 6.0	0.98 0.98	0.5	- -	- -	- -	- -	7280 7320	13,110 13,170
11107	Wells Gulch	3.1 2.6	31.2 31.4	48.4 48.6	17.3 17.4	1.89 1.90	0.5	- -	- -	- -	- -	6260 6290	11,270 11,330

Corcoran and Cozzette and one coal above the Rollins. Southward the Corcoran disappears at Kannah Creek, but the Cozzette, although thin, persists into Delta County. Their section at the Rollins Mine shows only one coal above the Rollins Sandstone. Beneath the Rollins lies an 80-ft-thick tongue of Mancos Shale over the thin extension of the Cozzette. Thus, although the Rollins is not the base of the Mesaverde, it marks the base of the coal-bearing portion.

The question of the Sego also complicates matters. Only Fisher and others (1960) extend the Sego into the Grand Mesa field, and they say Lee mistook the Sego for the Rollins. If the Sego extends as far southeast as Watson Creek, then it is the base of the Mount Garfield Formation and is overlain in turn by a tongue of Mancos Shale, Corcoran, Cozzette, tongue of Mancos, and finally the Rollins. If the Sego does not extend that far, then the Corcoran may be taken as the base of the Mount Garfield Formation nearly to Kannah Creek. South of there, the Cozzette, although barren of coal, becomes the base.

Map Boundary

At the north end of the Grand Mesa field, the lower boundary of the coal MRA on Plate 2 represents the basal Corcoran or the base of the Mount Garfield Formation. From Whitewater Creek to Kannah Creek the line still indicates the base of the Mount Garfield but now corresponds to Gill and Hail's extension of the Cozzette. Between Kannah Creek and the Delta County line the base of the Mount Garfield approximates Lee's Rollins Sandstone, which was traced on airphotos northwest from the vicinity of the Rollins Mine.

The upper map unit boundary from the Colorado River to North Fork Kannah Creek is a continuation of the Mount Garfield-Hunter Canyon Formation contact from the Book Cliffs field--the top of the dominantly shale sequence below the massive sandstones. Where the outcrop line is broken by the broad alluvial fans, colluvial slopes, and earthflows, this line was projected on the basis of topography, dip, and elevation. South of North Fork Kannah Creek the heavily vegetated and covered slopes do not permit convenient projection of this contact. Therefore, the upper boundary approximated the Mesaverde-Wasatch contact, which was determined by subtle topographic breaks, tone and texture changes on the airphotos, and Williams' (1964) geologic map. The map unit in this area then indicates the entire Mesaverde section.

Coal Occurrence and Quality

Coal seams in the Grand Mesa field continue southeastward from the Book Cliffs field but become more numerous. Only one important coal, the Bowie, occurs in the lower part of the section and is exposed in a 3.3-ft-thick seam at the Stokes Mine. The upper or Paonia coals contain six to eight persistent seams, although only two or three seams usually are present in any one local section. The lowermost Paonia seams, up to 7 ft thick, are the most persistent and productive in the field.

Compared to Book Cliffs coals, the Grand Mesa coals are of slightly lower rank--high-volatile C bituminous to subbituminous A. Hornbaker and others (1976) give the following composite analysis (as-received) of several Paonia coals varying from 4.5 to 14 ft in thickness.

Moisture.......	9.8-20 %
Ash............	2.1-16.1 %
Sulfur.........	0.5-1.8 %
Btu/lb.........	9,360-11,670

In Table 12b Lee (1909, 1912) found properties of Grand Mesa coals similar to those of Book Cliffs coals. He noted, however, decreases in fixed carbon and heat values southward into Delta County.

Gunnison River District

Coals in the transition zone between the Dakota Group and Mancos Shale have been known for many years, but their status as an individual field is doubtful. Lee (1912) included Dakota coals in his discussion of the Grand Mesa field, and Woodruff (1912) described the occurrences in another report but did not use the term *field*. Hornbaker and others (1976) classify the Dakota coals as a *subregion* of the San Juan region. Landis (1959) and Jones (1976) show the Gunnison River and Dakota coals of Mesa County as the northernmost extension of the Dakota Sandstone area of southwestern Colorado, which includes the Nucla-Naturita field in Montrose County. In this report I will refer to Dakota coals as the *Gunnison River district*.

Physiography

The coal-bearing Dakota Group in Mesa County marks the boundary between the Uncompahgre Plateau and both Lower Grand Valley (northwest) and the Lower Mesas of Grand Mesa (southeast) (Plate 1b). Around the northwestern end of the Plateau the Dakota characteristically is exposed in deeply dissected hogbacks. Along the Gunnison River the Dakota caps long mesas and arcuate cuestas separated by deep narrow canyons having as much as 700 ft of relief. Below Bridgeport the Gunnison River itself flows through a rather spectacular canyon that was eroded through one of the larger cuestas.

Structurally the Dakota lies on the northeastern flank of the Uncompahgre Uplift. The beds dip gently to the northeast and locally are warped or slightly offset by the northwest-trending monoclines and normal faults.

Geology

The interfingering contact between the Dakota and Mancos is similar to that between the Mancos and Mesaverde except that now we are looking at the westward transgression of the great inland sea and the fluctuating replacement of coastal plain environments by the marine environment. Lee (1912) recognized this transitional zone and on the basis of the marine fossils that he found in the sandstone above the coal, placed the zone in the lower Mancos Shale.

Young (1959, 1960a) presents the most detailed stratigraphy of the Dakota Group on the Colorado Plateau. Here he recognized two facies--an inland-flood plain environment in the west (Cedar Mountain Formation) passing into littoral marine, lagoonal, and lowland environments to the east (Naturita Formation). Of importance in this area is the upper Naturita Formation, carbonaceous mudstone and lenses of conglomerate, sandstone, siltstone, carbonaceous shale, and coal. The upper part of the unit averages 100 ft in thickness and contains tongues of littoral marine sandstone and shale. This interfingering with the Mancos Shale indicates a fluctuating shoreline of the Cretaceous inland sea. When the sea first advanced, marine shales were deposited over carbonaceous lagoonal deposits. A brief retreat of the sea allowed beach and lagoonal deposits to accumulate. With the final transgression of the sea, the area was covered with marine shale. The inland sea moved northwestward with each successive transgression, the direction opposite to its retreat as recorded by the Mancos-Mesaverde contact described earlier.

Map Boundary

The Gunnison River coal district MRA shown on Plate 2 includes the uppermost Dakota Group exposed on hilltops and on mesas closest to the Gunnison River and major points of access. I have also shown Dakota exposures in the Redlands area and along the nose of the Uncompahgre Uplift in the northwestern part of the county. The mapping was modified after Williams (1964), Lohman (1963), Cashion (1973), and Hart (1976).

Coal Occurrences and Prospects

Both Lee (1912) and Woodruff (1912) examined coal exposures and prospects along the east side of the Gunnison River between Grand Junction and Delta County. Lee's local sections show a 40- to 50-ft-thick sequence of carbonaceous shales, siltstones, and coals with 3-in.- to 3.3-ft-thick seams, the thickest having been observed in Wells Gulch about 3 miles south of the county line.

In addition to several prospects along the Gunnison River, a few productive shafts and adits supposedly were driven many years ago. Of all the prospects shown on the early maps, only a few could definitely be located. For example, at least one adit was driven into coal seams exposed in the railroad cut south of Grand Junction in SW/4 sec. 23, T1S, R1W, Ute P.M. Lee examined one accessible entry that was at least 125 ft long and found several seams having an aggregate thickness of about 8 ft. The mine produced coal that was used in Grand Junction probably in the very late 1800's, but the production of better coal from the Book Cliffs forced the mine's abandonment. During my examination of this exposure, I found that most of the cut slope had been obscured by man-made fill and riprap from the commercial developments on the terrace edge above. No adits were visible, and hopefully any old tunnels would have collapsed long before the land above was developed.

Another 100-ft-long entry was made in a river meander southwest of Whitewater Hill in sec. 5 or 8, T2S, R1E. Woodruff sampled the coal here and found 2 seams with a total thickness of 2.25 ft and separated by a 3-in. shale. Lee examined the same locality and found 2 more seams totalling 2.2 ft and located about 22 ft below the upper seams. Again I could not find an adit here but marked the approximate site on Plate 2 with a prospect.

On the north side of Deer Creek near the Delta County line, two coaly seams crop out about 20 to 40 ft below the sandstone ledge on the rim of the canyon. One possible prospect was located here. At the Wells Gulch mine, 4 miles to the southeast in Delta County, a 200-ft entry along a 3.3-ft-thick seam yielded coal that reportedly was used for domestic fuel and in blacksmithing (Lee, 1912).

I located two other apparently barren prospects in this district. The first is a small hillside excavation about 3 miles east of Little Park Road near Billings Canyon in sec. 15, T12S, R100W. The second prospect is an aproximately 100-ft-deep shaft in the Mancos Shale on Deer Creek about 0.25 mile from U.S. 50 near the center of sec. 25, T3S, R2E.

No activity has been noted in the Dakota coals exposed in the Redlands area or along the hogbacks west of Loma. A trench in the ridge top 1.5 miles southwest of Loma could have been either a coal or clay prospect.

Coal Quality

Although Lohman (1965a) used the term lignite to describe the Dakota coals at Grand Junction, Hornbaker and others (1976) cite a great variation in rank of the coals, but most surprisingly are classed as high-volatile C and B bituminous. Woodruff (1912) analyzed coals from Grand Junction, Whitewater Hill, and Wells Gulch, and the results in Table 12c show, from north to south, increases in sulfur, fixed carbon, and heat content. Using these eight analyses in the ASTM procedure for coal classification gave an even distribution of grades from high-volatile A to C bituminous, with half of the samples resulting in high-volatile B bituminous. Therefore, I have used this rank and grade for classification of the MRA on Plate 2.

Coal Production

As the reader saw in the section dealing with natural gas resources, analysis of production statistics can be done largely by graphical methods. The available 89-year record of coal production in Mesa County lends itself well to graphics, and I hope the following diagrams will be more meaningful to the reader than will long tables of production numbers. Most of the numbers themselves actually are not as important as are rates of change, percentage increases and decreases, and projections that can reasonably be made from the production histories of individual mines and of the entire county.

The records of mines that operated for 3 years or less are listed in Table 13. The locations of only four of these low-production mines could be determined from Colorado Division of Mines files. Total cumulative production from these 11 mines amounts to 5,505 tons.

TABLE 13. Production records of small coal mines in Mesa County

Name	Location	Year	Production (tons)	Cumulative Production (tons)
Bear-Cat	?	1922	147	147
Big Tree	?	1932	360	
		1933	85	445
Mesa	?	1888	300	300
Midway	SE SE sec. 17 T12S, R97W	1922	320	
		1923	1110	
		1925	102	1532
Forest Service	NW SE sec. 17 T12S, R97W	1934	51	
		1935	75	
		1936	200	326
Lorimer	?	1900	100	100
Lynch	?	1916	430	
		1918	87	517
Service	SE sec. 10 T1N, R1E	1925	340	
		1926	933	1273
Ulice	?	1933	153	153
Valley Commercial	sec. 28 T8S, R101W	1917	400	
		1918	87	487
Waldron	?	1932	25	25

Figures 19, 20, and 21 show the production curves for the remaining mines. For convenience mines with peak productions of 1,200 tons or less are grouped as low-production. The cutoff value between medium and high production is 10,000 tons. The histories of the Cameo and Roadside Mines are shown separately because of their very high rates of production. The records of the 20 low-production mines (Table 13 and Figure 19) show that, with only three exceptions (Mesa, Peacock, and Hunter), all operated in the 36-yr period from 1916 to 1952. The curves are characterized by great yearly variations, consecutive zero-production years, and frequent changes in operators, especially during the 1930's. The 13 medium-range mines (Figure 20) operated in the 67-yr period from 1903 to 1970 and had many fewer zero-production years than did the low-range mines. No consistency is apparent among the peak production years or the intervals of highest production. The five mines with maximum 33,000-ton peak productions (Figure 21a) operated in the 61-yr period from 1890 to 1951. Compared to the other graphs, this one shows that most of the early Book Cliffs mines were high-tonnage producers that predated development of most other mines by 15 to 25 years. The county's two most productive mines, the Cameo and the Roadside, have operated nearly continuously since 1899. The curve for the Cameo Mine (Figure 21b) shows peak production intervals from 1910 to 1929, 1941 to 1953, and 1957 to 1969, with a peak production of 140,000 tons in 1917. The Roadside Mine(Figure 21c)reached peak production levels in 1911, 1928, 1932, and 1969. Although its reported production dropped to zero in 1973 and 1974, the 1977 production reached a new

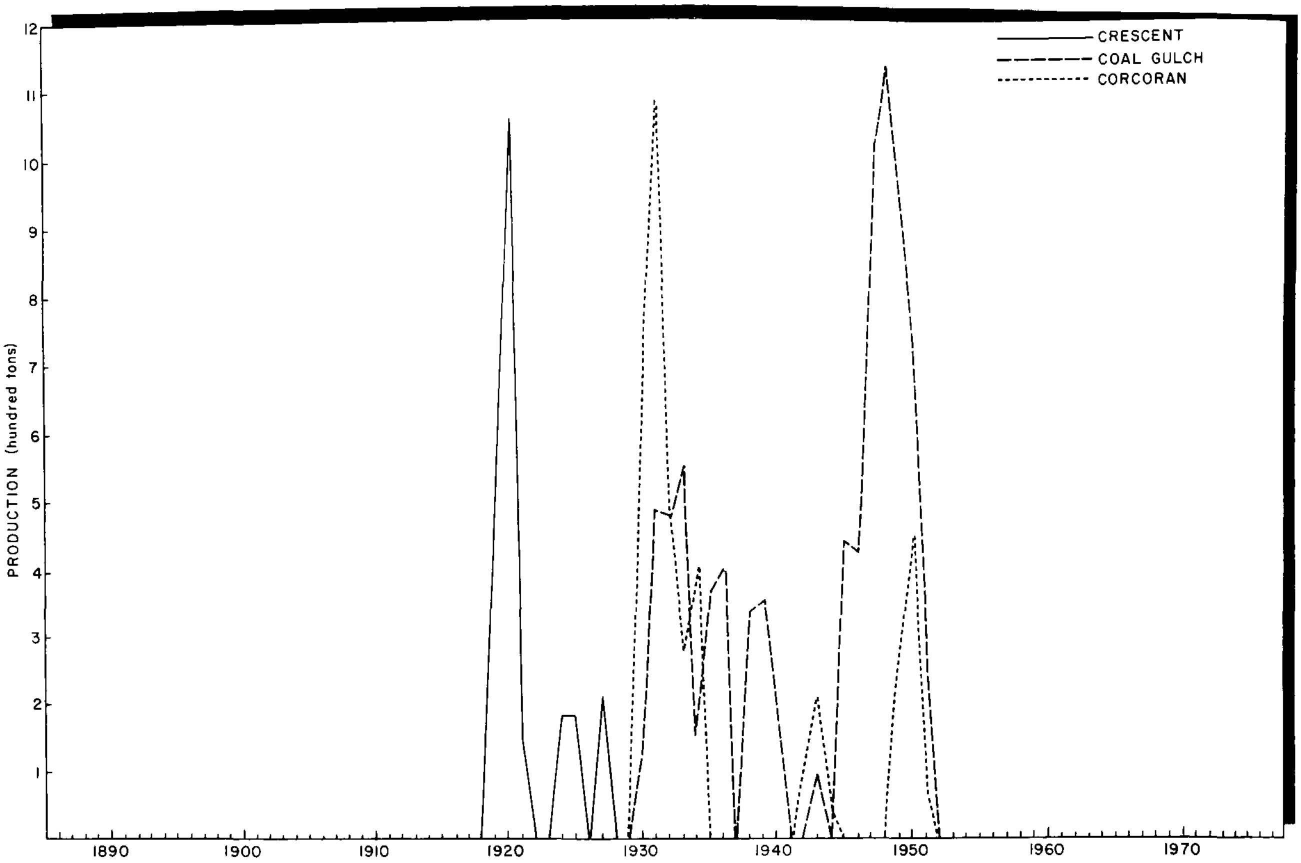


FIGURE 19a. Mesa County coal mine production histories (low-tonnage mines).

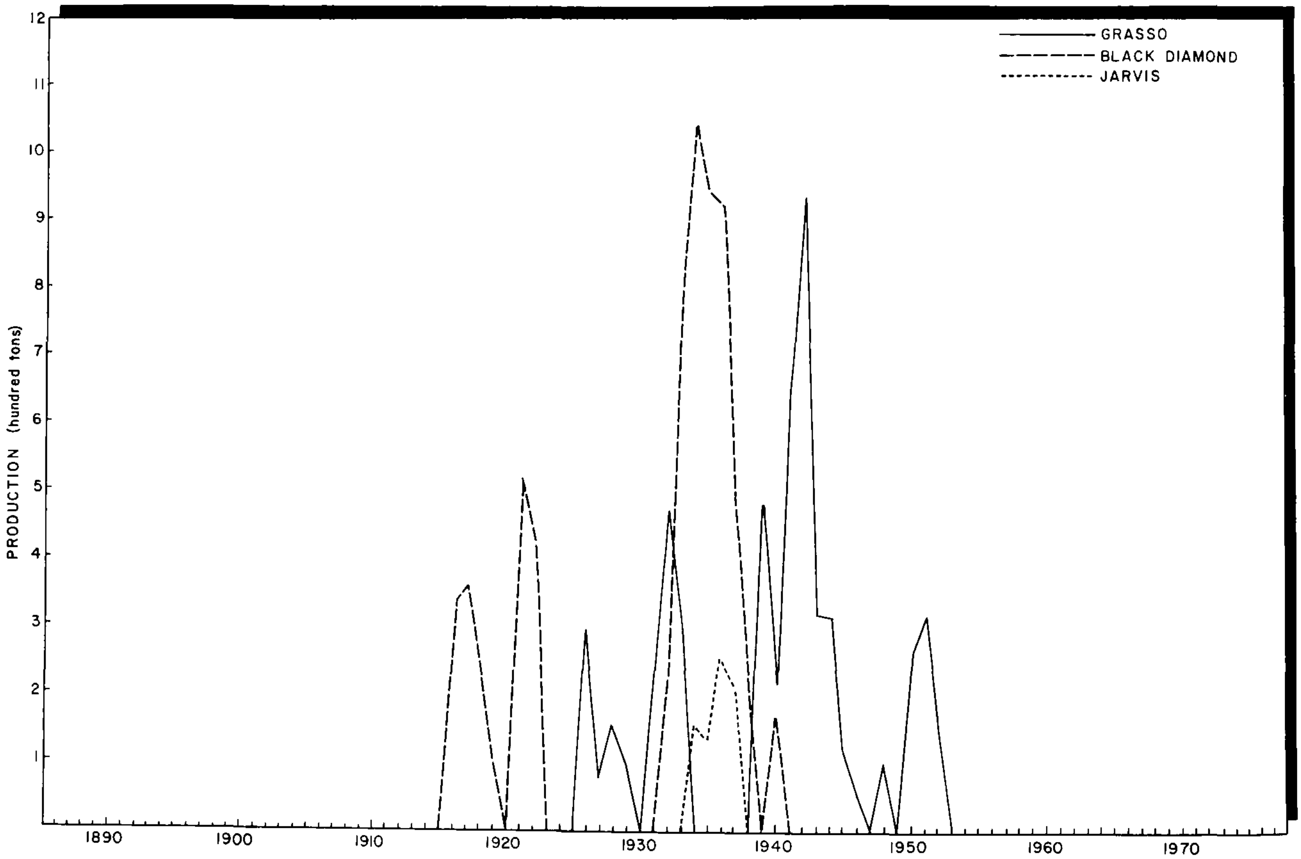


FIGURE 19b. Mesa County coal mine production histories (low-tonnage mines).

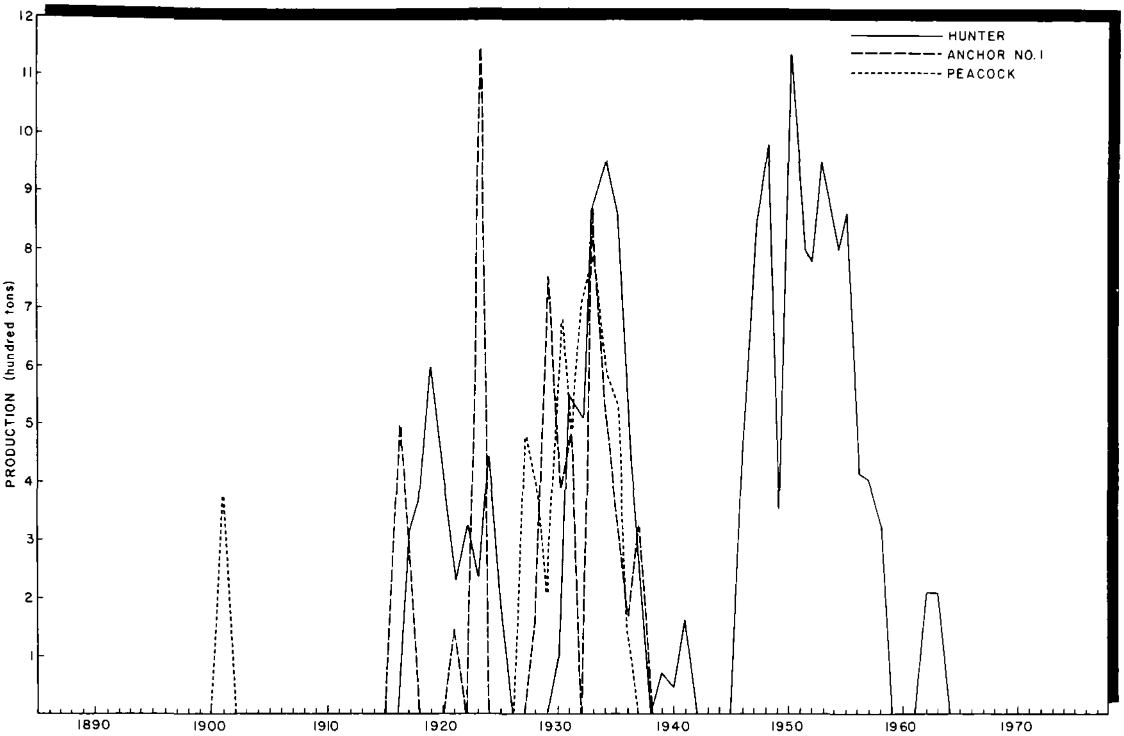


FIGURE 19c. Mesa County coal mine production histories (low-tonnage mines).

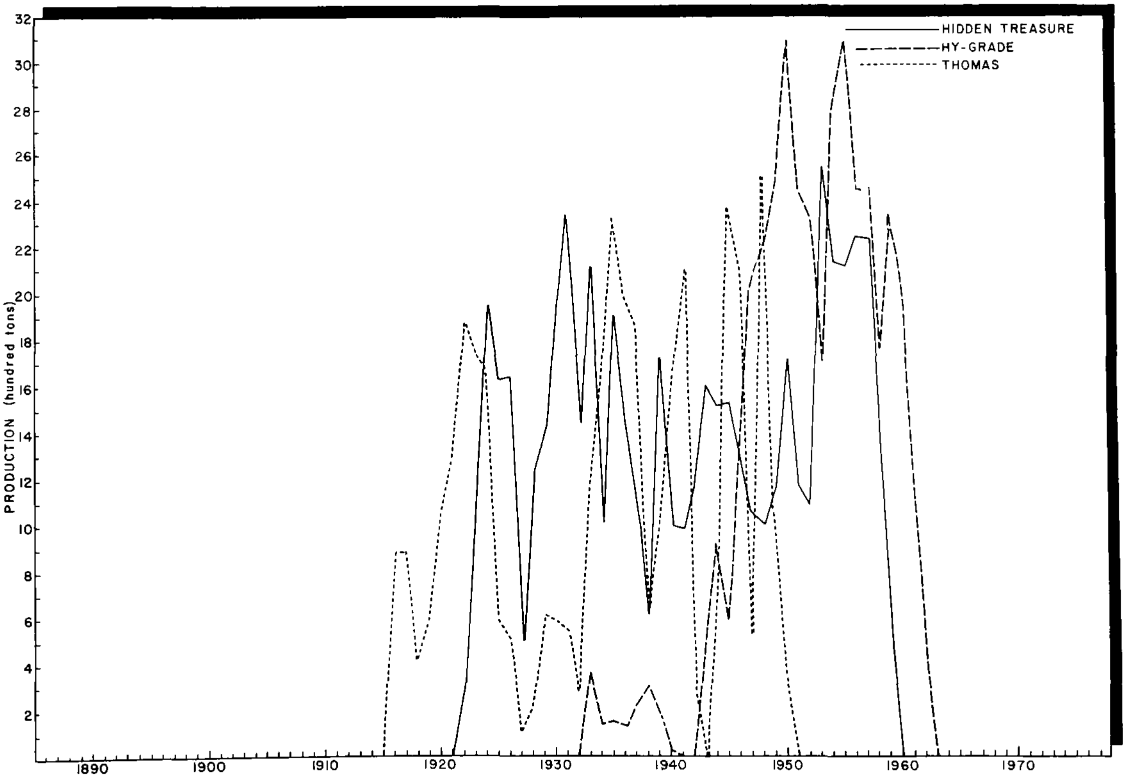


FIGURE 20a. Mesa County coal mine production histories (intermediate-tonnage mines).

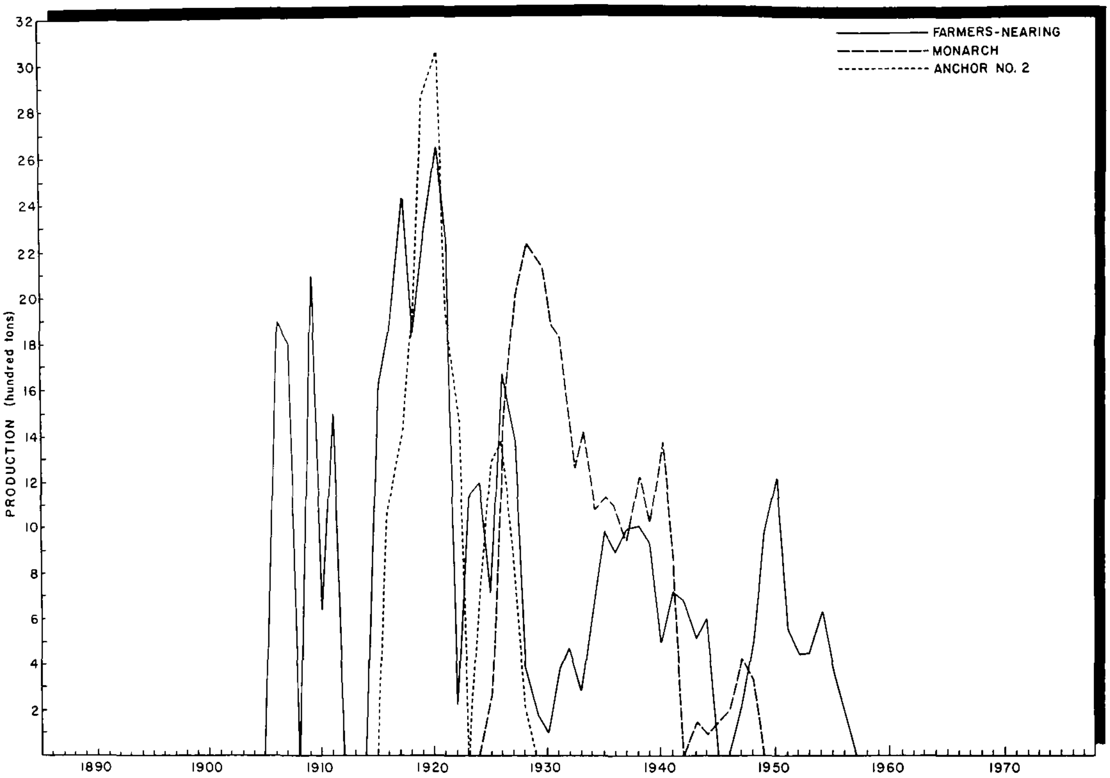


FIGURE 20b. Mesa County coal mine production histories (intermediate-tonnage mines).

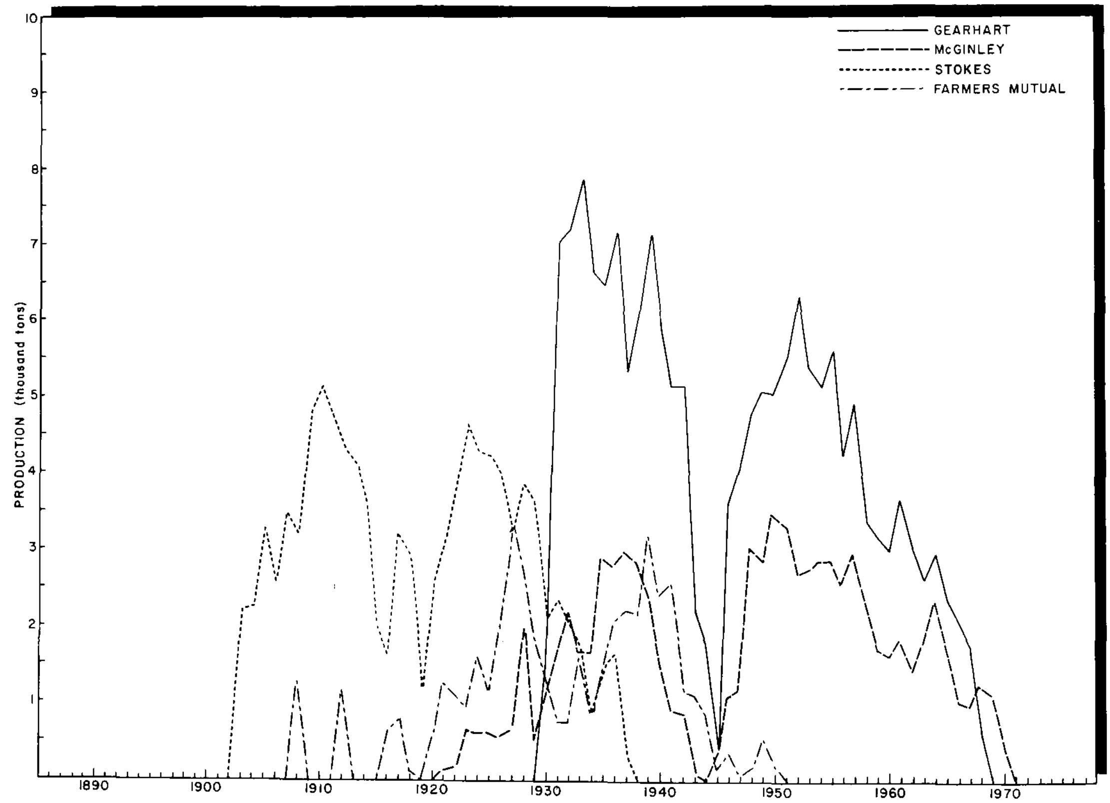


FIGURE 20c. Mesa County coal mine production histories (intermediate-tonnage mines).

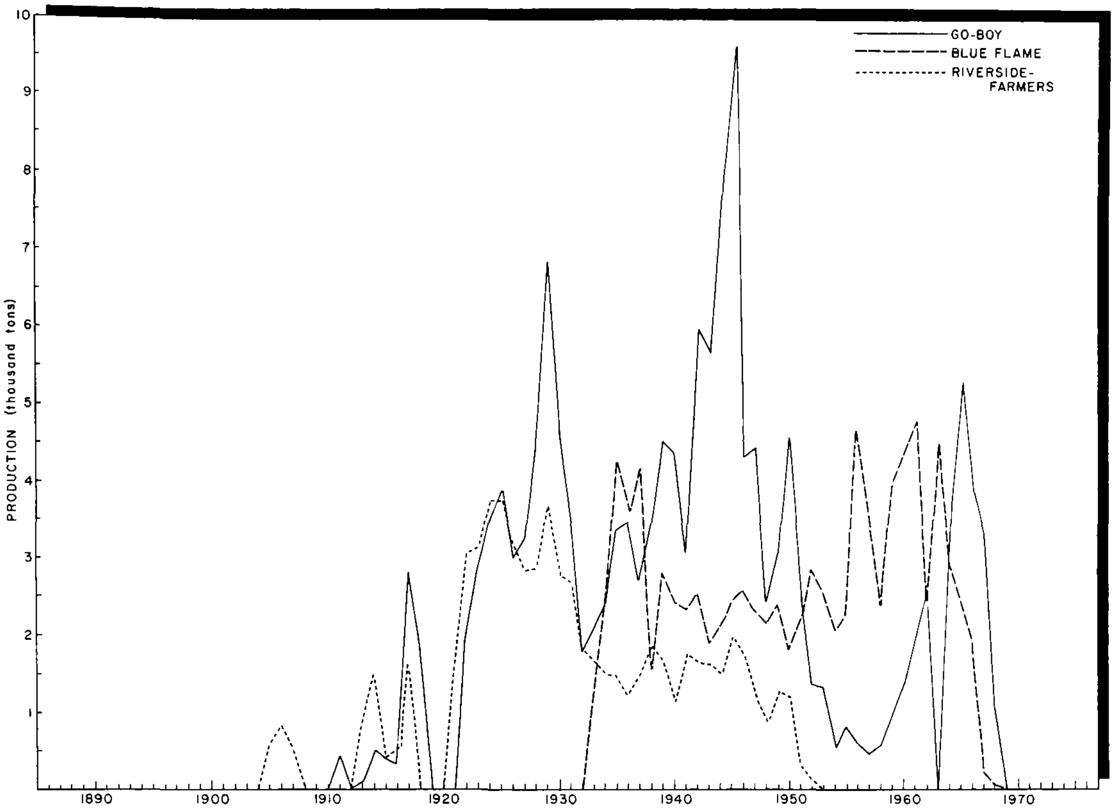


FIGURE 20d. Mesa County coal mine production histories (intermediate-tonnage mines)

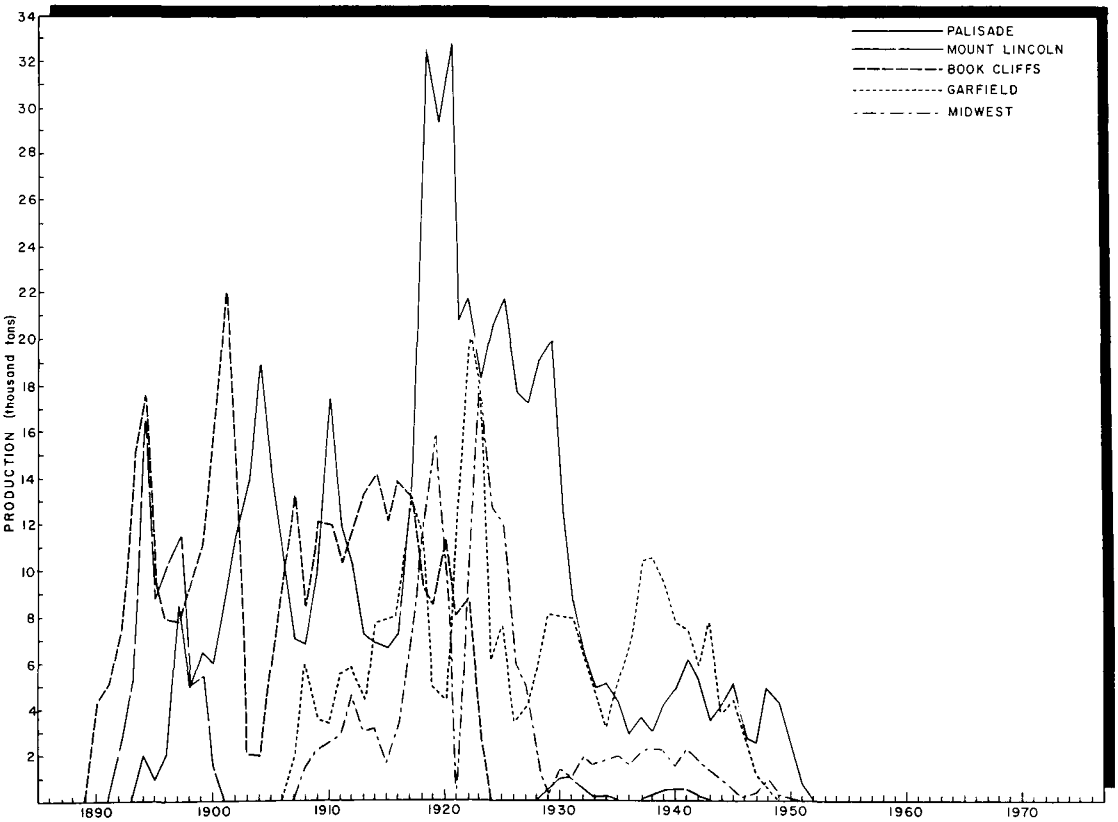


FIGURE 21a. Mesa County coal mine production histories (high-tonnage mines).

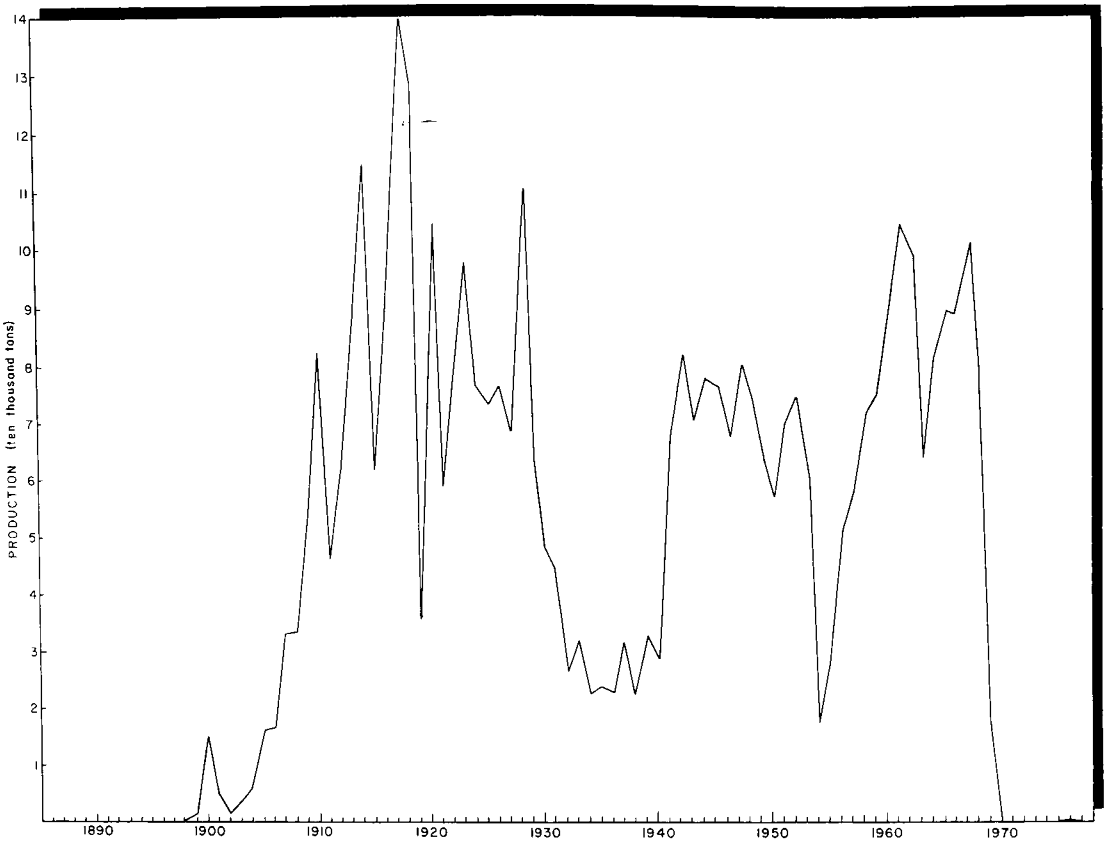


FIGURE 21b. Mesa County coal mine production histories (Cameo Mine).

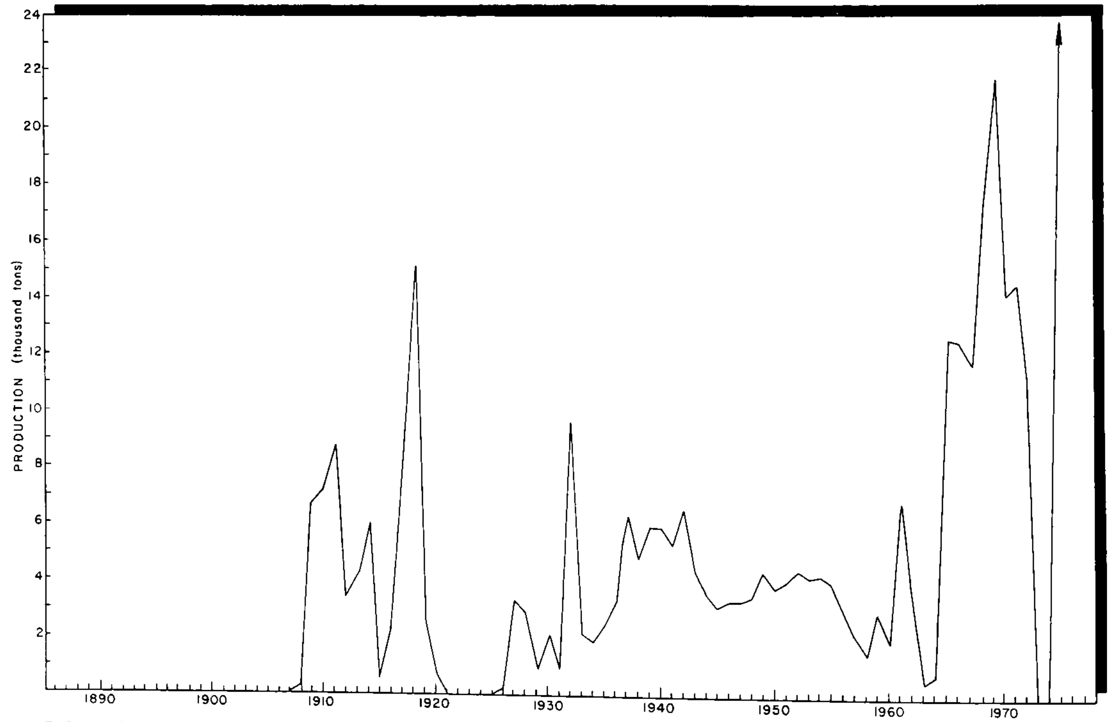


FIGURE 21c. Mesa County coal mine production histories (Roadside Mine).

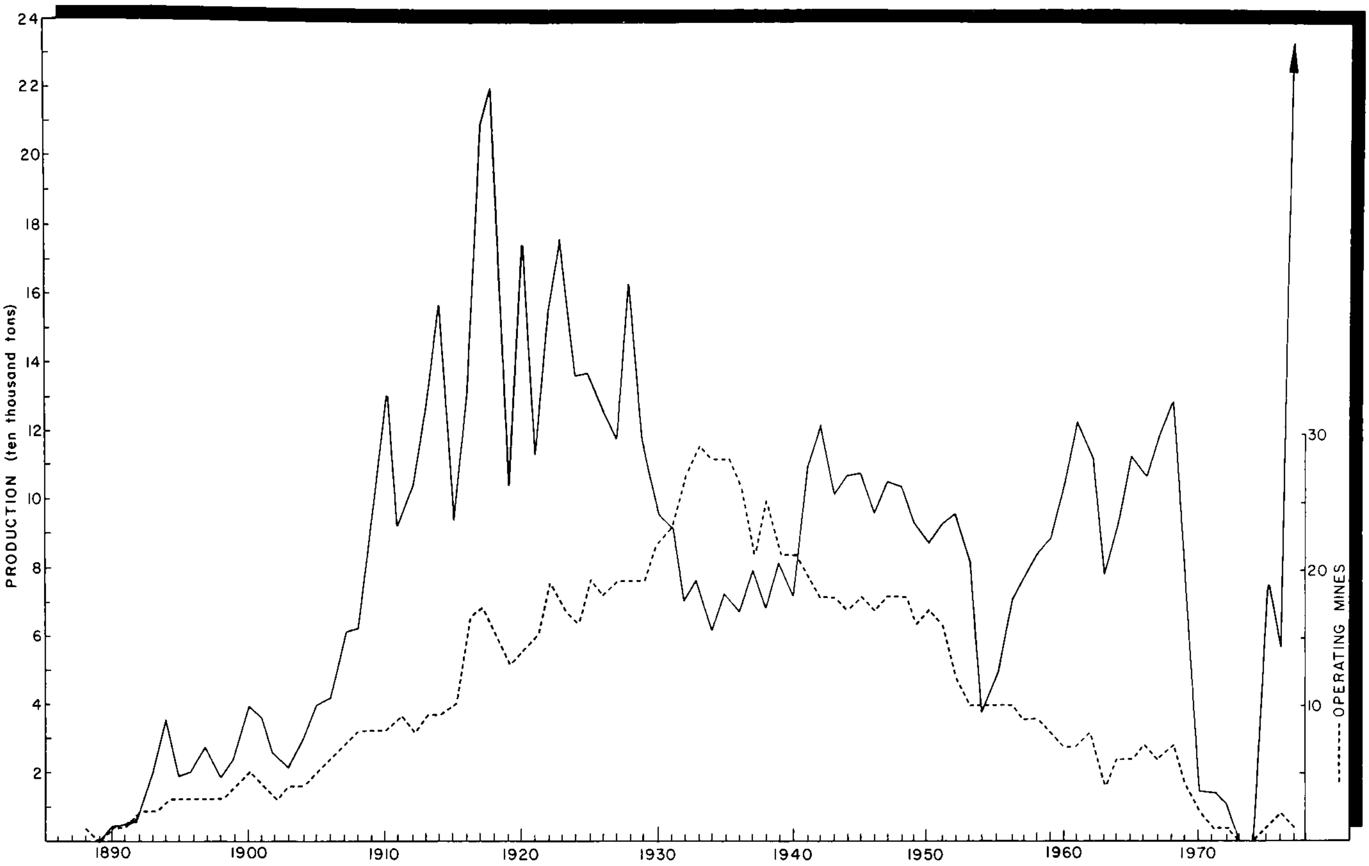


FIGURE 22. Total coal production in Mesa County, including number of operating mines.

high of about 300,000 tons. With the recent completion of new supply contracts, the Cameo and Roadside mines are expected to produce a record-breaking 450,000 to 1,000,000 tons/yr by 1980.

Cumulative mine production figures in the county give a total of about 7 1/4 million tons through 1976. Of this total, the Grand Mesa field accounts for 13.5 percent or about 977,000 tons. The Roadside Mine alone accounts for about 47 percent of the Grand Mesa field's production. Roadside's production of 300,199 tons in 1977 boosts the county cumulative to 7,547,000 tons and the Grand Mesa field contribution to 17 percent. In the Book Cliffs field, the Cameo Mine has produced about 70 percent of the cumulative field total.

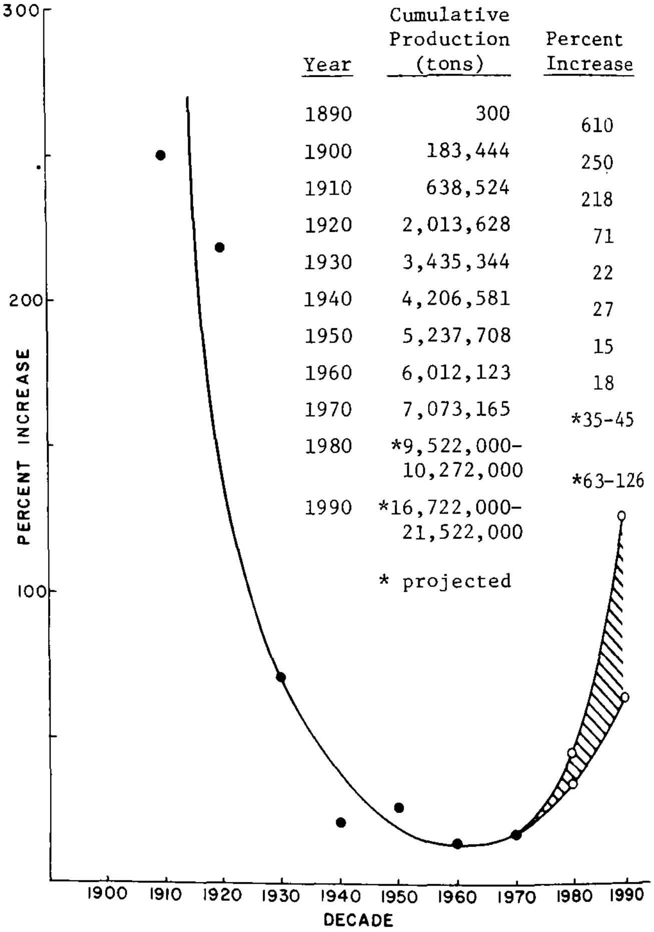
The analysis of the county's production history is based on Figure 22, which shows annual production and the number of mines that operated each year through 1977. At first glance, one notices an overall cyclic nature of the curve, with peak production intervals from 1909 to 1929, 1941 to 1952, 1959 to 1968, and a fourth interval beginning in 1975. The record production of 220,369 tons in 1918 was exceeded only last year with a new peak of 300,199 tons, an increase of more than 36 percent. Annual mine production dropped by one-half during the depression era of the 1930's. Ironically, during the same decade, as many as 29 mines were active, and the greatest number of changes in operators were recorded. World War II bolstered production for a few years, but a fluctuating decline led to a new low in 1954--the lowest annual production in 50 years. After another significant increase in the 1960's, the county's output dropped to zero in 1973. Since 1975, production from the Roadside Mine has exceeded anything yet seen in the county's 90-yr production history. The curve should continue its dramatic rise for several more years. Near-future production will come from four or five mines at most, the fewest that have operated since the turn of the century.

New contracts resulting from the increased demand for coal in electrical generating plants will profoundly affect the county's production record. Projected annual tonnages and county cumulative totals for the next few years appear in the following table (Louise Dawson, 1978, pers. comm.). The amounts in brackets are my totals based on the actual

	1977	1978	1979	1980
CMC	261,553 [300,199]	350,000	500,000	500,000
Cameo	0	100,000	200,000- 500,000	200,000- 500,000
McGinley	0	0	25,000	100,000- 250,000
Ann. Total	261,553 [300,199]	450,000	725,000- 1,025,000	800,000- 1,250,000
County Cumul. Total	7,507,983 [7,546,629]	7,957,983 [7,996,629]	8,682,983- 8,982,983 [8,721,629- 9,021,629]	9,482,983- 10,232,983 [9,521,629- 10,271,629]

1977 reported production.
Within three years, annual production could increase fourfold.

Let us see how these projections might affect the cumulative production curve. Figure 23 below shows the percentage changes in cumulative production by decade. Plotted on a graph, the percentage points define a curve that declines rapidly from 1890 to 1940, levels out at 1960, and then increases. During the first few decades of the record, production increased rapidly because new seams were developed and many new mines opened. The rapid increase in the initial small production figures gives very large percentage increases. Through the 1940's and 1950's annual production declined, and more mines closed. Thus the increase in cumulative production became smaller. Since 1960, production has increased slightly but has increased tremendously during the 1970's. Thus the curve reverses its trend and begins to climb, indicating increasing changes in cumulative production. The reliable projections for 1980 confirm the upswing and indicate increases of 35 to 45 percent of cumulative production. The projection for 1990 assumes consecutive annual production rates of 800,000 to 1,250,000 tons. The upper and lower limits of this production range give two possible curves, and the actual cumulative total may lie anywhere within the hachured area. If the assumed rate is not maintained throughout the decade, the curve will tend to level off and then decline. In either case a substantial increase is forecast.



Year	Cumulative Production (tons)	Percent Increase
1890	300	
1900	183,444	610
1910	638,524	250
1920	2,013,628	218
1930	3,435,344	71
1940	4,206,581	22
1950	5,237,708	27
1960	6,012,123	15
1970	7,073,165	18
1980	*9,522,000- 10,272,000	*35-45
1990	*16,722,000- 21,522,000	*63-126

* projected

FIGURE 23. Ten-year changes and projected increases in cumulative coal production.

This future trend can also be thought of in terms of time intervals in which cumulative production doubled. Shown below are the years and intervals in which cumulative production increased at least by 100 percent. Again the highest changes are recorded in the early years during initial development of the mines. The first significant break in the trend comes during the period 1920 to 1941. The drastically lower annual production during the depression era probably is responsible for the larger time interval. The projected output in 1980 shows that cumulative production again will double by 1979. Projections from Figure 23 suggest that the number may again double by 1990, only an 11-yr interval.

100%-increase year	Interval (yr)
1891	
1892	1
1893	1
1894	1
1897	3
1902	5
1908	6
1913	5
1920	7
1941	21
1979*	38
1990*	11

*projected

Coal Reserves

Essentially all future coal mining in the county will take place underground. The cliff-side exposures and great overburden do not readily permit surface extraction. The largest producing mines already are extensively developed underground and will expand to meet the projected production. Landis and Cone (1971) tabulated the following measured and indicated, and inferred bituminous reserves for the Book Cliffs and Grand Mesa fields in Mesa County. Their estimates included beds from 14 in. to over 42 in. thick and with 0 to 3,000 ft of overburden. Most of the county's measured reserves lie in the Cameo bed, followed by the Palisade, Anchor, and Carbonera beds, respectively. Measured reserves in Mesa County total 268,630,000 tons, 85 percent of which are contained in the Book Cliffs seams. Adding in over 1 billion tons of inferred reserves gives a total reserve outlook of 1,300,000,000 tons for the county, nearly 90 percent of which lie in the Book Cliffs field.

Table 14. Bituminous coal reserves in Mesa County (from Landis and Cone, 1971)

	Reserve Category	Reserves by bed (million short tons) Anchor	Palisade	Cameo	Carbonera	Total
Book Cliffs field	M	24.24	100.82	83.93	19.36	228.35
	I	41.25	663.85	228.11	-	993.21
	T	65.49	764.67	312.04	19.36	1,161.56
Grand Mesa field	M	-	7.36	32.92	-	40.28
	I	-	26.78	71.71	-	98.49
	T	-	34.14	104.63	-	138.77
Mesa County	M	24.24	108.18	116.85	19.36	268.63
	I	41.25	690.63	299.82	-	1,031.70
	T	65.49	798.81	416.67	19.36	1,300.33

M - measured and indicated; I - inferred; T - total

These figures indicate, however, the original in-place reserves in each field and must be modified by depletion (production plus mining and processing losses). Losses from mining may be taken numerically equal to cumulative production, which through 1977 amounts to 7,546,629 tons. Therefore, total depletion amounts to 15,090,000 tons and lowers the measured in-place reserves to 253,540,000 tons.

Matson and White (1975) modified Landis and Cone's (1971) estimates of measured and indicated reserves by bed and found the following. Their total of 229,350,000 tons is 14.6 percent lower than Landis and Cone's total. The depletion lowers this revised estimate to a new total of 214,260,000 tons.

bed	million tons
Carbonera	16.33
Cameo	104.22
Palisade	84.56
Anchor	24.24
Mesa Co.	229.35

Land-Use Aspects

Increased coal production in Mesa County naturally will have its greatest surface impact near the Roadside and Cameo Mines and the Cameo power plant. Cameo Coal Company, owned by GEX-Colorado Company, is currently driving a new adit about 0.3 mile northwest of the power plant. Roadside Mining Corporation is currently building a loading facility and washing plant on the Rio Grande Western Railroad at the mouth of Jerry Creek about 1 mile northeast of the power plant. Coal from the Roadside Mine will be transported to the new plant and loading station by an underground conveyor, which crosses the Colorado River just south of the power plant access road. It was apparent to me that the expanded underground and surface facilities are being engineered so as to lessen potential impacts on the immediate area and yet insure efficient operation.

Redevelopment planned at the McGinley Mines likely will involve improvement of the road from 21 Road along Little Salt Wash to Hunter Canyon. The projected 100,000-ton/yr or more production may even warrant the construction of a rail line to facilitate the haul.

Proposed activity at the other end of the Book Cliffs comes through a recent conditional-use request from Coal Mining Partners of Rifle, Colorado. A new adit is proposed on a 160-acre tract that surrounds the Farmer-Nearing Mine about 12 miles north of Fruita.

Fortunately, development has not encroached on these important mineral resource areas because of difficult access, rugged terrain, and lack of water. Thus, although one potential conflict is removed, expansion of these mining operations still must straightforwardly deal with air and water degradation and water consumption.

PART 4: NONMETALLICS

INTRODUCTION

The third principal group of minerals in Mesa County, the nonmetallics, includes various industrial minerals and construction materials. In a few cases only scattered occurrences have been reported, and, in the cases of bitumens and insulation materials, the county is more noted for its contribution in the processing end of the industry rather than mining. Much of this section will focus on the construction materials--sand, gravel, and stone--which together comprise the fourth category of the county's most productive mining industries.

BITUMENS

Bitumens are naturally occurring solid and semisolid hydrocarbons formed apparently by the evaporation or natural fractionation of petroleum. Also called asphaltites, common varieties of bitumens include uintaite (gilsonite), wurtzilite (elaterite), grahamite, and ozocerite (also ozokerite). The most important bitumen deposits in the United States lie in the Uinta Basin of Utah, although others have been mined in Oklahoma and West Virginia. In Colorado, asphaltic veins have been reported in Moffat, Rio Blanco, Garfield, and Grand Counties, but none in Mesa County. Readily obtainable summaries of the geology and mining of bitumens can be found in Cashion (1964) and Barb and Ball (1944). Due to the proximity of the bitumen district in Utah and to Mesa County's intimate involvement in bitumen processing, I will present an historical outline of the Utah occurrences, and mining and processing technology.

Of greatest economic importance is gilsonite, produced only in Utah, which also has the largest reserves. According to G. M. Jones, gilsonite was discovered in 1883 by a local prospector, Sam Gilson, who mistook the material for coal until he found that it would not burn. Bostwick (1975), however, reports its discovery in 1862 on the Uintah Indian Reservation near Fort Duchesne. Gilsonite, the local name given to this bitumen, was formally named *uintahite* and described by Blake (1885). The lustrous black substance resembles solidified tar and breaks with a conchoidal fracture. Barb and Ball (1944) give the following physical and chemical properties:

Hardness: 2
Spec. Grav.: 1.01-1.10
Melt. Point: 230° - 350°F
Thermal Value: 9,650 cal/g
17,370 Btu/lb
Composition: C - 88.3%
H - 9.96%
S - 1.32%
ash - 0.10%

Gilsonite is used in a variety of industrial applications, including the production of gasoline and metallurgical-grade coke, paint, varnishes, battery boxes, inks, brake lining, electrical insulation, asphaltic tile, and sealers.

In eastern Utah, gilsonite occurs in nearly vertical northwest-trending veins through the Duchesne River, Uinta, Green River, and Wasatch Formations, all of Tertiary age. The veins vary in width from a fraction of an inch to 18 ft and extend as long as 18 miles. The widest and most productive veins are found in the Uinta and Green River Formations exposed in eastern Uintah County.

Mining

Gilsonite mining began on a low level about 1888 but soon increased to meet new demands once the material's versatility was recognized. Early mining essentially was controlled by three firms--American Gilsonite Company, G. S. Ziegler and Company, and Standard Gilsonite Company. In the early years of the century the Barber Asphalt Corporation acquired many of the area's claims and staked out many more. After Congress opened the Uintah Indian Reservation to mineral location in 1903, Barber constructed the narrow-gauge Uintah Railway from Mack, Colorado, to Dragon, Utah, and later extended it 10 miles to Watson. Portions of the old grade are still visible near Mack and along West Salt Creek (Plate 2). When the railroad was abandoned in 1938, the towns of Dragon and Watson were moved to the Bonanza site, about 72 miles northwest of Grand Junction.

American Gilsonite Company, a subsidiary of Barber Asphalt Corporation and Standard Oil Company of California, operated three major veins in the district--the Cowboy, Big Bonanza, and Little Bonanza. Until World War II all the underground mining was done by underhand stoping from the shafts. Miners handpicked and sacked the ore, and the 200-lb sacks were hoisted to the surface. Ladders were the only access to the 700-ft-deep shafts. In 1942 a labor shortage brought about by the war forced the companies to mechanize their operation. Shrinkage stoping was initially tried, but explosive gilsonite dust produced by this method was quite dangerous. In addition, the efficiency of blasting was diminished by the elasticity of the gilsonite ore. These problems led company researchers to develop a mining method that did not involve blasting.

Consequently, hydraulic mining was introduced in 1957 (Kilborn, 1964). In this process 2,000-psi water jets penetrate and fracture the ore, which is then washed away in a slurry. The ore-water mixture is derocked, screened, and crushed in an underground facility before being pumped to a surface slurry-preparation plant. This method had the economic advantage of less underground manpower, timbering, and bolting. In the early 1960's American Gilsonite improved the hydraulic mining method by *vertical cutting*, in which a vertical shaft and lateral drifts are first constructed in the vein. From the surface, pilot holes are drilled downward through the vein to intersect the tunnels. High-pressure water jets mounted on a rotary bit are brought up through the holes, and the cut ore falls to the tunnel level where it is collected in a sump.

Transportation

In the early days of gilsonite mining in Utah, ore was hauled by wagon to Price and Heber, Utah, and to Rifle and Loma, Colorado. The construction of the Uintah Railway in 1903 provided an outlet from the Dragon-Watson area to the Denver and Rio Grande Western Railroad. The Uintah line would have been extended to Bonanza, but the construction of U.S.

40 north of Bonanza provided a much cheaper means of transportation to a standard-gauge track (Barb and Ball, 1944).

In 1954 it was shown that gilsonite could be refined by a conventional petroleum process known as *delayed coking* (J.H. Henderson, Jr., 1957). The decision to build a refinery was based largely on the cost of transporting the ore from the mines. An economic study showed that a slurry pipeline would be a cheaper means of transportation than trucks. Ideally a refinery site had to be located near a railroad in an area with ample labor, housing, schools, and other facilities. After a number of sites in Colorado and Utah were considered, a site was selected 2.5 miles northwest of Fruita on U.S. 6 and 50 and the D&RGW Railroad (Figure 24).

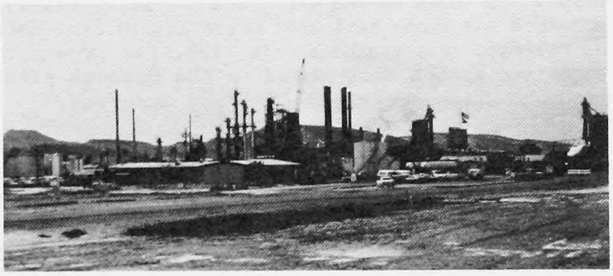


FIGURE 24. Gary Western Company's oil refinery, owned by the Gary Operating Company of Englewood, Colorado. The plant, located west of Fruita, manufactures gasoline, by-product coke, and other petroleum products.

As a result of designing and testing at the Colorado School of Mines Research Institute, a 72-mile-long slurry pipeline, the first slurry line in the country, was built in 1957 from Bonanza to the refinery at a cost of $2 million. At the time of its construction, the slurry line represented more than $4/ton savings in operating costs over trucking alternatives to Rangely, Meeker, or Rifle. Initial specifications at the preparation plant called for the slurry to contain a 35-percent concentration of gilsonite crushed to approximately minus-8 mesh. Before entering the 6-in.-diam line, the slurry was pumped to one or two 5,000-bbl batch tanks for quality control. Water for the slurry came from the White River. At the pumping station, three 300-hp reciprocating slurry pumps maintained a pumping rate of 360 gal/min, thus transporting about 750 ton/day of ore.

Refining

Operations at American Gilsonite Company's refinery began in August 1957. As stated earlier, the refinery is unique from three standpoints. In addition to incorporating the first slurry pipeline, the plant was the first privately financed system in the country to produce conventional petroleum products from a nonpetroleum source. Thirdly, the plant has the dual capability of manufacturing and calcining special-purpose by-product coke. The refinery consists of four complex plants--a filter, melter, delayed coker, and calciner.

The filter plant, endpoint for the pipeline, consists of a 5,000-bbl agitation tank into which the slurry is fed and disc filtered to 20-percent moisture content. The filter cake then is conveyed either to a 20,000-ton stockpile or to the melting plant. Hot oil recycled from the delayed coker contacts the damp filter cake in a 450°F melting tank. The mixture is agitated to insure the release of steam and then fed to the delayed coker.

In the delayed coker the combined feed is pumped into a direct-fired heater in which coke precipitates from the hot liquid and is discharged to a coke drum. When full, the drum is emptied by the action of 2,200-psi water jets. After the water is drained away, the green coke is crushed to a 3-in. size. Vapors and gases that form during the coke precipitation are drawn off and passed to a fractionator where wet gas is separated and used for plant fuel and where unstabilized gasoline or naphtha is condensed. After stabilization, the naphtha is fed to a complex catalytic reformer, wherein nitrogen compounds in the naphtha are converted to ammonia and drawn off. Finally, the reformer produces premium- and regular-grade gasoline, propane, and butane.

In the calciner, the fourth plant, green coke from the delayed coker is cured by gravitating through a 10-ft diam, 180-ft-long inclined rotary kiln in which water, volatiles, and combustible materials are removed. The calcined coke then passes through an 8-ft-diam, 80-ft-long rotating drum cooler. Hot waste gases that are produced are used to fuel the furnace and compressors.

The American Gilsonite slurry pipeline carried gilsonite until late 1973 when the refinery ceased processing gilsonite and was sold to Gary Operating Company of Englewood, Colorado. The pipeline was converted in 1977 to carry crude oil from Roosevelt, Utah (Arthur Corrigan, 1977, pers. comm.). By November 1977, the Gary Western refinery converted to crude oil from the Rangely district. The facility, which currently employs approximately 100 people, has increased its capacity to about 14,000 bbl/day.

Other Bitumen-Related Industries

The Tusco, Inc., mixing plant is located immediately behind the Gary Western refinery. In the spring of 1977 the company began processing the old gilsonite tailings to manufacture an asphaltic sealer for use in road repair (Arthur Corrigan and Jack La Follette, 1977, pers. comm.). Naphtha and fillers are blended with the gilsonite to produce a flexible viscous compound.

Gilsabind Company operates a plant at Mack and manufactures an asphaltic sealer known as Gilsabind, which is composed of a gilsonite-base asphalt and a diluent. The sealer has been shown, in test pavements, to resist the degrading effects of air, water, and solar radiation and to improve the skid resistance of the pavement.

Land Use

Economics of the industries described above dictate that they be located near railroads to facilitate long-distance hauls. At the same time, U.S.

6 and 50 provide ready access from the plants to local markets. It is not likely that new plants will start up in this area, but with ample land available, expansion of existing facilities could be anticipated with little impact on the area other than increased truck traffic on the highway.

CLAY

Mesa County clays occur in a fairly wide interval of the geologic column, including the Brushy Basin Member of the Morrison Formation, the Dakota Group, lower Mancos Shale, Green River Formation, and Quaternary terrace deposits. Complete production statistics for clay are not available, but the Colorado Division of Mines shows a cumulative production value of $23,239 for the period 1959 through 1966. This amount does not include what may have been produced in the 1920's.

Occurrence and Clay Properties

The Brushy Basin Member of the Morrison Formation exposed south of Grand Junction contains a 275-ft shale interval that has yielded bentonitic clays for both construction and industrial uses. The grayish-green mudstones and silty claystones in this sequence crop out in smooth, rounded slopes and hills (Figure 25a). The bentonitic nature of the clays is indicated by their slipperiness when wetted and by a "popcorn" texture when dried (Figure 25b). Bentonite itself is a rock composed of any of the montmorillonite-biedellite group of clay minerals derived from the alteration of volcanic ash. Although these clays have been utilized in the Grand Junction area, I could find no chemical or physical analyses.

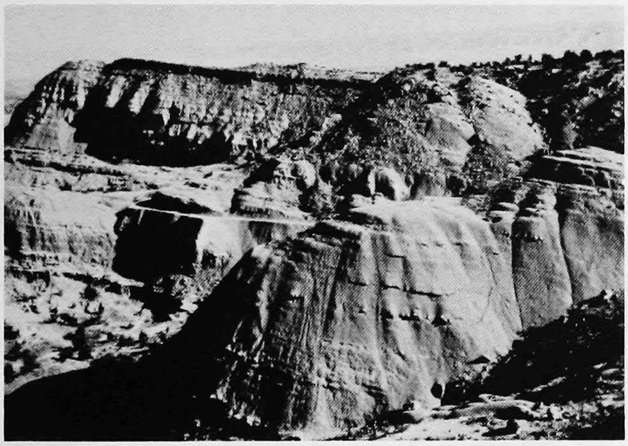


FIGURE 25a. Bentonitic clay horizon in the Brushy Basin Member of the Morrison Formation, exposed along Little Park Road southwest of Grand Junction. Note the smooth and rounded appearance of the hills. Sandstone of the Burro Canyon Formation caps the ridge in the immediate background. View is to the north-northwest.

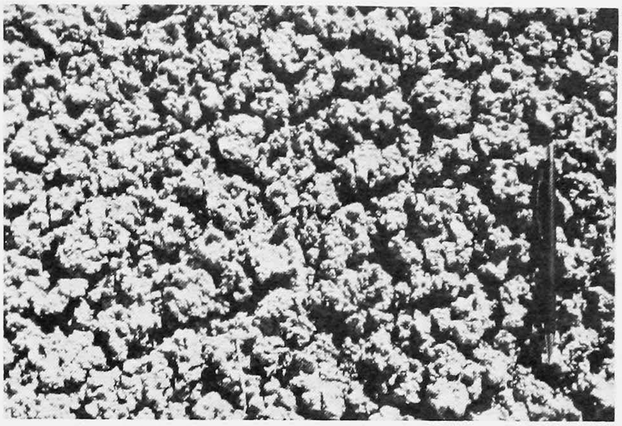


FIGURE 25b. Upon drying, bentonitic clay shrinks to form a distinctive "popcorn" texture. The pencil at right is 14 cm long.

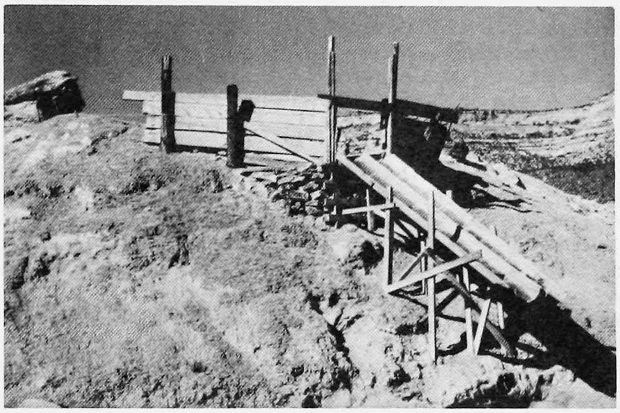


FIGURE 25c. Loading chute at the Kirby bentonite pit south of Riggs Hill in Redlands. The small hilltop excavation produced bentonitic clay for industrial use.

Morrison bentonitic clays have been mined at three sites in the Redlands-Grand Junction area:

1. NE/4 sec. 30, T12S, R100W--1 mile southeast of Little Park Road at southwest end of Horse Mesa.
2. sec. 18, T12S, R100W--on Little Park Road 5.2 miles south of Colorado 340.
3. SW/4 sec. 26, T11S, R101W--0.25 mile south of Riggs Hill off South Broadway in Redlands.

Of the first two pits, operated by the BLM, the second is still active. Bentonitic clay has been mined intermittently for use in canal and ditch linings, and because of the bentonite's swelling properties, it forms an effective seal against leakage. Clay from the third pit (Figure 25c) apparently was last mined in 1965 and reportedly used for industrial purposes (John E. Kirby, 1977, per. comm.).

The Dakota Group was discussed earlier in the section about the Gunnison River coal resources. Clay resources in the upper Dakota essentially coincide with the Gunnison River coal resources as shown on Plate 2. The Dakota, well known for its high-quality refractory clays, has been extensively mined on the eastern slope of Colorado and elsewhere. Butler (1914) examined Dakota clays at four sites just southwest of Grand Junction and found that the clays might be suitable for pressed and soft-mud brick but that the products would likely warp or crack. Along the Gunnison River 2 miles south of the city he found the clays suitable for pottery and brick manufacture. Butler's clay firing tests (Table 15) indicate that even the strongest and most cohesive Dakota clays fall below the lowest fusion temperatures necessary for low-duty refractory products. Van Sant's (1959) analyses in Table 16 similarly indicate nonrefractory or marginally low-duty refractory clays in the Dakota both along the Gunnison River and in the hogback area near Loma. The high porosity and low fire shrinkage of one Gunnison River sample (#37) resulted in a higher PCE, indicating moderate refractory properties. Sample 42 (a composite of samples 37 through 41) represents a total bed thickness of 12.8 ft and gives a PCE of 19, the lower cutoff value for low-duty refractory clay. At such a marginal quality, it is doubtful if a composite thickness could be maintained in any one area to provide sufficient raw material for an operation. At best it appears that the Dakota clays are suitable for nonrefractory uses — earthenware, pottery, stiff-mud brick, and possibly floor and wall tile, dry-press brick, ladle brick, and stoneware.

Mancos shale underlies the Colorado River flood plain and Grand Valley. Butler (1914) sampled the lower part of the formation near Loma, Fruita, and Grand Junction. His samples (Table 15) were fired to incipient vitrification, to vitrification, and to the viscous state. The results at all three firing states give very low Seger cone values that, according to their fusion-temperature equivalents, indicate nonrefractory materials.

Clays from the Mancos Shale have been used for brick manufacture in Grand Junction for many years. Butler (1914) mentions the Clark and Atkinson brick yard near the northwestern edge of the city, but neither the pit nor plant site could be located. Van Sant (1959) states that the Grand Junction Brick Company, 2400 North 17th Street, was constructed in 1922 and manufactured face and common brick and various structural forms (Figure 26a) at an annual capacity of 2.5 million units. At the present time only the plant's foundations and considerable rubble remain on the site (Figure 26b). According to the Colorado Division of Mines, the plant last operated in 1962. The clay pit that supplied the plant is located on 27 1/4 Road about 0.3 mile north of Patterson Avenue and now is used as a dump (Figure 26c). The Mancos Shale from this site reportedly

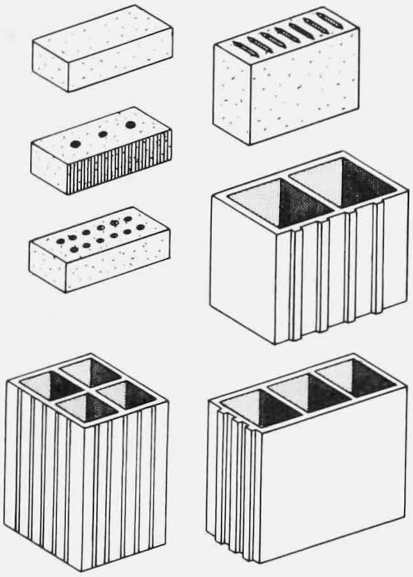


FIGURE 26a. Various bricks and structural clay forms manufactured at the Grand Junction Brick Company, 2400 North 17th Street. Specimens were identified from the rubble at the dismantled plant.

FIGURE 26b. Foundations of the dismantled Grand Junction Brick Company plant. Mancos Shale is exposed on the hills behind the old works.

FIGURE 26c. Abandoned clay pit of the Grand Junction Brick Company, located on 27 1/4 Road northwest of the dismantled plant.

TABLE 15. Firing tests of Mesa County clays (from Butler, 1914).

Sample	Rock Unit	Location	Degree plasticity	Degree cohesion	Percent water for maximum plasticity	Percent air shrinkage	Tensile strength (lb)	Incipient Vitrification Seger*	Incipient Vitrification % Fire Shrnk.	Incipient Vitrification % Abspt.	Vitrification Seger	Vitrification % Fire Shrnk.	Vitrification % Abspt.	Viscosity Seger
394	Kd	2 mi south of Grand Jct.	G	S	33.3	12	119	05	2	11.1	3	5	4.2	5
395	Kd	do.	G	S	42.6	16	17.5	010	3	15.1	03	6	2.9	5
396	Kd	do.	G	S	25.5	21	22.5	010	3	9.2	05	3	2.8	3
397	Kd	SW/4 sec. 22, T1S, R1W Rosevale	F	W	23.8	4	51	010	3	15.8	3	4	6.2	5
398	Km	northwestern Grand Jct.	G	S	19.1	4	53	01	3	13.5	2	3	5	3
399	Km	SE/4 sec. 6, T1S, R1E	F	W	18.7	1	56	05	0	13.2	3	5	3.5	8
400	Km	sec. 31-32(?), T1N, R1E northeastern Grand Jct.	F	S	20.7	3	81	03	4	13.0	01	-	-	01
401	Km	do.	(practically the same as No. 400)											
402	Km	do.	F	W	20.4	3	79	03	1	22	3	9	3	5
403	Km	near Fruita	Fn	S	26.4	5	73	07	0	17.2	1	0	14.6	5
404	Km	SE/4 sec. 35, T2N, R3W	G	W	22.9	1	35	3	1	21.6	5	1	12.8	8

CHEMICAL ANALYSES

		Ultimate Analysis (%)										Rational Analysis (%)					
		SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	K_2O	Na_2O	ign. loss	Moist.	Total	kaolin	quartz	feld.	limonite	calcite	Total
394	Kd	65.02	20.25	3.20	1.15	2.64	1.29	0.45	4.78	2.44	101.22	45.50	35.76	11.94	3.74	2.15	99.09
396	Kd	63.44	16.28	4.51	0.82	1.38	2.12	1.02	3.85	5.69	99.17	30.10	34.52	22.35	5.38	2.52	94.87

abbreviations:			
	Kd-Dakota Sandstone	G-good	S-strong
	Km-Mancos Shale	F-fair	W-weak
		Fn-fine	

* Former standard clay firing test. Cone intervals correspond to 20- and 30-C° intervals of fusion temperature. Range from low 022 to high 36. To compare, Seger 19 1/2=PCE 19, but PCE intervals are not proportional to Seger intervals.

Seger cones		010	07	05	03	01	1	2	3	5	8
Fusion temp.	°C	950	1010	1050	1090	1130	1150	1170	1190	1230	1290
Fusion temp.	°F	1742	1850	1922	1994	2066	2102	2138	2174	2246	2354

TABLE 16. Firing tests of Mesa County clays (from Van Sant, 1959).

Sample	Rock Unit	Bed Thk. (ft)	Location	Atterberg water of plasticity	Percent dry shrinkage	Porosity (%) Firing temperature °F						Linear Fire Shrinkage (%) Firing temperature °F						Bloating temp. °F	PCE*
						1800	2000	2100	2200	2300	2400	1800	2000	2100	2200	2300	2400		
32	Kd	8.0	NW/4 sec. 9 T1N, R3W near Loma	30.5	7.5	11.7	4.7	2.3	1.0	0.8	1.5	9.0	12.0	14.0	14.0	12.5	11.0	-	18-19
33	Kd	1.0	do.	35.5	9.0	13.0	6.5	3.3	0.1	0	0.1	10.0	14.0	16.0	14.5	15.5	13.0	-	18
34	Kd	2.0	do.	28.0	6.5	14.3	5.5	2.3	0.6	1.8	28.0	7.5	15.0	15.0	12.0	5.5	+2.5	2300	8
35	Kd	1.0	do.	36.0	8.0	8.5	5.2	2.7	2.7	5.6	24.7	10.0	10.0	9.0	7.5	2.0	0	2000	4 1/2
36	Kd	5.0	do.	27.0	7.0	15.0	13.4	9.7	7.0	3.7	6.5	7.5	9.0	10.5	12.0	10.5	7.0	2300	5
37	Kd	5.0	Gunnison R. @ Delta Co.	19.0	3.0	19.3	19.5	17.5	16.3	15.7	15.7	3.0	4.0	5.0	6.0	6.0	6.0	-	28-29
38	Kd	2.5	do.	27.0	7.0	13.0	2.5	7.8	5.7	0.7	13.6	8.5	12.5	8.0	8.0	7.0	7.0	2100	3
39	Kd	1.2	do.	36.5	5.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-
40	Kd	1.6	do.	27.0	6.5	12.7	5.4	2.8	5.0	7.9	5.7	9.0	13.0	13.0	11.0	9.0	9.0	2200	5
41	Kd	2.5	do.	23.5	6.0	14.9	11.0	7.3	3.9	3.7	9.3	7.5	10.0	11.0	12.5	12.0	9.5	-	18
42	Kd	12.8	do.	22.0	4.0	15.8	13.3	9.8	5.7	5.2	0	6.5	7.5	9.0	11.0	10.5	10.0	-	19
43	Km	-	SW/4 sec. 1 T1S, R1W GJ Brick Co.	23.0	4.0	17.4	14.2	0	-	-	-	5.5	7.0	+2.5	-	-	-	2100	3
57	Kd	1.8	S/2 sec. 28 T12S, R99W	33.5	8.0	13.8	3.7	0.9	1.3	4.8	7.2	10.0	15.0	16.0	13.5	-	-	2200	5
58	Kd	1.8-2.5	do.	33.0	7.5	16.5	11.4	5.7	1.8	1.7	2.3	9.5	12.0	15.0	16.0	13.5	12.0	2300	14-15

Kd - Dakota Sandstone Km - Mancos Shale

* Pyrometric Cone Equivalent (PCE) is a standard test for the refractoriness of a clay. Molded cones of the clay are fired with standard cones. The temperature at which the cone bends over and touches its base is taken as the PCE and is recorded as the number of the standard cone most nearly the same as the test cone. PCE values for refractory clays are:

19-26	(2768°-2903°F)	low-duty
26-31 1/2	(2903°-3074°F)	moderate
31 1/2-33	(3074°-3173°F)	high
33-34	(3173°-3200°F)	super-duty

gave a cream color to the brick. To obtain a red brick, the company used ferruginous (iron oxide-stained) bentonitic clay from somewhere south of Grand Junction, possibly from the Brushy Basin Member. Another pit in Mancos Shale is located just south of H Road at Walker Field, but I could not determine what use was made of the excavated shale.

Regarding the utilization of Quaternary clays, Aurand (1920b) cites the use of river terrace clays near Grand Junction. The clay pit at the mouth of No Thoroughfare Canyon west of Rosevale might well be this reported excavation, but the site has been reclaimed for homesites, and I could not determine whether actual terrace clay was mined or whether underlying Dakota clays were used and mistaken for or mistermed terrace clay.

The latest development in the clay products industry in Mesa County is the new Coors Porcelain Company plant located at 2449 River Road on the west side of Grand Junction. Opened in 1977 the plant will process clay bodies that are trucked here from the company's factory in Golden (George White, 1977, pers. comm.).

Future Potential

Assuming that any future development of Dakota clays would involve somewhat lower specification uses such as brick, stoneware, or pottery (based on available analyses), we may investigate three possible sites--the Loma, Whitewater, and Deer Creek areas. All these sites are located near extensive Dakota outcrops, close to major transportation routes, and away from principal residential districts.

In the Mack-Loma area the Dakota outcrop is readily accessible from Interstate 70 at the Mack and 13 Road interchanges. The eroded southeastern side of the hogback could support a hillside surface excavation. Market distances from a plant site at Mack or Loma would be 5 to 8 miles to Fruita, 18 to 21 miles to Grand Junction, and 25 to 31 miles to Clifton and Palisade.

Sites in the Whitewater area accessible from Colorado 141 include the mesa between Bangs Canyon and East Creek and the top or east side of Ninemile Hill. The lower Kannah Creek area south of Whitewater is accessible from U.S. 50. Market distances from a plant site in Whitewater would be 9 miles to Grand Junction and 8 to 13 miles to Clifton and Palisade.

The chemical analyses presented earlier indicate somewhat higher quality clays in the Deer Creek area, which also is readily accessible from U.S. 50. Although the east-dipping slopes would support a surface excavation, entry in the canyon of Deer Creek probably would necessitate a hillside adit. Market distances from a plant site near U.S. 50 would be 20 miles to Grand Junction, 18 to 24 miles to Clifton and Palisade, and 19 miles to Delta.

Feasibility of future clay resources development will be governed largely by transportation costs and haulage distances because, like gravel and stone, brick clay can be classed as a low unit-value commodity. In addition substantially more exploration and physical and chemical testing will be required to define areas of sufficient proven reserves. Before such detailed investigations can be made, one must determine if anticipated residential and commercial development near Grand Junction could increase the demand for such building materials as brick and adobe to the point that they could compete with imported materials and other locally produced materials.

Future mining development in the Mancos Shale is much more difficult to evaluate because the formation is so much more extensive than the Dakota throughout the Grand Valley. Similar economic criteria would, however, apply--potential sites must be located close to markets and to adequate transportation routes.

EVAPORITES
(Gypsum, Halite, Potash)

Potentially economic evaporite minerals occur in Sinbad Valley, a geologically complex and fascinating element of Paradox Basin geology in southwestern Mesa County (Plate 1a). The geology and structure of Sinbad Valley were referred to briefly in the discussion of copper deposits, and I will now present a more detailed picture of the geology as it relates to potentially usable gypsum, salt, and potash.

Geology and Structure

Above the Precambrian crystalline rocks exposed in Unaweep Canyon and other deep canyons to the south is a sequence of sedimentary rocks whose known thickness exceeds 15,000 ft. Within the Pennsylvanian Hermosa Formation, the oldest sedimentary rocks in the valley, Cater (1970) recognized the Paradox Member, composed mostly of evaporites in the lower part and limestone in the upper part. The Paradox Member crops out on the valley floor in badlands-type topography in the highly eroded areas and as low rounded hills where alluvium covers most of the valley floor (Plate 2). This member consists of carbonaceous shale, gypsum, limestone, and some coarse-grained feldspathic sandstone. The gypsum occurs in porous, earthy, and densely crystalline forms, but a sugary texture is most common. In Gypsum and Paradox Valleys to the south, gypsum is more abundant than shale. Extreme folding, crumpling, and solution activity in the Paradox beds do not permit an accurate determination of thickness, but the member could well exceed 4,000 ft.

The upper member of the Hermosa, exposed locally in the center and along the sides of the valley, consists of thick-bedded, gray, fossiliferous limestone with thin shales and sandstones. Although the upper member is nowhere completely exposed, it has a probable thickness of 2,000 to 2,200 ft.

Sinbad Valley lies near the northeastern boundary of the Paradox Basin, an oval structural basin covering about 11,000 sq mi in the Four Corners region. The most striking feature in the northern part of the basin is the series of northwest-trending anticlines paralleling the Uncompahgre Uplift and forming elongated valleys with steep, fault-lined inner rims generally downdropped into the valley. The Sinbad Valley anticline lies on the same trend with Fisher and Salt Valleys in Utah. To the south lie Paradox and Gypsum Valleys in Montrose and San Miguel Counties, and Lisbon and Moab Valleys in Utah. All comprise the salt fold and fault belt of the Paradox Basin (Kelley, 1955a). The Salt Creek graben, a small downdropped block, flanks Salt Creek, the northeastern entrance to Sinbad Valley. Cater (1970) noted a maximum 700-ft displacement on the southeastern fault and 400 ft of displacement near the center of the fault zone on the northwestern side. The remaining faults encircling the interior of the valley have downdropped the rocks both toward and away from the valley center.

Sinbad Valley is known as a *salt anticline*, a structural feature generally thought to have originated because of salt and other evaporites' tendency to deform plastically under great pressure and their ability consequently to "intrude" overlying rocks. Because the mechanics of formation are quite complicated, the reader is referred to the literature. The gypsum-halite core of the Sinbad Valley salt anticline consists of five or six contiguous *cells* that presumably rose from a central mass in a deeply buried ridge or roll extending the length of the anticline. On Plate 2 the Hermosa outcrops, fault locations, and approximate salt cell boundaries have been modified after Shoemaker (1955) and Shoemaker and others (1958). Some of the smaller faults in the complex may have been omitted because they were indiscernible on the airphotos. All or parts of four of the six cells lie in Mesa County, and their outer boundaries essentially coincide with the major normal faults that encircle the valley. The inner boundaries are shown diagrammatically on Plate 2 (short dashed lines) as faults. In addition to the salt cell complex, three smaller salt *plugs* lie along the Fisher Valley-Sinbad Valley anticline--a) under Pace Lake just across the Utah state line, b) in Kirks basin about one mile northwest of the state line, and c) Roc Creek about 3 miles to the southeast in Montrose County.

The Sinbad Unit #1 well, a dry hole located near the center of the valley, penetrated salt at a depth of 400 ft and remained in salt for more than 9,000 ft. Other wells drilled in the Paradox Basin anticlines show a 70.4-percent average salt content of the cores but only 42 percent in Sinbad Valley. The salt content decreases toward the shallower northeastern edge of the basin where the proportion of clastic rocks (sandstone and conglomerate) in the evaporite sequence increases.

Regarding potash occurrences, Hite (1960) identified at least 29 evaporite cycles in the Paradox Basin. Each cycle represents a deposition of limestone, dolomite, anhydrite [$CaSO_4$], and halite-potash, and repeated in reverse order. Potash deposits were found in 18 of the cycles, and potentially valuable potash found in 11 cycles, with K_2O contents exceeding 30 percent in the form of sylvite (KCl] and carnallite [$KCl \cdot MgCl_2 \cdot 6H_2O$]. Although the potash is found at depths from 1,700 to 14,000 ft, it probably lies closer to the surface in the salt anticlines than in the nonintrusive anticlines. Considerable drilling will be needed to identify potash cycles that might lie beneath Sinbad Valley.

Resources

Until 1972 the only underground potash mine outside the Carlsbad district was a shaft mine developed in 1961 on the Cane Creek anticline (nonintrusive) south of Moab, Utah. The 11-ft-thick potash bed contained 25 to 30 percent K_2O and lay at depths of 2,400 ft to 4,000 ft. In 1972 the mine was converted to solution recovery because of bed deformation that was encountered. Although potash development in Sinbad Valley does not appear likely, the evaluation will depend on the geology, structure, thickness, depth, and K_2O content of potash beds that may be encountered during exploration.

A probable thickness in excess of 10,000 ft with only 400 ft of overburden indicates a vast and attainable salt resource beneath the floor of Sinbad Valley. Probably the most suitable and most economical method of salt extraction in this area is brine evaporation. One variation involves pumping saline water directly out of the ground and into evaporation pans. A second and somewhat more complicated procedure involves the injection of water or other solvent and the recovery of saturated brines for evaporation. The latter method will require careful evaluation of economic and water-consumption factors. One 90-ft-deep brine well operated in the Paradox Valley of Montrose County and yielded 600,000 gal of brine at 22-percent salt content (U.S. Geological Survey, 1968c).

Most of the Sinbad Valley gypsum is likely to be silty, thus detracting from its economic potential. The crystalline beds are probably most promising, but no information is available about their thickness, extent, or purity. Northeast of Sinbad Valley along the Dolores River a 4- to 6-ft-thick crystalline gypsum bed occurs locally at the base of the Moenkopi Formation. On Plate 2 I have mapped outcrops in secs. 1, 2, and 11, T50N, R19W and in sec. 35, T51N, R19W. Two small quarries in sections 2 and 11 yielded gypsum that was processed in Gateway and used for building block and other forms (Argall, 1949). In 1959 the Colorado Division of Mines reported that these quarries, the Gypsum Group, were operated by K. L. Etter Construction Company of Grand Junction and owned by Scientific Soil Products Corporation, also of Grand Junction. A crusher and small processing plant operated at 943 4th Avenue in 1959 and 1960. Although this bed is well exposed in places and accessible from Colorado 141, I doubt if any significant use can again be made of the deposit.

FLUORSPAR, LIMESTONE, AND SULFUR

Fluorspar is an industrial name applied to fluorite ores containing any of various impurities such as calcite, silica, alumina, and barite. Principal uses for this commodity include flux for open-hearth steel-making, ceramic enamels, and colored glass. In the chemical industry fluorite is used to manufacture hydrofluoric acid (HF) necessary for the production of fluorocarbons. The four major fluorite-producing districts in Colorado include Jamestown (Boulder County), Browns Canyon (Chaffee County), Northgate (Jackson County), and Wagon Wheel Gap (Mineral County). Although Mesa County lies near none of the major districts, two deposits--Unaweep Canyon and Ryan Park--warrant some discussion.

As mentioned earlier in the discussion of the Unaweep mining district, colorless and light-green fluorite occurs as an accessory mineral in northwest-trending faults and fissures in Precambrian and Triassic rocks near the Nancy Hanks Mines. The mineral occurs as fine- to medium-grained columnar crystals in zoned intergrowth with quartz and amethyst. Brady (1975) reports coarsely crystalline fluorite in northeast-trending fissures in the Wingate Sandstone near the Wiel (Taylor) Ranch. The northeastward orientation probably is related to the faults and alignments that I have mapped about 1 to 4 miles south-southwest of the Unaweep district between Jacks Canyon and Gibbler Gulch (Plate 2).

Ryan Park straddles the Colorado-Utah line about 12 miles northwest of Gateway. A broad surface of Wingate Sandstone and Kayenta Formation apparently was downdropped between several large northwest-trending faults, including the Ryan Park fault zone (Plate 2). Brady (1975) notes fluorite occurring with barite and galena in erratically distributed, nearly vertical veins through the Precambrian and Wingate Sandstone on the south side of Ryan Creek about 3 miles west of the Utah line (NW/4 sec. 24, T22S, R25E, Salt Lake P.M.). Although he did not note the extension of these veins into Colorado, the occurrences do warrant prospecting along the Ryan Creek fault zone and along the northeast-trending faults and alignments I have shown around Renegade Point and Haystack Peaks.

Many rock formations in Colorado contain limestone, but very few have yielded beds of economic importance. In Sinbad Valley the Hermosa Formation contains limestones in its upper member, but very little data are available for speculation about its economic potential. On the Uncompahgre Plateau the Salt Wash and Brushy Basin Members of the Morrison Formation contain numerous but thin and lenticular crystalline limestones. The only reported commercial use of Morrison limestones in this area comes from Aurand (1920b) who mentions that a small quarry near Dominguez in Delta County was operated for building stone. This quarry apparently is the small excavation at the mouth of Wells Gulch near the Dominguez siding in SW/4 SE/4 sec. 26, T14S, R98W. The quarry operated in a thin bed of dense, gray, crystalline, and seemingly high-purity limestone in the Salt Wash Member. Although the Salt Wash and Brushy Basin are widespread throughout the county, bed thinness and lenticularity will seriously limit any possible exploitation of the limestones.

Smith (1918) first mentioned the occurrence of sulfur near Grand Junction. Aurand (1920b), Vanderwilt (1947), and Argall (1949) all paraphrased Smith's note but could not confirm the report or give a specific location. If sulfur does occur near the city, it is likely a minor occurrence associated with the coal and carbonaceous shales of the Dakota-Mancos transition zone exposed south of the city.

GEM STONES AND FOSSILS

Gem stones and fossils usually are not considered mineral resources, but they are natural materials that have scientific and possibly minor but personal economic importance. Many of these collectors' rocks and specimens are widely distributed and, in most cases, cannot be shown as specific occurrences on Plate 2.

Barite has been reported from several localities in the county. Chenoweth (1977, pers. comm.) reports that collectors have obtained specimens from the dry washes around the southern slopes of Mount Garfield north of Interstate 70. I have found barite crystal fragments on hillsides along Mitchell Road about 2 miles west of Douglas Pass Road. The fragments were mixed with float from the hilltop gravel deposits, but because the barite is too fragile to have been deposited with the gravel, it most likely originated from pods or thin veins in the underlying Mancos Shale. Another barite locality is reported about 3 miles south of Gateway, where a 3-ft-wide white and iron-stained vein occurs near the top of the Cutler Formation (Pearl, 1965; Stewart and others, 1960). According to the Colorado Division of Mines' 1957 annual report, the prospect, known as the White Star #1, was operated by L. E. Schooley and Associates, Grand Junction, but the use of the mineral was not known.

Opal, agate, chalcedony, and other forms of silica [SiO_2], are the most common specimens found in Mesa County. Opal Hill, the most noted locality, lies 1 mile southwest of Fruita in NW/4 sec. 19, T1N, R2W. A gravel road leads past the hill from Colorado 340 just south of the river. Sandstones of the Burro Canyon Formation form the ridge, and two prospects in a vein at the top of the hill yielded white to light bluish-gray opal. A chalky appearance, probably due to dehydration, was apparent on fracture surfaces.

About 1 mile south of Whitewater, I found an agate- and chalcedony-bearing gravel in the fourth terrace level north of East Creek (SE/4 SW/4 sec. 28, T12S, R99W). Specimens were of various colors and granular to pebbly in size. I have noted another locality on a small isolated hilltop on the south side of the road about 0.3 mile south of Casto Reservoir and Gill Creek. The gravel here consisted almost entirely of chert and chalcedony with small fragments of agate.

Another popular collecting area is Pinon Mesa, a long broad Morrison and Dakota outcrop area extending from south of Glade Park into Utah. The forested mesa forms the highest segment of the Uncompahgre Plateau north of Unaweep Canyon. Minor (1945) suggested traversing the route of the aqueduct south of Glade Park for chalcedony and banded and moss agate. The Johnson Creek and North East Creek areas have yielded petrified wood, smoky chalcedony, and blue and white banded jasper. Farther south, from Windy Point into the Fruita Division of Grand Mesa National Forest, others have reported *desert roses*, which are quartz pseudomorphs after barite.

A prominent Dakota cuesta, known as the Indian Hunting Ground, covers a 12-sq-mi area between the Gunnison River and U.S. 50 and between Deer Creek and Kannah Creek. Minor (1951) noted the occurrence there of high-quality black petrified wood.

According to Colorado Division of Mines reports, the Copper Queen Mine in the Unaweep district was operated for amethyst in 1964 and 1965. The copper prospects in the Dominguez district also have yielded amethyst.

The Plateau Creek valley gravel deposits contain a predominance of basalt derived from the Grand Mesa and Battlement Mesa lava flows. In basalt boulders in many of the gravel pits, roadcuts, and other exposures, I noticed numerous *zeolites* , a general name given to a large group of minerals composed of hydrous silicates of aluminum, sodium, and calcium. The zeolites commonly occur as amygdules, which are gas bubbles in the lava flow that later filled with secretionary minerals. Breaking the stones to obtain fresh surfaces will reveal white blebs 1 to 5 mm in diameter showing crystal growth oriented toward the center of the amygdule.

A number of uranium and vanadium minerals were first identified in mines on the Colorado Plateau. For example, the minerals coffinite $[U(SiO_4)_{1-x}(OH)_{4x}]$ and doloresite $[3V_2O_4 \cdot 4H_2O]$ were discovered at the La Sal #2 Mine, and sherwoodite $[Ca_3V_8O_{22} \cdot 15H_2O]$ was first identified at the Matchless Mine. The Uravan mineral belt yields many rather exotic uranium-vanadium minerals, many of which are unidentifiable to the amateur or casual collector. In addition to bright-yellow sandstone-impregnating carnotite and black uraninite, the area is noted for fervanite, hewettite, metahewettite, tyuyamunite, metatyuyamunite, pascoite, rauvite, roscoelite, and vanoxite.

A variety of plant and animal remains can be found throughout a wide stratigraphic interval in western Colorado. Again such occurrences have more historical, scientific, and conversational value than monetary worth. Plant fossils have been found in the Chinle and Green River Formations, and in the Dakota and Mesaverde Groups. Invertebrates are found in rocks of Pennsylvanian through Tertiary age. Crinoid remains occur in the limestone member of the Hermosa Formation exposed in Sinbad Valley. Pelecypods and other mollusks are found in the Morrison Formation limestones and in the Mancos Shale. The widespread Green River Formation yields arthropods and other insects.

In the field of vertebrate paleontology, Mesa County is perhaps best known for its dinosaur discoveries in the Morrison Formation, the most prolific fossil beds of the western interior. Riggs Hill, located just west of Redlands, is the site of *Brachiosaurus*, discovered by Elmer S. Riggs during a Field Columbian Museum expedition in 1900 (Riggs, 1903a). The site is marked by a bronze plaque on the west end of the hill near the road. The large sauropod now resides in the Field Museum of Natural History in Chicago. Another sauropod site is located on a hillside 1.5 miles south of Fruita and east of Colorado 340. The rear half of *Apatosaurus* was recovered also by Riggs, and the entire mount, with parts of animals from Utah and Wyoming, also is exhibited in Chicago (Pearl, 1964). West of the old Riggs diggings, the BLM maintains a 200-acre paleontological study site in sec. 24, T1N, R3W southwest of Fruita. Other remains from the Colorado National Monument area include the sauropod *Diplodocus*, the theropod *Antrodemus*, and the armor-plated dinosaur *Stegosaurus*. Pearl (1964) describes an interesting trace fossil--34 in.-diam theropod footprints on the ceiling of the Thomas Mine in the Book Cliffs coal field north of Grand Junction. Mineralized dinosaur bones were the sites of many small uranium mines on the Colorado Plateau that developed during the uranium boom of the 1950's.

Patterson (1939) described fossil mammals from the Wasatch Formation of Paleocene (earliest Tertiary) age. A mammal quarry in Mesa County is located east of De Beque Cutoff Road on the north edge of sec. 26, T9S, R97W in the Atwell Gulch Member of the Wasatch. Eocene mammals lie near the base of the Shire Member at the Molina Member's type locality--a hill north of Plateau Creek and 1 mile west of Molina in secs. 10, 11, 14, and 15, T10S, R96W. The Green River Formation in the western states notably yields well-preserved fish remains.

Collectors are advised to contact local landowners before collecting fossils, gem stones, and other mineral specimens on private lands.

PEGMATITES

Most of Colorado's large pegmatite districts were known to geologists by the turn of the century, and some were mined as early as the 1880's. Pegmatites may be defined as dikelike intrusive bodies characterized by coarse grain sizes and interlocking crystal texture. Found in the mountains and high plateaus of Colorado, pegmatites are commonly associated with large plutonic igneous masses, most commonly granitic in composition. In a particular natural or geographically restricted region (a pegmatite province), all the pegmatites tend to be related in terms of origin (age), mineral assemblage, and textural and structural features. The bulk of most pegmatites consists of the common rock-forming minerals--quartz, feldspar, and mica. In addition to scientific interest in their origin and composition, pegmatites are important economically from the standpoint of their concentrations of scarce minerals that rarely occur in minable quantities in other kinds of rocks. Most notably, the rarer accessories include beryl, lithium and columbium- or niobium-tantalum minerals, garnet, tourmaline, rare earths, and radioactive minerals such as thorite and autunite. However, much of our domestic production of quartz, feldspar, and mica also comes from these same deposits.

Pegmatites in the Precambrian rocks of Mesa County do not lie within a formal province, but one deposit, at Ladder Canyon, has been worked for many years. The Ladder Canyon mine, also known as Williamson, King, or Que #2, lies near the junction of Ladder Canyon and Rough Canyon and is accessible by a dirt road south from Little Park Road. Precambrian schist and gneiss crop out on the narrow valley bottom and lowest slopes. These rocks are overlain by the Chinle Formation and the steep-walled Wingate Sandstone, which also caps the immediate mesas. The sedimentary rocks dip 2° to 5° to the northeast off the flank of the Uncompahgre Uplift. Locally the beds steepen across the axis of the Ladder Creek monocline, which itself is offset by the Ladder Creek fault.

Sterrett (1912) gave the first detailed description of the deposit. He measured the dike to be about 200 ft wide at the base, thinning upwards. The well-zoned pegmatite consists of an irregular mass of feldspar in the interior grading outward into quartz. A nearly continuous 1- to 3-ft-wide streak of mica that separates the masses consists of tufts and radiating aggregates or *books* of muscovite. Individual crystals, similar to the pages of a book, easily cleave off into transparent A-shaped and wedge-shaped sheets. Black tourmaline is the dominant accessory mineral, although I found minute light-green beryl crystals up to 5 mm long and imbedded in the muscovite.

Benton Cannon reportedly discovered the Ladder Canyon deposit in 1895. Until about 1950 the mine operated only for scrap mica, or mica that, because of impurities, smaller size, and unfavorable cleavage characteristics, cannot meet the higher-specification industrial applications of sheet mica. According to Lohman (1965a), Mica Corporation of America operated the mine between 1948 and 1950 and trucked mica and feldspar to Grand Junction. From there, mica was transported by rail to eastern markets and used in the manufacture of insulation, paints, and greases. From the early 1960's to the present, the quarry has been worked for decorative quartz. Since 1976, American Forest and Stone Company has owned the quarry and operated the crusher located about 700 ft downstream from the mine (Figures 27a and 27b).

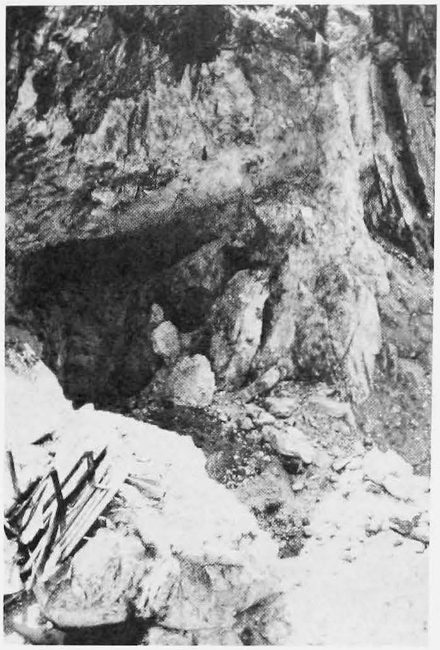


FIGURE 27a. Main cut at the Que #2 pegmatite mine in Ladder Canyon southwest of Grand Junction. Although the mine originally produced muscovite, only decorative quartz has been mined in recent years. This view eastward into the cut is approximately normal to the trend of the zoned pegmatite.

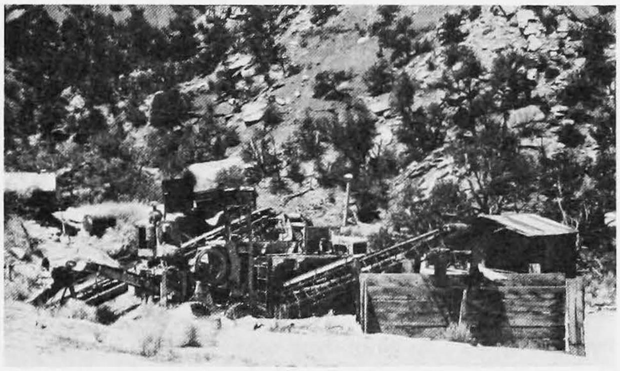


FIGURE 27b. Rock crusher located downstream from the Que #2 mine in Ladder Canyon. Slopes in the background are underlain by Chinle Formation. Precambrian rocks form the canyon floor.

BUILDING AND DECORATIVE STONES

A casual drive through Grand Junction and Redlands neighborhoods will show that natural and cut stone play important roles in residential construction and landscaping. Most of the building and decorative stones produced in the county have come from the northeastern flank of the Uncompahgre Plateau but from rocks spanning a geologic time interval from Precambrian to Quaternary. Structurally such building stones, in the form of ashlar, flagstone, and fieldstone, are used in the construction of walls, veneers, fireplaces, chimneys, retaining walls, walkways, fences, and curbing. Moss rock, fieldstone, gravel, and varieties of crushed stone are used to decorate lawns, gardens, flower beds, and office lobbies and foyers. Selection of stone for any of these uses depends mainly upon the rock's color, texture, strength, bedding characteristics, and ability to split. Of course, the stone's availability and cost of finishing and transporting are primary economic concerns.

Production

Building stone has been quarried intermittently for many years in Mesa County, but production records are quite incomplete. Table 17 lists the U.S. Bureau of Mines tonnage statistics for stone as reported since 1960. For several years, actual tonnage could not be reported because of company confidentiality.

TABLE 17. Mesa County stone production (from U.S. Bureau of Mines mineral yearbooks).

Year	Quantity (thousand short tons	Value (thousand dollars)
1960	1	18
1961	-	-
1962	3.864	46.201
1963	1.489	19.931
1964	W	15.650
1965	9.350	32.973
1966	2.534	19.424
1967	7.656	31.761
1968	W	W
1969	0.244	8.48
1970	W	33
1971	W	16
1972	5	43
1973	9	23
1974	W	W

W - withheld to avoid disclosing individual company confidential data

Precambrian Stones

The only operation noted in Precambrian igneous rocks is located on Divide Road on the southern edge of the Unaweep mining district. Perkins' (1975) Curecanti-type granite was quarried here in 1928 by Ady and Lindas of Colorado Springs, according to the Colorado Division of Mines annual report. The cliff-edge operation apparently was abandoned because of the inability to obtain large enough blocks. Despite this difficulty and the somewhat precarious site, the rock appears to be of fine quality--white, medium-grained, equigranular, biotite-muscovite granite. In an engineering study during the 1950's, the Department of Defense drilled numerous core holes and at least one adit in this granite possibly to evaluate its potential for an underground nuclear detonation test.

An article in Stone (1913) reports another granite operation about 6 miles from Grand Junction near No Thoroughfare Canyon. Neither my airphoto nor field investigations in this area could confirm this report. I would not think that granite bodies of any significant size exist here.

As mentioned earlier, crushed quartz from the pegmatite at the Que #2 mine in Ladder Canyon is used as decorative stone in and around Grand Junction.

Triassic Stones

The Wingate Sandstone and Kayenta Formation have yielded all the Triassic-age building stone in Mesa County. The upper Wingate Sandstone was quarried on a broad dipslope south of Unaweep Canyon about 3 miles by road from the Taylor Ranch. The Golden Stone quarry (Figure 28), as it was known, yielded a light reddish-brown, fine-grained, well-cemented feldspathic flagstone. Although much of the quarry floor has revegetated, many piles of scrap rock still remain.

FIGURE 28. Golden Stone sandstone quarry south of Unaweep Canyon. This shallow excavation is situated on a dipslope of the upper Wingate Sandstone.

The Kayenta Formation, a light-colored thinner bedded sandstone overlying the Wingate, has been quarried at several sites in the northern part of the county. The Loma Quarry is located on the Spann Ranch road 1 mile southwest of the Loma (13 Road) interchange on Interstate 70. The quarry is developed in two low benches (Figure 29a), the lower of which

FIGURE 29a. Working face at the Loma sandstone quarry. This northwestward view is across the upper of two benches cut into the Kayenta Formation. The thin, evenly bedded, flaggy nature of the reddish-brown stone is readily apparent on the out face. The massive, light-colored Entrada Sandstone forms the prominent ledge in the left background.

may actually be Wingate Sandstone. Better stone apparently came from the upper bench--reddish-brown, fine-grained, thin-bedded sandstone. Thin laminations on the cut faces give the flags a subtle striped appearance that enhances the stone's beauty. According to the Colorado Division of Mines, the quarry was last operated in 1962 by United Stone Products Company, Grand Junction. East of the quarry is a stockpile of cut flagstone and curbstone (Figure 29b). Some of the old machinery also was seen, including scales, hoist, and the mast of the dismantled crane.

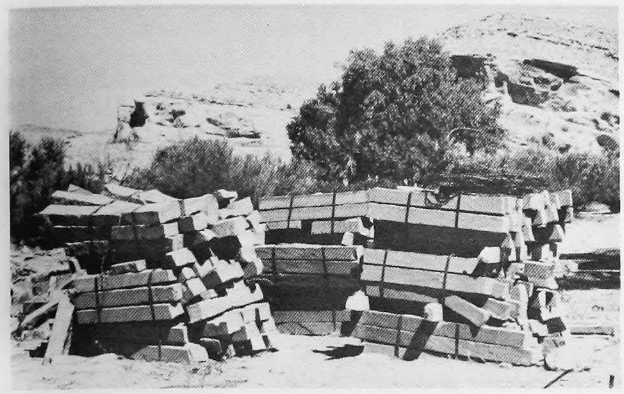


FIGURE 29b. Stockpiles of cut curbstone at the Loma quarry.

One of the few mining operations in western Mesa County lies near Long Mesa northwest of Sieber Canyon. Accessible by dirt roads from BS Road in Glade Park, the quarry was developed by one low bench in the middle Kayenta Formation that forms the floor of the 0.3-mile-wide valley (Figure 30). One variety of stone quarried here is a yellow to white, medium-grained, friable, somewhat fissile sandstone that weathers to light yellow. The second and more competent variety consists of pink and brown, fine- to medium-grained sandstone that weathers to light reddish-brown. Apparently only 3 or 4 ft of the stone was evenly bedded enough to be of use; the overlying beds became prominently cross-bedded and, therefore, unusable. Colorado Division of Mines reports that the quarry last operated in 1964 and 1965.

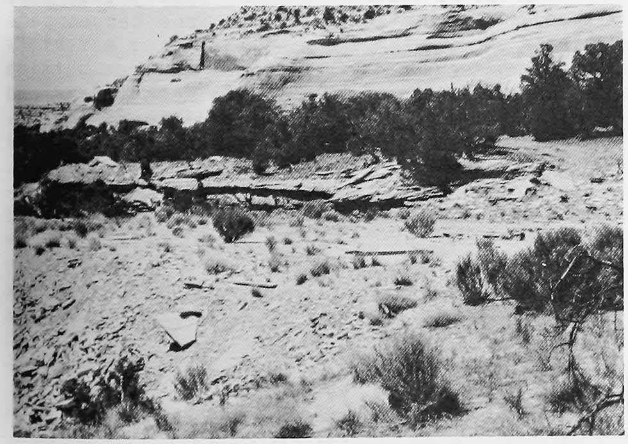


FIGURE 30. Sandstone quarry near Long Mesa. Flagstone here was quarried from a low bench in the Kayenta Formation. In contrast to the evenly bedded flagstone, note the strongly cross-bedded sandstone immediately above the quarry face. Scrap rock lines the stream bank in the foreground. The massive Entrada Sandstone forms the prominent smooth ledge in the background.

Two more quarries in the Kayenta were noted near both entrances to Colorado National Monument. The east quarry, located on the main monument road northeast of Cold Shivers Point, contains little of what could be termed flagstone. Most of the rock I observed consisted of rubble and irregular block that probably was used in the construction of retaining walls and appurtenant structures within the monument. The west quarry (Figure 31), located west of the main road near the head of Fruita Canyon, was developed on three benches in tan and reddish-brown to brick-red, fine- to medium-grained sandstone that weathers to light-reddish-brown. The abandoned quarry now is used by the National Park Service for equipment and materials storage.

FIGURE 31. Sandstone quarry at the northwestern end of Colorado National Monument. Loading chute (at left) and numerous drill holes are still visible on the working faces. The quarry site now is used for storage.

Jurassic Stones

Several years ago a most unusual project was undertaken by a Glade Park resident. At a site on 16.5S Road 2.7 miles south of Glade Park, J. L. Kruckenburg excavated Entrada Sandstone from two hillside adits. According to the Colorado Division of Mines, the excavated rock was sold for construction purposes. Mr. Kruckenburg's plan was to finish the inside of the tunnel, close off both west-facing adits, and convert the mine to living quarters. Although the project was not completed, the present owner, Russell Holtz, hopes to convert some of the approximately 1,500 sq ft of available underground space to storage. Figure 32 is an approximate plan of the 8- to 10-ft-high tunnel.

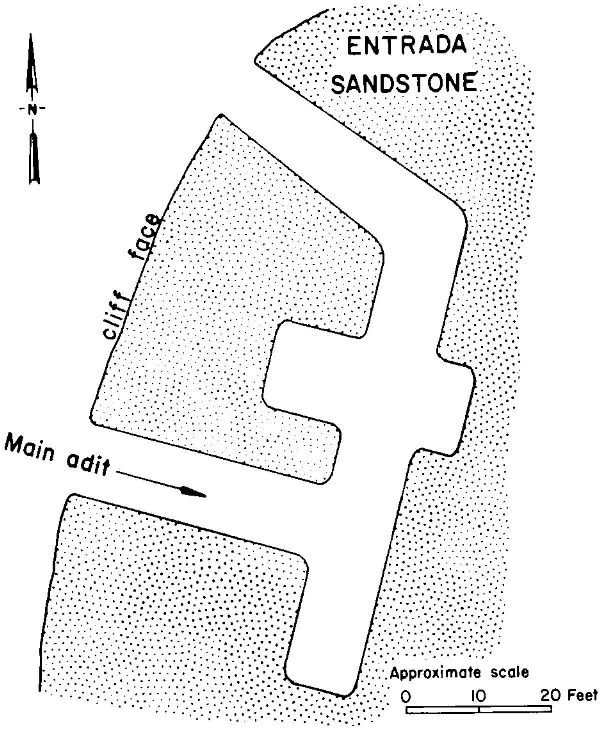


FIGURE 32. Approximate plan of the Kruckenburg quarry, located south of Glade Park. This underground excavation in the Entrada Sandstone was originally designed for conversion to a homesite.

Cretaceous Stones

Stone (1890) cited the quarrying of red sandstone on the west side of the Gunnison River 1 mile above its confluence with the Colorado River. According to the article the area was known as Palmer Flats, which could correspond to the river meander around the present Department of Energy complex. The base map shows other named *flats* in similar meanders in the Gunnison River upstream. The reference to red sandstone is rather questionable because the truly red sandstones occur in the Triassic formations, and only gray, tan, and yellowish-brown Burro Canyon and Dakota sandstones are exposed along this stretch of the river (Lohman, 1963; Cashion, 1973). I could locate no old workings here by airphoto examination.

Abundant fieldstone from the Burro Canyon and Dakota litter the northeastward-trending dipslopes in the Redlands and Little Park Road areas. Much of this stone is collected and used in residential construction as well as landscaping. Only one quarry in Dakota sandstone was identified--2 miles west of Whitewater on the north bank of the Gunnison River. Tan, massive to thickly cross-bedded, medium-grained quartzose sandstone was quarried from this abandoned hillside operation. On fresh surfaces, scattered yellowish-brown iron-oxide alteration stains give the rock a speckled or salt- and-pepper appearance. Because of the massive bedding characteristics, the sandstone tends to break into angular blocks rather than thin slabs or flags.

I could determine neither the destination nor use of the stone.

At several coal mines and camps along the Book Cliffs, miners utilized angular sandstone slabs and rubble from the Mesaverde to construct small mortarless buildings and retaining walls. The sandstones used in a some home foundations and other structures in Grand Junction to some extent resemble Mesaverde sandstone but probably are imported.

Tertiary and Quaternary Stones

The youngest building and decorative stones in Mesa County include the Grand Mesa basalt and the flood-plain and terrace gravels along the Colorado River. Basalt rubble and boulders derived from the Grand Mesa caprock are used most commonly in the Plateau Creek valley near the communities of Mesa and Collbran. A number of foundations and even entire buildings were built with this distinctive black and brown rock (Figure 33).

In addition to its use as aggregate, which will be discussed in the next section, pebbly and cobbly gravel from the Colorado River deposits is washed and used to landscape lawns and gardens.

Land-Use Considerations

From the standpoint of color and workability, Triassic formations (Wingate and Kayenta) afford the best opportunities for development of the county's building stone resources. The most extensive exposures of these rock units nearest the urban and suburban markets are found northwest and south of Colorado National Monument on the northeastern flank of the Uncompahgre Plateau. Although farther from markets, the plateaus at the east end of Unaweep Canyon also afford readily accessible quarry sites. A principal economic factor in the development of such resources is whether or not locally quarried, finished, and marketed building stone can compete on a large scale with imported building materials such as lumber and brick. Operable quarries outside Colorado National Monument could be reactivated and probably expanded with little additional impact. Other sites probably cannot be operated because of their precipitous or otherwise awkward positions. Access and siting are important factors in the development of any new operations, whether on broad dipslope surfaces or in steep narrow canyons. Problems that must be dealt with include

1) proper disposal or placement of waste rock,
2) displacement of sparse vegetation and thin soil cover, and
3) probable long-term but intermittent operation of sites.

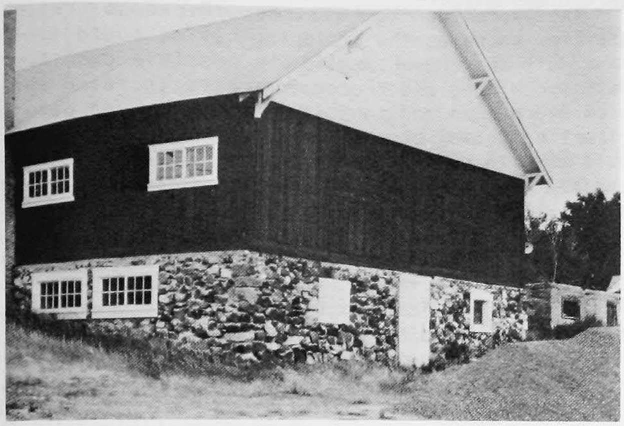


FIGURE 33a. Basalt and sandstone barn foundation in Mesa. These stones are abundant and easily found in the glacial and alluvial deposits that fill the area's stream valleys.

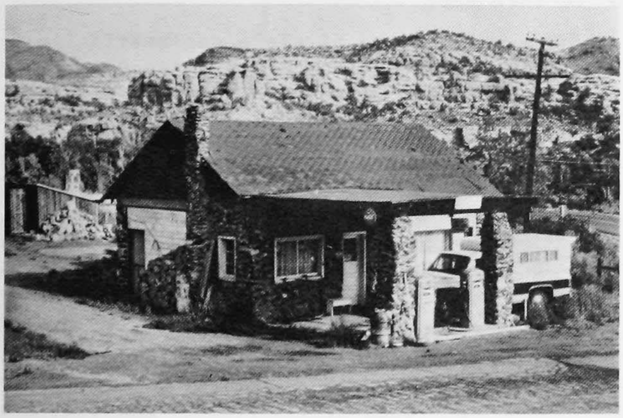


FIGURE 33b. Basalt fieldstone building near Atwell homestead, Plateau Creek valley. Massive sandstones of the Hunter Canyon Formation form the low cliff line in the near background.

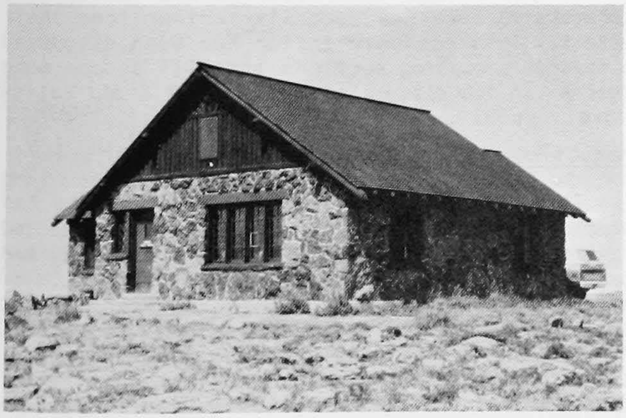


FIGURE 33c. Lands End observatory, a visitor's center built of basaltic fieldstone found in Ground Mesa.

SAND, GRAVEL, AND CRUSHED STONE

INTRODUCTION

Many people may think of sand and gravel as rather mundane mineral resources, but few realize that gravel and crushed stone actually dominate the country's nonmetallic mining industry, in terms of both value and tonnage. Gravel and crushed stone comprise the fourth sector of Mesa County's principal mining industries, and their distribution and conservation in the county's populated areas are critical for planning purposes. I will outline the major identification and evaluation criteria and present a summary of the resources and mining activity in seven geographic areas of the county. Finally I would like to offer projections about future supply and demand in the Grand Valley and several recommendations for planning in that area.

Mapping Criteria

The distribution, form, composition, and texture of sand and gravel deposits tell much about the recent geologic and stream history of a region. Consequently, one can use physiographic history as a tool to explore for gravel deposits and to predict, to some extent, the quality of potentially usable deposits. During the HB 1529 (1973) gravel mapping project along the Front Range, the Colorado Geological Survey showed that aggregate resources could readily be identified on airphotos by recognizing several basic landforms. The stable geologic and geomorphic nature of resource maps produced in this way provides useful tools for planning purposes. With only slight modification, the following identification scheme has been used successfully in other parts of the state, including Mesa County:

F-physiographic *flood plains* along major rivers and streams
T-older channel deposits in *terraces* adjacent to and higher than the flood plains
V-undifferentiated *valley fill* deposits where flood plains and terraces are not prominent or discernible
A-less sorted gravel and debris in *alluvial fans* formed at topographic breaks between hills and plains or valleys
U-isolated dissected *upland* remnants of older alluvial fan, flood-plain, or terrace deposits
G-*glacial* moraines, outwash, or till
E-*eolian* or wind-blown sand, usually in distinct dunal form

Although any particular landform may not contain economic sand and gravel throughout, its boundaries represent the best first approximation of the resource. Later, as more subsurface and analytical data become available, boundaries may be adjusted or even eliminated.

Each of the above-listed deposits may be rated according to the quality and quantity of aggregate contained and to several other physical aspects that also determine economic utility. Again, this rating is a first approximation that later may be modified:

Coarse Aggregate

(at least 30% retained on #4 screen, visual estimation)

1 Gravel: relatively clean and sound
2 Gravel: significant fines, decomposed rock, calcium carbonate.

Fine Aggregate

(greater than 70% passing #4 screen, 60% retained on #200 screen, visual estimation)

3 Sand

Unevaluated Resource

4 Probably aggregate resource

Fine and coarse grain sizes are distinguished by field observation and by mechanical analyses. The industry-oriented grain-size scale used in these investigations appears in Table 18 (Appendix 2). Other important field observations that can be made include overburden thickness, percentage fines (silt and clay), weak or incompetent rock, and calcium carbonate (caliche) development.

Factors Influencing Gravel Formation, Quality, and Utilization

Source-area geology profoundly affects the composition and quality of gravel deposits. Rock debris derived from shale, siltstone, soft sandstone, gypsum, fine-grained metamorphics, and some coarse-grained igneous rocks generally will deteriorate the quality of a gravel deposit. Rock types that readily abraid result in fine- to very fine-grained deposits or those composed of weak clasts and a great range of grain sizes. In high-quality deposits only a small percentage of such material can be tolerated for most specifications. On the other hand, the most desirable deposits contain more durable rock types such as fine-grained igneous and coarse-grained metamorphic rocks, and crystalline limestone and well-cemented sandstone.

The relative resistance of bedrock units to erosion can affect the physical extent of valley-fill or other gravel deposits. For example, a stream that must develop its valley across very erosion-resistant rocks generally will form a narrow valley deposit. A wider valley and more extensive deposits can be developed over less resistant beds such as shale, mudstone, and siltstone, or over beds that have been intensely fractured or sheared.

Weathering and soil formation are important factors particularly in successively older terrace, alluvial fan, and upland deposits. Repeated episodes of soil formation tend to weaken rock clasts, produce more fines, and increase calcium carbonate accumulation, thereby lowering the quality of the deposits. In addition the higher isolated deposits become more susceptible to erosion, which through stream dissection reduces a deposit's surface area. As a result of these normal geologic processes, upland and other older deposits are not avidly prospected for high-specification materials.

The overburden-to-resource thickness ratio, sometimes known as the stripping ratio, could limit the utility of a gravel despite its possible excellent quality. Mining and processing costs increase when thick overburden and topsoil must be removed before extracting gravel of a given thickness. Ideally one would wish to extract the maximum gravel thickness possible and remove the thinnest overburden possible to minimize the stripping ratio.

Utilization of sand and gravel usually depends on whether or not the deposit meets certain grain-size and other physical specifications for a specific intended use. Grain-size requirements vary considerably among concrete aggregate, bituminous aggregate, base course, subbase, riprap, structural fill, and industrial sands. Low-quality gravel can be used for "lower" uses because of the greater tolerance to grain-size variations, but to meet higher specifications, certain grain-size fractions must be reduced or others added. Sometimes such readily accessible heterogeneous mixtures as colluvium, rubble, talus, or even bedrock will meet specifications for certain uses.

Since the passage of state reclamation laws, the cost of rehabilitating mined sites has become an integral part of most operations. Reclamation costs depend primarily on the intended afteruse of the site--whether recreational pond-type conversion or landfill followed by residential or commercial construction. Regardless of what reclamation method is selected, the overall value of the land increases. Reclamation potential and possible afteruses may then enter pit-site evaluations at an early stage.

Distance to market is in most cases the most important factor in evaluating a deposit and selecting a pit site. A major conflict that often arises is that high-quality gravels usually occur and are mined along major waterways, which historically are the sites of major cities and metropolitan areas. Pits that 15 to 20 years ago operated on the outskirts of cities are now surrounded by development. This situation not only causes local land-use and legal problems but unnecessarily brings about the loss of once-recoverable reserves and forces mine operators to seek new deposits farther from their markets. This economic factor has been discussed in several preceding sections and will become more apparent in the discussion of the lower Grand Valley gravel deposits.

Production

In terms of dollar values reported by the Colorado Division of Mines (Figure 34), sand and gravel have ranked second in the county during the years 1962 to 1966, 1969 to 1972, and 1975 to 1976. Only the combined value of uranium and vanadium was higher. Between 1966 and 1969 sand and gravel ranked third behind uranium-vanadium, and natural gas. In 1972 the value of sand and gravel was higher than either uranium or vanadium separately. In 1973 and 1974 sand and gravel led all sectors of the county's mining industry in terms of production value. The county's 1973-1974 peak production of $1,809,000 reflected a nationwide peak production that exceed $1 billion.

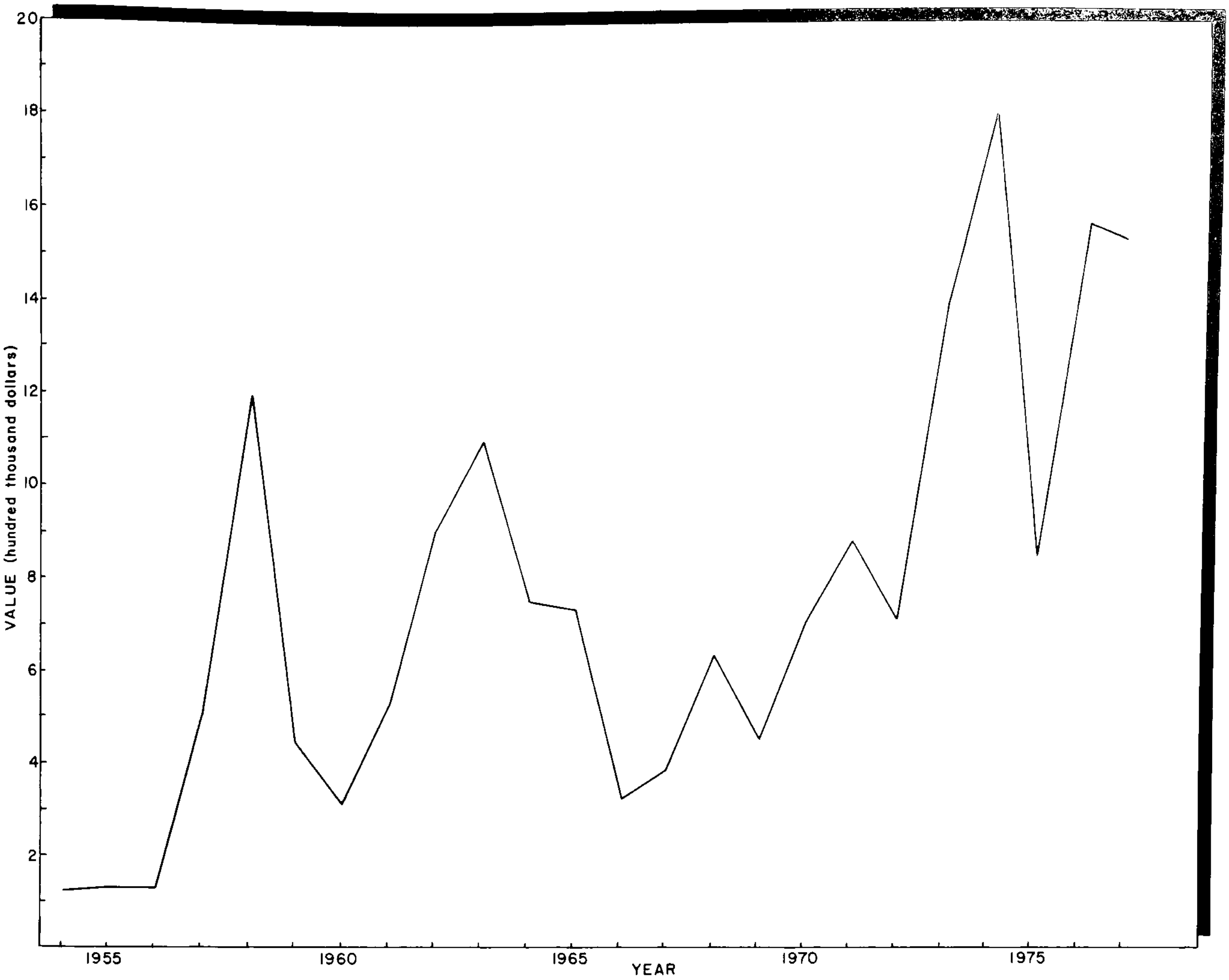


FIGURE 34. Value of sand and gravel produced in Mesa County (from Colorado Division of Mines records).

GEOLOGY, OCCURRENCES, AND MINING ACTIVITY

Due to the strong influences on aggregate quality by landform type and source-area geology and the fact that most aggregate landforms within a drainage basin are related genetically, I will discuss gravel resources and mining activity within seven drainage basins and physiographic divisions, starting from the southwest:

1) Dolores River valley
2) Uncompahgre Plateau
3) Gunnison River valley
4) Plateau Creek valley
5) Upper Grand Valley
6) Upper Colorado River Valley (De Beque to Book Cliffs)
7) Lower Colorado River Valley (Book Cliffs to Utah line)

Dolores River Valley

In its 22-mile-long course through the southwestern corner of the county, the Dolores River flows through a relatively narrow canyon from the Montrose County line to about Gateway. Valley-fill deposits that have been mapped in wide areas of the canyon contain well-rounded and durable igneous rock derived from the upper reaches of the Dolores River and San Miguel River in the San Juan Mountains.

Of greater importance are the prominent alluvial fans that flank the lower 4 miles of West Creek and the Dolores River below Gateway. All the fans lie on the lower eroded slopes of the Cutler Formation, and some overlap the fine-grained alluvial apron along the river valley bottom. The 60- to 100-ft-thick fans contain a heterogeneous mixture of coarse sand and sandstone fragments derived from the Precambrian, Triassic, and Jurassic formations exposed along the deeply dissected margin of the Uncompahgre Plateau. Their thickness, heterogeneity, and clear-cut topographic form suggest very rapid or instantaneous deposition, probably the result of brief but torrential rains in the source-area canyons. Well-rounded and sorted gravel of Dolores River origin is exposed on the deeply dissected lower edges of some fans. Obviously at a previous time in its history, the Dolores River flowed past the lower edges of these fans, actually truncated them, and reworked the fan gravel with its own. The very deeply eroded alluvial fan at the mouth of Cave Canyon also shows considerable Dolores River influence. Valley-fill deposits along West Creek were mapped where the valley floor widens or at the contact between resistant Precambrian rocks and less resistant Cutler Formation.

Gravel pits in the Gateway area are located on the lower edges of alluvial fans where the Dolores River has upgraded the material. The large pits were operated by the Colorado Division of Highways in the 1950's. More than a dozen small borrow pits in John Brown Canyon and along the lower flanks of The Palisade yield coarse-grained sand derived from the disintegration of the Cutler Formation.

Uncompahgre Plateau

Although the Uncompahgre Plateau covers a large portion of the county, it contains only a few of what could be termed "commercial" gravel deposits, although the area has yielded some sand, gravel, and crushed stone for road materials and ballast. The narrowness of headwater canyons and the proximity to source generally have not allowed the development of significant valley-fill deposits. Those along the Little Dolores River and Coates Creek, despite their thickness, are composed essentially of unusable sand and silt derived from the sedimentary formations. Most of the material utilized in this section of the county consists of coarse-grained sand and fine pebbly material known as *grüs*--the product of physical disintegration of Precambrian granite.

Covering most of the southwestern two-thirds of Unaweep Canyon is a series of coalescing alluvial fans composed of a heterogeneous mixture of sandstone and Precambrian lithologies, including grus. The only fan of importance that I have mapped lies at the mouth of North Lobe Creek. The other important deposit in the canyon lies in Cactus Park near the mouth of Gibbler Gulch. The well-rounded pebbles and cobbles of varied igneous and metamorphic lithologies indicate a Gunnison River origin. This small but high-quality deposit deserves special consideration because of its role in deciphering the drainage history of the area and the origin of Unaweep Canyon.

Geomorphologists and geologists agree that East Creek and West Creek are too small or "underfit" to have formed Unaweep Canyon. What forces were responsible for the canyon's formation, and why is such a large canyon drained by two small streams flowing in opposite directions? Throughout the 100-yr-old controversy two schools of thought have developed.

In the first theory, described by Lohman (1961), the striking alignment of the upper Colorado River valley with Unaweep Canyon immediately suggests that the Colorado originally flowed southwestward from Cameo along the line of Unaweep Canyon (at a higher level of course) and joined the Dolores River at Gateway. The ancestral Gunnison River flowed in its present course to the vicinity of Bridgeport from which it changed direction, heading up lower Big Dominguez Canyon and into Cactus Park where it joined the ancestral Colorado. The present course of the Colorado in eastern Utah and across the northwestern end of the Uncompahgre Plateau was actually a large tributary that eroded headward (eastward) through the Mancos Shale, maintaining its course during uplift of the arch. Somewhere east of Grand Junction, this tributary "captured" the ancestral Colorado and diverted its flow westward. Unaweep Canyon southwest of Cactus Park was then occupied solely by the Gunnison. A tributary of the new Colorado River eroded southeastward and captured the Gunnison River probably between Bridgeport and Wells Gulch. Thus the Gunnison was diverted into its present course, and Unaweep Canyon was abandoned. Continued uplifting of the Plateau caused the abandoned valley fill to erode, and a low drainage divide formed near the axis of the uplift. Ancestral East Creek then flowed east and southeast through the Gunnison's abandoned course. A southward-eroding tributary of North East Creek captured ancestral East Creek at Cactus Park and diverted the flow through the present canyon to its confluence with the Gunnison at Whitewater. Lohman believed that the Cactus Park deposit represented original Colorado River or Gunnison River gravel first laid down in Unaweep Canyon and later redeposited by ancestral East Creek.

In the second theory of formation, Cater (1966) cites three lines of evidence that the Colorado River never flowed through Unaweep Canyon. Cater first approximated the Colorado's present course westward from Palisade. The ancestral Gunnison flowed through Cactus Park but was the sole occupant of the canyon. In the first place the terrace gravels above Gateway contain fewer basalt pebbles than typical Colorado River gravel; therefore, they more closely resemble Gunnison River deposits. Secondly, Unaweep Canyon north of Cactus Park is much narrower and steeper than the rest of the canyon and contains no river gravel remnants, thus eliminating formation by a large river. Third, it is unlikely that the tributary of the captured Colorado River eroding toward Whitewater would have completely transected the Colorado's abandoned channel without being diverted one way or the other. Cater maintains that a tributary of the original Colorado eroded southeastward from Grand Junction along the Gunnison's present course and captured the ancestral Gunnison between Bridgeport and Wells Gulch. A tributary of the new Gunnison began eroding southward from Whitewater, breaching the abandoned Gunnison channel at Cactus Park and establishing the present East Creek drainage.

Another line of evidence for Cater's theory is the dissected sequence of Gunnison River terrace gravels at Whitewater. The highest and oldest levels far up on the hillside obviously predate the canyon of East Creek and suggest that East Creek canyon formation followed abandonment of Unaweep by the Gunnison and diversion into the present course past Whitewater. Based on my observations of gravel lithologies in Unaweep Canyon and northeast of Whitewater, I would support Cater's theory of a Gunnison River origin for Unaweep Canyon. The discussion above points out that the petrology and geomorphology of a few remnants of river gravel helped to decipher the drainage history of this magnificent canyon and suggest that such interpretations could be useful tools in exploring for other high-quality gravels in otherwise aggregate-barren areas.

Numerous borrow pits are located along Colorado 141 in the narrow northeastern section of Unaweep Canyon. In addition to colluvium and rubble, thin sandstones and claystones were utilized directly from Morrison Formation outcrops. Pit activity varies more in the southwestern end of the canyon between North Lobe Creek and Bull Draw. Most of the material used there comes from the alluvial apron that covers the wider parts of the valley floor. The narrow southwestern end of the canyon yields sandy grüs-type colluvium derived from the Precambrian and valley-fill sand derived from the Precambrian and Cutler Formation.

Very few gravel resources exist south of Unaweep Canyon, but very little material is required in the area. Along Indian Creek and near Pine Mountain, road materials include rubble, grüs, and crushed sandstone from the Kayenta Formation. Near Casto Reservoir lies a small isolated gravel remnant about 280 ft above Gill Creek and 440 ft above La Fair Creek. The 15- to 20-ft-thick deposit consists of sandstone, orthoquartzite, and chert and was worked by the Colorado Division of Highways in the early 1950's. Graded slopes in the pit have been replanted with pine trees.

Another interesting geomorphic problem in this area is the Gill Creek drainage anomaly. A look at the Gill Creek valley and Williams' (1964) geologic map suggests that ancestral Gill Creek might have flowed northeastward along the present course of Dominguez Creek. The older and wider Gill Creek valley now lies more than 400 ft above Dominguez Creek, which occupies a narrow, steep-walled canyon. More peculiar is the fact that Gill Creek now flows westward--backward over its original course. I believe that the anomaly was caused by interactions of the Gill Creek fault and pulses of uplift of the Plateau, both of which dammed up the old Gill Creek drainage, forcing tributaries to join together and eventually tilting the basin slightly to the west. I will leave the details of this puzzle to some enterprising student of geomorphology.

North of Unaweep Canyon gravel resources also are scarce. Although the valley fill of the Little Dolores River exceeds 50 ft in thickness, it consists of silty sand derived locally from the Triassic and Jurassic section. Sand, colluvium, and some bedrock have been utilized in a few places near Colorado National Monument, Miracle Rock, and Windy Point. The Mesa County Road Department operates the largest pit on this part of the plateau. The operation is located on A.2 Road 2.7 miles northwest of DS Road above the Little Dolores River. The road material appears to be a deeply weathered colluvium derived from the old eroded Precambrian surface near the contact with the Chinle Formation.

Gunnison River Valley

The Gunnison River drains about 8,000 sq mi of western Colorado. The lower 30 miles of the basin includes nearly one-half of the Uncompahgre Plateau within Mesa County and most of the top and western flanks of Grand Mesa. Elevations in the lower basin range from more than 10,800 ft near the head of the river's principal tributary, Kannah Creek, to about 4550 ft at the confluence with the Colorado River. The great variation in elevation and physiography is reflected in an equally varied sequence of aggregate deposits (from east to west):

1) Grand Mesa basalt caprock
2) Grand Mesa glacial moraines
3) fan-terrace sequence
4) Whitewater upland gravels
5) Gunnison River flood plain and terraces

Straddling the Mesa-Delta County line is Grand Mesa, the highest and most well-known landmark in the county. The prominent caprock is formed by a series of eight or nine basalt flows having a combined thickness of 200 to 500 ft. According to Young and Young (1968), slight uplifts of the Uncompahgre arch during middle Tertiary times caused streams in the area to drain eastward and erode the Green River and Wasatch Formations from the southwestern margin of the Piceance Creek Basin. Broad valleys developed beneath the sites of Grand Mesa and Battlement Mesa. Near the end of the Miocene Epoch, igneous intrusions formed the Elk and West Elk Mountains and caused local uplifting, which reversed the direction of the ground surface. As the intrusives cooled, lava flows extruded from east-west-trending subsidence fractures southeast of Leon Peak and from others in easternmost Mesa County and in Pitkin and Gunnison Counties. The flows poured into the old valleys, ran downslope and then upslope into the tributaries as far as gravity would permit. There the flows ponded, cooled, and solidified. The junction of two of these ancient valleys forms the "Y" shape in the west end of Grand Mesa. The eventual ponding of water behind the solidified flows caused a drainage course, probably the ancestral Gunnison River, to develop toward the west. More episodes of uplift caused the softer rocks around the lava flows to erode away. What is seen today is a spectacular reversal of topography--basalt flows that once filled valley bottoms now occupy the highest points in the area.

The Grand Mesa caprock consists of a dense, hard, fine-grained basalt that varies in color from gray to bluish-gray to black. Reddish-brown zones visible in roadcuts and on the cliff faces are ancient soil horizons that developed on the flow surfaces and then were covered and baked by later flows. Vesicular zones formed when bubbles of trapped gas rose through the molten lava and accumulated near the top. Some later filled with zeolite minerals.

The Pleistocene Epoch was a time of widespread glaciation in North America. Ice caps were prominent during several glacial intervals in the Rocky Mountains. Glacial, alluvial, and colluvial materials on and around Grand Mesa were deposited during two periods of glaciation. Of most economic importance in the area drained by the Gunnison and its tributaries in Mesa County are four glacial moraines on the western lobes of Grand Mesa. During the older of the two glaciations, glacial till of the Lands End Formation (Yeend, 1969) accumulated to a depth of 10 ft on the north and south lobes of the mesa. Two recessional moraines of the Lands End Formation are shown on Plate 2. The western moraine lies between Cottonwood Creek and Whitewater Creek and rises about 40 ft above the mesa top. The eastern moraine, a 6-mi-long arcuate ridge, extends from one edge of the mesa to the other and rises about 60 ft above the surface. The coarse fractions of these moraines consist of weathered pebbles, cobbles, and boulders of basalt. The matrix consists of about 73 percent silt and clay and 27 percent sand.

The upper and lower till members of the younger Grand Mesa Formation differ from the Lands End in that they contain more unweathered basalt fragments and a wider range of grain sizes in the matrix, namely less clay but more silt and sand. The Grand Mesa terminal moraine lies about one mile east of the Lands End recessional moraine. It, too, is an arcuate ridge 5.5 miles long, 600 to 1,300 ft wide, and 20 to 40 ft high. This moraine not only crosses both lobes of the mesa but also crosses the intervening Kannah Creek valley, proving that the Kannah Creek drainage was established before the ice cap moved down. A small Grand Mesa recessional moraine lies immediately in back of the terminal moraine at Carson Lake.

Gravel pits were operated in the Lands End recessional moraine 0.25 mile south of Old Lands End Road and on the Grand Mesa terminal moraine just south of the same road. The pebbly to cobbly basalt gravel in the fine-grained matrix, essentially low-quality material, was excavated in relatively shallow cuts into the hummocky ground. Because the glacial moraines act as natural dams for water storage, till from the reservoir sites was used in construction of the embankments. Large basalt boulders were used to riprap the reservoir sides of the dams.

The U.S. Forest Service operates a crushed-rock quarry near Skyway Point on Colorado 65 at the northern edge of the mesa. The hillside excavation is developed in several low benches. Although no crusher or other equipment was present when I visited the site, crushed rock had been stockpiled. The Grand Mesa basalt resource is essentially infinite, but commercial development is limited by inadequate access and the fact that most of the deposit lies within the Grand Mesa National Forest. Supplies of crushed rock are more than adequate for Forest Service use, and the morainal gravel, although readily accessible, is quite limited in its utility because of the high content of fines.

A spectacular sequence of alluvial fans flanks the southern end of Grand Mesa in Mesa and Delta Counties. Reconstruction of some of the old surfaces shows that major debouchments have fluctuated through space and time and that, overall, the break between Grand Mesa's Lower Bench and Lower Mesas has moved westward. The fan remnants in Mesa County vary from 500 ft to 1.2 mile in width and 0.5 to 8 miles in length and have radii as long as 4 or 5 miles. Older and topographically higher fans appear to have steeper westward gradients than younger fans, 400 to 560 ft/mile as opposed to 120 to 220 ft/mile. Reconstruction also suggests that some contemporaneous fans coalesced to form a broad alluvial apron. For example, below Hallenbeck Reservoir, Reeder Mesa and Purdy Mesa probably once formed a continuous surface that later was dissected by North Fork Kannah Creek. During the latest cycles of erosion, Kannah Creek has created narrow terraces along the lower edges of several fans, but wider terraces predominate downstream between the fans and the outcrops of Dakota sandstones.

These alluvial fan gravels consist almost entirely of basalt pebbles and cobbles, with frequent boulders up to 3 ft in diameter. Very calcareous silty sand makes up the matrix. The deeply weathered soil profile is characterized by thick rinds of calcium carbonate on the stones and irregular crystalline masses up to 2 in. thick. In the gravel pit along U.S. 50 south of Kannah Creek one can see a well-defined mudflow contained within the deposit. The flow appears as a structureless mass of silt and sand containing scattered coarse sand grains, cobbles, and boulders. This flow probably occurred when a torrential rainstorm in the Kannah Creek headwaters saturated the easily erodible Green River and Wasatch claystones, and large masses suddenly dislodged and flowed down the stream valley picking up stray boulders along the way. Mudflows probably are not uncommon in the other alluvial fan deposits in this area.

Only a few actual gravel pits were observed in this sequence of deposits. In the largest pit, mentioned above, the entire 15-ft thickness was excavated, exposing Mancos Shale on the pit floor. Several other pits in alluvial fan and upland deposits were operated for embankment material in the construction of Cheney, Hallenbeck, and Juniata Reservoirs. Mancos Shale was extracted from most of the borrow pits along GS Road and Kannah Creek.

Whitewater Upland Deposits

The Gunnison River and Colorado River both drain a prominent line of gravel-capped hills and small mesas that extends from Halls Basin westward to the end of Orchard Mesas and to the north bank of the Gunnison River near Whitewater (Plate 2). Three discernible surfaces of gravel lie approximately 80 to 100 ft, 120 to 140 ft, and 160 to 180 ft above local stream level. The intermediate level is the most extensive.

At first glance one might think that these gravels would be composed of Grand Mesa lithologies, based on their gradient away from Grand Mesa and their proximity to the alluvial fans previously discussed. However, I found evidence that the deposits are of river origin--rounded, variegated river gravel containing basalt, granite, gneiss, sandstone, and other minor lithologies. Exposures on high-level remnants in secs. 29 and 32, T1S, R2E show a noticeable lack of Green River shales, a common constituent of Colorado River gravels. Thus, I believe most of these deposits were laid down by the ancestral Gunnison River. This is partly confirmed by measured transport directions toward the north-northwest. However, exposures along the northwestern edges of the hills indicate a dominant Colorado River influence. What we see then in these deposits could be the ancient Gunnison-Colorado confluence that has migrated through time and space westward to its present location at Grand Junction. The ancient flood-plain deposits are left as an alluvial sheet that, through time, has become deeply dissected but preserved as isolated mesas and hills. A more valid solution to this intriguing geomorphic problem will require a detailed study of pebble lithologies, transport directions, soil-profile development, and elevations of the gravel-bedrock contact.

In addition to the peculiar variety of rock types seen in the higher level gravels, channel sands and gravels at the contact with the Mancos Shale have been locally cemented into a resistant ledge of sandstone and conglomerate. At the top of the deposit a thin layer of basaltic outwash from Grand Mesa overlies the older river gravels.

Despite the deeply weathered profile and calcium carbonate development in the western deposits, these upland gravels actually have been extensively utilized. The largest pits are located on Whitewater Hill and on the hill southeast of the Department of Energy complex. Only a narrow fringe of gravel remains around the latter excavation, and the Whitewater Hill pit, an abandoned Colorado Division of Highways operation, is now undergoing landfill.

Gunnison River Flood Plain and Terraces

Gravel deposits directly along the Gunnison River represent the most recent deposition in the valley. The flood-plain and terrace deposits are very confined spatially and not well developed except at Whitewater, where the river widened its valley at the expense of Mancos Shale just above the contact with the Dakota Group. Elsewhere the more resistant bedrock has prevented the formation of a wide flood plain. As theorized earlier, the canyon between Grand Junction and Bridgeport likely was an ancient headward-eroding Colorado River tributary that captured the Gunnison River and diverted its flow out of Unaweep Canyon. The river may have been forced to occupy an originally narrow course. Further support of Cater's theory can be seen at Whitewater where East Creek has dissected the sequence of river terrace gravels, which indicates that East Creek's canyon postdated development of the Gunnison's course and that the ancestral Colorado did not flow here.

At Whitewater five discernible terraces lie from 20 to 300 ft above the river. The gravels contain typical Gunnison River lithologies--igneous, metamorphic, and sedimentary rock types. In the lowest terrace gravel, about 20 ft thick, one can see channel sands and pebbly to cobbly gravels cut into the underlying Dakota Sandstone.

Small terrace gravel deposits predictably lie on the insides of meanders at eight other sites along the river. At Deer Creek three small river terrace remnants lie on the outside of the meander immediately below the tributary but are covered by basalt and sandstone gravel derived from Grand Mesa.

Little information could be obtained about the thickness of the flood-plain gravels, but a pit at Whitewater showed a maximum of 20 ft. In the same pit (NE/4 sec. 29, T12S, R99W) I observed a Dakota Sandstone bedrock high that protruded nearly to the top of the deposit.

Nearly all the mining activity in the Gunnison's lower terraces and flood plain has been centered at Whitewater. The Colorado Division of Highways has operated pits on a low terrace between U.S. 50 and 32.5 Road. Although some spoil piles remain, they are hardly recognizable because of revegetation efforts. Both pits have been beautifully reclaimed to ponds and wildlife habitat (Figure 35). In a large hilltop pit on a remnant of the third-level terrace 1.5 mile south of Whitewater, nearly all the gravel was removed by the Mesa County Road Department. The site has partially revegetated, as has a smaller pit to the north. Whitewater Building Materials Corporation has operated the most and largest pits in the flood-plain deposits at Whitewater. The older pits in the eastern river meander either have naturally revegetated or have been partly converted to the plant operations site. Operations in the western meander include a large worked-out pit currently being backfilled and replanted, an active pit and

FIGURE 35. Colorado Division of Highways reclaimed gravel pit southeast of Whitewater. Thick vegetation surrounds the pond, which also supports such wildlife as the ducks visible on the water surface just left of the center of the picture.

large area from which the overburden has been removed (Figure 36), and another abandoned and revegetated pit. Other smaller pits are located in the flood plain and on various terrace levels north and south of the river.

FIGURE 36. Whitewater Building Materials Corporation gravel pits west of Whitewater. This eastward view shows various stages of operation: revegetated fill in foreground; in near center, excavated pit undergoing backfill (at right), gravel and overburden thickness visible at left; at top center are excavation machinery and stockpile in the active pit. Overburden has been removed in back of machinery in preparation for mining.

Plateau Creek-Divide Creek Valley

Plateau Creek, West Divide Creek, and East Divide Creek and their tributaries drain most of the eastern panhandle of Mesa County and include all or parts of seven physiographic divisions. Plateau Creek flows westward and joins the Colorado River about 3 miles north of Cameo. West Divide Creek joins East Divide Creek about 9 miles north of the county line and empties into the Colorado River 2 miles east of Silt. The 45-mile-long Plateau Creek-Buzzard Creek basin is separated from Divide Creek drainage by a sinuous forested divide. The eastern end of Grand Mesa forms part of the high divide that separates Plateau Creek and West Divide Creek from the Crystal River, Muddy Creek, and North Fork Gunnison River drainages. The diversity in physiography and geology here is reflected in a variety of aggregate and crushed-rock resources--glacial till, alluvial fans, flood plain and terraces along Plateau Creek, upland deposits, and igneous rocks.

During the deposition of Grand Mesa Formation till (Yeend, 1969), ice moved down Plateau Creek and its major tributaries from centers of accumulation on the highest parts of Grand Mesa and at the heads of Leon Creek, Willow Creek, and several creeks in Delta County. Yeend believes that a 6-sq-mi dissected bedrock surface north of Monument Creek may have been an ice center because of the absence of glacial drift deposits there. During maximum glacial activity ice lobes extended down Mesa Creek, Bull Creek, Cottonwood Creek, Deacon Gulch, Big Creek, and Leon Creek. Some lobes apparently joined together along Plateau Creek and formed a continuous sheet, isolating hills of Wasatch Formation. For example, the very long Leon Creek lobe extended to the Plateau Creek-Buzzard Creek confluence, turned left, and flowed down Plateau Creek to join the Big Creek ice sheet at Collbran. The Leon Creek lobe also dammed Plateau Creek and formed an ancient lake on the present site of Vega Reservoir.

A noticeable effect of glacial activity in this area was the disruption of preexisting drainage. Thick masses of glacial till that ultimately filled the old valleys caused post-glacial streams to relocate commonly along the margins of the valley fill. For example, the original confluence of Plateau Creek and Buzzard Creek was probably near the mouth of Brush Creek, but the ice lobe and resulting valley fill caused the streams to separate there, forcing Buzzard Creek to the north edge of the valley and lengthening its course by 7 miles. Other pairs of relocated and newly formed streams include Leon Creek and Park Creek, Big Creek and Grove Creek, Bull Creek and Spring Creek, Mesa Creek and Coon Creek.

Despite the extent of glacial activity and till deposition, I have mapped only a few selected glacial deposits on Plate 2--those deposits that have been utilized or are located in accessible areas that do not contain other types of gravel, and morainal deposits that may contain a higher percentage of coarse material. The Peninsula, a 7-mile-long topographic prominence that terminates at Collbran, contains at least 120 ft of Grand Mesa Formation till, but below Hawxhurst Creek, Yeend (1969) has shown the deposit as an alluvial facies. Roadcut exposures near Collbran confirm that the lower portion contains abundant coarse basaltic gravel of alluvial origin. For this reason I have approximated Yeend's glacial-alluvial contact and have labeled the lower portion as a terrace deposit. At the confluence of Plateau Creek and Park Creek I have mapped part of the till deposit that once dammed up Plateau Creek. Apparently some of this material was used in the construction of the dam at Vega Reservoir. The other mapped glacial deposits include a few small moraines along Bull Creek, Cottonwood Creek, and lower Buzzard Creek.

Alluvial fans are most prominent and numerous along the south side of Plateau Creek. Remnants of a higher and older fan sequence are preserved on Windger Flats, Georgia Mesa, Mormon Mesa, and unnamed mesas flanking King Gulch and lying southeast of Big Creek. Yeend (1969) classifies these gravels as alluvial facies of a probable pre-Lands End glaciation. The fans at lower elevations along Plateau Creek and its tributaries represent alluvial facies of the Grand Mesa Formation. Exposures in roadcuts and gravel pits along the lower (northern) edges of the fans show that the gravels are quite thick, 40 to 80 ft and perhaps more. The gravels consist almost entirely of pebbles, cobbles, and boulders of basalt and very little sandstone in a fine-grained calcium-carbonate-impregnated matrix. Abundant oversize material includes boulders up to 5 ft in diameter.

Four gravel pits and one borrow pit were noted in the fan sequence. The Mills Construction pit operates on the lower edge of a fan on Jerry Creek 2 miles west of Molina. The apparent high quality of this deposit may be due to reworking of the southern edge by Plateau Creek (Figure 37). The Nichols pit (Figure 38a), 0.8 mile southeast of the Mills pit, lies at the contact between a fan and lower Plateau Creek terrace. Some of the chaotic bedding seen in Figure 38b is obviously the result of rapid, high-energy streams draining the northern flank of Grand Mesa. Two abandoned pits at Plateau City show at least 30 ft of well-bedded cobbly basalt gravel.

FIGURE 37. Working face at the Mills Construction Co. gravel pit at Jerry Creek. Note the thin, deeply weathered topsoil, scattered oversized basalt boulders, and sand lenses. This exposure represents the upper 20 ft of the alluvial fan deposit.

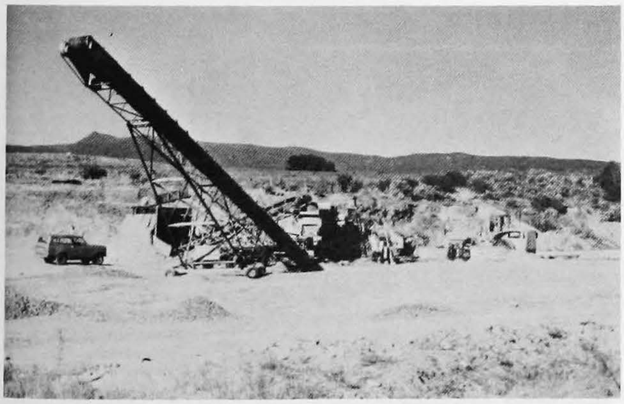


FIGURE 38a. Crusher conveyors at the Nichols gravel pit, located west of Molina and the contact between a Spring Creek alluvial fan and lower Plateau Creek terrace. The pit floor essentially lies at the terrace level with the fan rising southward in the background.

FIGURE 38b. Chaotic bedding in gravel deposits at the Nichols pit. Calcium carbonate forms thick white rinds on clasts at top of picture. Hammer rests on irregular gravel lens bounded by sand layers.

Terrace deposits are not extensively developed in the Plateau Creek valley. Most remnants lie along the south bank of the creek and along Salt Creek and upper Buzzard Creek. Between Big Creek and Mesa Creek, Plateau Creek has cut one terrace level into the lower edges of the flanking alluvial fans and has reworked the older fan and glacial material. Farther upstream several terraces have been cut into the Wasatch Formation at heights of 40 to 120 ft above stream level. Terrace gravel on bedrock at Collbran and Cheney Creek probably does not exceed 20 ft in thickness. Although largely basaltic in composition, the terrace gravels along upper Buzzard

Creek contain more sedimentary rock fragments than deposits downstream because their source areas lie in the Wasatch and Green River Formations beyond the glaciated areas.

A particularly interesting series of terrace deposits lies along the north side of Plateau Creek between Clover Gulch and Anderson Gulch and at a height of up to 100 ft above stream level. Instead of deposition on top of an eroded bedrock surface, these basaltic gravels appear to have been "plastered" against the lower edges of the mesas. Although considerably thick, the deposits apparently do not extend into the hillside more than about 150 ft because Wasatch Formation is exposed on the lower slopes of the mesas just a short distance up several tributary canyons. Projections of the terraces up these tributary canyons suggest a Battlement Mesa origin.

Of the ten terrace gravel pits observed, the largest active operation is the Mesa County Road Department pit at the mouth of Durant Gulch. From the 40-ft-high working face, gravel is hauled to a crusher and stockpile located on the valley floor. Other high-faced pits can be seen at Plateau City, at Collbran, and on Buzzard Creek near Cheney Creek. The shallow pits at Vega Reservoir were probably operated during construction of the new road and facilities for the recreational area.

The Plateau Creek flood plain is discernible nearly the entire distance from Vega Reservoir to the Colorado River. Just below Vega Reservoir the flood-plain deposits were either scoured out by ice movement down the valley or covered by glacial till. Below Collbran the margins of the flood plain are obscured by low-profile alluvial fans composed of sand and fine-grained sediment derived locally from glacial till and from the soft bedrock formations. On Plate 2 the margins of the gravel deposits beneath these fans are approximated by barbed dashes. In the upper three-fourths of Plateau Creek's course the stream has meandered over a relatively straight valley fill, developed in the easily erodible Wasatch Formation. At Atwell Gulch the stream passes over the contact between the Wasatch and the more resistant Hunter Canyon Formation and so has entrenched itself in a canyon. The cliffs rise over 800 ft above the creek near its confluence with the Colorado River. Very little information is available about the thickness and quality of the flood-plain deposits, but a few exposures of pebbly and cobbly gravel would suggest a minimum thickness of 10 ft and relatively high quality. I have labeled the deposits as high quality (*F1*) in the stretch from Collbran to Fleming Point.

Mining activity appears to be minimal in the flood-plain gravels. One pit, situated in a creek meander 0.5 mile east of Fleming Point, has been regraded and revegetated (Figure 39). A number of small ponds at Coon Creek, Molina, and Plateau City could not be confirmed as former gravel pits.

Upland gravels are of minor importance in Plateau Creek valley. Those mapped in the glaciated area probably represent remnants of very old and deeply eroded alluvial fans. In the highest reaches of Plateau Creek and West Divide Creek very old Quaternary or latest Tertiary gravels cap Oil Well Mountain, Spruce Mountain, Elk Knob, Flagpole Mountain, and several high places beyond the eastern county line (Tweto and others, 1976). Because access to most of these is, at best, difficult, I have not attempted to evaluate them for this study.

FIGURE 39. Graded and revegetated gravel pit on Plateau Creek east of Fleming Point.

Sources of borrow material in the Plateau Creek valley include talus, colluvium, and rubble derived from the Green River, Wasatch, and Hunter Canyon Formations, and glacial till of the Lands End and Grand Mesa Formations. Grand Mesa basalt has been utilized from a landslide at Skyway for road material and riprap. A large volume of Green River shale and marlstone was excavated from two pits near Spruce Point along an abandoned section of the old road from Mesa to Skyway (Figure 40).

FIGURE 40. Green River Formation shale and marlstone exposed in a large pit along an abandoned section of highway near Spruce Point.

As mentioned earlier in the discussion of Gunnison River valley resources, the basalt flows on Grand Mesa represent a vast crushed-rock resource. Other rock resources in this area include the east-west-trending basalt feeder dikes at Plateau Ridge, Bronco Knob, Chalk Mountain, and Oil Well Mountain, and the granodiorite-quartz monzonite intrusive that forms Haystack Mountain. Although these rock units could be of exceptional quality, their utility is seriously limited by lack of access and the long distances to the nearest markets.

Upper Grand Valley

The Upper Grand Valley province lies between the Book Cliffs and Government Highline Canal and includes a sequence of genetically related gravels extending from Lewis Wash westward into Utah. These unusual deposits differ greatly in both morphology and composition from previously described gravels. On Plate 2 one can see that the alluvial fan and upland deposits form an arcuate band and generally point toward the center of the arc. Strings of terrace deposits along the larger washes extend below Government Highline Canal and into Lower Grand Valley.

Most fan surfaces on the northeastern side of the valley lie from 10 to 90 ft above stream level, but a few higher ones lie at 120 ft. Inversely, at the northwestern end of the valley most of the fans are greatly elevated, 250 to 350 ft above stream level, with lower surfaces 80 to 110 ft above stream level. Other changes apparent from east to west are a decrease in the number and density of the fans but a general increase in total length of individual series of fans. The changes in morphologies occur across Big Salt Wash, the southernmost of three large tributaries that drain the Colorado portion of the Book Cliffs and Roan Plateau. The reasons for these changes are complex and beyond the scope of this study but are most likely related to a) effects of uplift on the Uncompahgre Plateau and b) geometric statistics of the individual drainage basins.

Source-area geology again has played a controlling role in the composition and quality of the Upper Grand Valley gravels. Predictably these gravels consist of sandstone and shale and lesser amounts of marlstone and oölitic limestone derived entirely from the Mount Garfield, Hunter Canyon, Wasatch, and Green River Formations. The elongated and flattened shapes of most pebbles reflect the thin-bedded and flaggy, fissile nature of the bedrock units. Only the larger cobbles and boulders retain a blocky or equidimensional shape. The alluvial fan and upland deposits attain thicknesses of 10 to 25 ft, the thicker deposits generally lying in the west.

FIGURE 41. Profile of well-cemented alluvial fan gravel and conglomerate near West Salt Creek. Note the varying grain sizes from layer to layer and the different degrees of cementation and expression. Mancos Shale underlies the gravel in the lower right corner of the picture.

A spectacular manifestation of cementation can be seen in fan deposits in the northwestern corner of the county. Some gravel layers are so completely cemented with silica and calcium carbonate that they can be classified as *conglomerates*. Figure 41 shows that gravel layers differing greatly in grain sizes, porosity, and permeability have been cemented to varying degrees, forming reentrants and resistant ledges. The phenomenon also is notable at the gravel-bedrock contact where the resistant well-cemented gravels overhang the more easily erodible Mancos Shale. Cementation sometimes is so complete that the conglomerate breaks *across* the sandstone clasts rather than *around* them, indicating that the cement is actually stronger than the rock clasts it binds.

Upland deposits are most extensive near the Utah line along Bitter Creek and Bar X Wash where they appear as broad surfaces that subtly change into fans upslope toward the Book Cliffs. Farther east along the Book Cliffs, upland deposits include long, narrow gravel-capped ridges and strings of gravel-capped hills, which probably represent very old and deeply eroded fans or actual channel phases of ancestral streams that once flowed out of the cliffs.

Terrace sequences are discernible only along the larger creeks and washes, notably West Salt Creek, East Salt Creek, Coyote Wash, Mack Wash, Lipan Wash, and East Branch Big Salt Wash. Generally I could distinguish only one or two levels that lie 10 to 120 ft above stream level. Thickness and composition of the gravels are similar to the upland and fan deposits, but no strongly cemented layers were seen.

The Mesa County Road Department and Colorado Division of Highways have operated numerous gravel and road materials pits in Upper Grand Valley, particularly west of Big Salt Wash where most of the county and state roads pass. Some of the smaller hilltop deposits have been completely mined out. Three of the many pits in the area are shown in Figure 42.

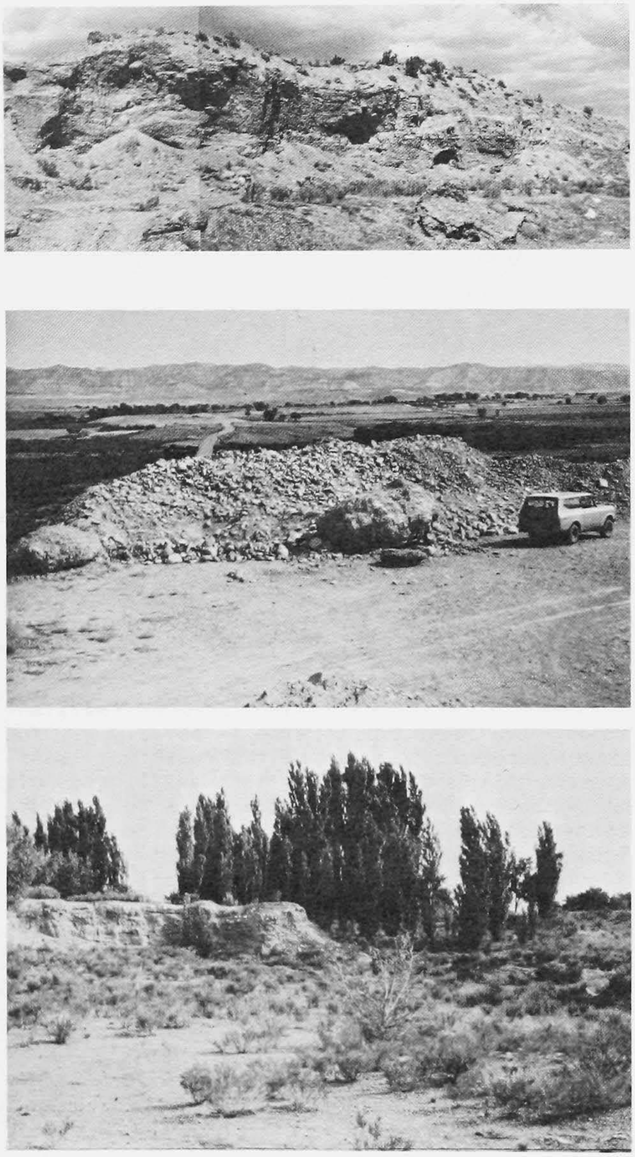


FIGURE 42. Gravel pits in Upper Grand Valley. At top, small alluvial fan deposit flanking West Salt Creek just below Prairie Canyon. Note the sand layers on the working face and blocks of conglomerate along the road in the foreground. At center, a hilltop pit in alluvial fans gravels on Mack Mesa, 10 Road at R Road. Note the large oversized block of conglomerate to the left of the vehicle. Low terrace gravels flank 10 Road in the background. At bottom, terrace gravel pit on 17 1/2 Road north of Fruita. The floor of this abandoned excavation has revegetated naturally.

Upper Colorado River Valley

The discussion of the gravels along the Colorado River marks the beginning of my summary of the county's most important aggregate resources. The upper river valley extends from the Garfield County line southwestward to the end of the Book Cliffs northeast of Palisade. The upper 8 to 10 miles of the valley is wider than the lower reaches because the river has developed its valley at the expense of easily erodible Wasatch Formation. At the beginning of De Beque Canyon the valley narrows as the river passes through the contact between the Wasatch and the much more resistant Hunter Canyon Formation. Consequently the valley deposits above De Beque Canyon are more varied and more extensively developed than those in and below the canyon.

Several large northwest-trending alluvial fans flank the southeastern side of the river valley near De Beque. The fan surfaces lie from 80 to 500 ft above local stream level. The gravels consist of pebbly to bouldery basalt of Battlement Mesa origin mixed with significant amounts of shale, sandstone, and marlstone derived from the Wasatch and Green River Formations. Remnants of three lower levels of fans visible near the county line were likely formed by Alkali Creek, Smith Gulch, and Moffat Gulch when these streams flowed at higher levels than present. A series of low coalescing alluvial fans cover much of the valley floor and valley-fill gravel deposits in this reach. On Plate 2 I have approximated the buried valley margin on the basis of present topography. Below De Beque the total valley fill beneath the alluvial apron may exceed 1.5 miles in width. Farther down-valley a second complex and deeply dissected alluvial-fan sequence lies at the mouth of Rapid Creek just south of Cameo. The gravels lie 200 to 320 ft above the Colorado River and, like those described above, are dominantly basaltic in composition.

Most mappable terrace deposits above De Beque Canyon lie in three levels above the Colorado River. Remnants above De Beque consist of well-rounded pebbly and cobbly river gravel locally influenced by fine-grained sediment contributions from small tributary streams. An isolated remnant of river gravel on De Beque Cutoff Road near Ashmead Draw indicates that the Colorado River at one time flowed 1.5 miles east of its present course.

On the west side of the river at the entrance to De Beque Canyon, four terrace levels have been developed at heights of 80 to 260 ft above river level. The terrace gravels north of Sulphur Gulch all consist of Colorado River lithologies, but the remnants below Sulphur Gulch are dominantly of locally derived material with admixtures of river gravel. These observations point out the strong effect that tributary streams may have on the composition and quality of the river deposit.

The high resistance of Mesaverde Group rocks to erosion has prevented the Colorado River from developing a significant valley fill in terms of areal extent. The gravel deposits in the canyon vary in width from 2,500 ft to as little as 300 ft.

Despite this physical constraint, the gravels constitute a valuable and readily accessible resource that has been utilized both within and outside the canyon. Little information is available on the thickness of the deposit, but gravel pits at De Beque indicate at least 20 ft. Principal lithologies include hard, well-cemented sandstone, medium-grained granite and biotite gneiss, basalt, and Green River shale and marlstone.

By far most of the mining activity in the upper river valley has centered on the flood-plain deposits. Most of the old pits were operated by the Colorado Division of Highways for construction of the old highway and for Interstate 70 through the canyon. Ample high-quality material was available adjacent to the right-of-way. The large pit at De Beque is now operated by the Mesa County Road Department. Another large pit, located northeast of Cameo, has been incorporated into the Island Parks State Recreation Area.

Lower Colorado River Valley

Gravel deposits of greatest economic importance in Mesa County lie along the Colorado River between the mouth of the canyon east of Palisade and the point near Loma at which the river enters canyon country of the Uncompahgre Plateau. Although the river's entire valley fill in Grand Valley is quite wide, only a small portion exposed along the river can be considered economically viable. This narrow strip of gravel along with the Redlands and Orchard Mesas terraces and several upland deposits constitute a relatively narrow but economically and socially critical corridor in the county.

Upland and alluvial fan deposits lie in a 2-mile-wide band south of the river between Palisade and Grand Junction. In the discussion of the Gunnison River resources, we saw that these upland gravels were of river origin and so were potentially more valuable than other nearby deposits of Grand Mesa origin. Alluvial fans along Watson Creek and Sink Creek and at Horse Mountain are of Grand Mesa origin, but their lower margins probably were influenced by the Colorado River. On Orchard Mesas a series of low, coalescing alluvial fans composed of locally derived very fine-grained sediment has formed at the mouths of many small tributary streams and washes. This alluvial apron has obscured the upper (southern) limit of some of Orchard Mesas' terraces. Farther westward the Redlands Alluvium (Hart, 1976), silt and sand derived from Colorado National Monument, has covered the terrace boundaries and prevented the mapping of all the deposits.

Colorado River terrace deposits extend from the mouth of the canyon near Palisade in a nearly continuous band to Fruita. Three discernible levels south of the river form the Orchard Mesas. The highest level underlies most of Central Orchard Mesa and extends from 28 1/2 Road to 32 1/2 Road beyond which it becomes obscured by the younger alluvial fans. The intermediate and most extensive level begins near Sink Creek and runs westward until it is truncated by the Gunnison River. A third terrace lies at a slightly lower level between Palisade and 33 Road. The intermediate terrace level persists through Redlands, although only the lower or northeastern portions are visible. High remnants of other terraces and terrace-fan complexes can be seen where the river again enters the canyons south of Loma.

Exposures along the northern edge of the intermediate terrace show 12 to 22 ft of river gravel overlain by 3 to 5 ft of overburden. A few well logs and exposures and geomorphic interpretation show that the overburden increases significantly southward or away from the river. In Redlands the southern margins of the deposits beyond Riggs Hill were based on the extent of dissection or the greatest exposure of gravel and, therefore, the limit of the most favorable stripping ratios (Schwochow, 1976). Although most exposures along the river bluffs show a dominance of gravel (Figure 43a), a predominantly sandy facies is exposed at the surface south of Fruita (Figure 43b).

FIGURE 43a. Central Orchard Mesa terrace gravel overlying Mancos Shale in a bluff exposure along the Colorado River west of 32 Road.

FIGURE 43b. Terrace exposure along Colorado 340 south of Fruita. Overlying the tilted and eroded Brushy Basin Member are a basal gravel layer and a thick sand sequence, illustrating a finer grained phase of deposition.

Compared to the adjacent flood-plain gravels, the Redlands and Orchard Mesas terrace gravels have not been exploited to any great degree. On Orchard Mesas mining has taken place only along the northern edge of the intermediate terrace between 31 1/2 Road and 29 1/2 Road. The Mesa County Road Department pits near 32 Road are now used by the county for equipment and materials storage. At the time I visited the site, the pit on 31 Road north of C Road had recently been operated and at the same time was in use for farm storage. On a small terrace northeast of Palisade, nearly all the gravel was mined for road construction by the Colorado Division of Highways. Two sand pits were operated in the upper sandy portion of the deposit near Fruita as shown in Figure 43b. Other pits have operated in terrace and upland deposits near the Loma interchange on Interstate 70.

Colorado River flood-plain deposits continue from the upper canyon section, through Grand Valley, across the northwestern end of the Uncompahgre Plateau, and into Utah. In Grand Valley the river meandered freely across the less resistant Mancos Shale and developed a relatively wide valley fill. A vast colluvial apron has, however, spread southwestward from the Book Cliffs and Upper Grand Valley and covered the northern boundary of the valley fill. As a result, only a narrow strip of flood-plain deposits is visible along the southern edge of the fill. A few available well logs and the existing topography indicate that the valley fill at Grand Junction extends as far north as Grand Valley Canal. Well logs in the Pear Park area suggest that a large buried meander may lie beneath Clifton. Other available well logs suggest that the northern edge of the buried valley fill closely approximates the course of Grand Valley Canal all the way to Palisade.

As we have seen, buried valley and terrace margins are common in other tributary drainage basins but on a much smaller scale. Because of the economic importance of the gravels along this stretch of the river, I felt it necessary to show a map unit with both geologic and economic connotations. As one might expect, the overburden here, in the form of reworked Mancos Shale, increases in thickness away from the river. Indeed the well logs and a few field observations confirm this. At some point the overburden-to-resource ratio becomes so high that the gravels cannot practicably be worked. Nearly all the gravel operations along the river are located where the overburden is thin (usually less than 5 ft) to nonexistent. This 5-ft cutoff also approximates a low topographic scarp that is traceable on airphotos throughout much of Grand Valley. The scarp formed when the meandering river cut into the lower edge of the encroaching alluvial-colluvial apron. This scarp, where visible, is taken as the northern boundary of economic flood-plain deposits shown on Plate 2. In some places farming and natural geologic processes have obliterated any scarp that may have been present. To define the boundary in these areas I have turned to the Grand Junction soil survey (Knobel and others, 1955). On Plate 2 deposits shown as *F1* represent river lowlands, which, on the soil survey, correspond to the Green River soil series and a "riverwash" land type--two soils characterized by coarse gravel and little or no overburden. Where a scarp is not visible, the extent of these two soils define the limit of flood-plain gravels. Northwest of Grand Junction the two areas designated as *F2* correspond to a phase of the Billings silty clay soil that consists of about 5 ft of overburden on river gravel. Because of the thicker overburden, *F2* represents flood-plain gravels of marginal or somewhat less quality than *F1* deposits, although a few gravel pits have operated in them.

To summarize, the southern boundary of the economically important flood-plain gravels along the Colorado River corresponds to the Dakota-Mancos bluff line. The northern boundary of the valley is buried by thick alluvial-colluvial sediment derived from the Book Cliffs and Upper Grand Valley. The northern limit of economic flood-plain gravels (*F1*) is defined by a topographic scarp and, where a scarp is not visible, by contrasting soil series. Marginally economic flood-plain gravels (*F2*) include two narrow strips of a Billings clay soil phase characterized by about 5 ft of overburden. Straight or other oddly shaped segments of the northern boundary are the result of modifications by farming and mining. The economic flood-plain gravels are arbitrarily terminated at Spann Ranch where the river channel enters the more resistant bedrock section at the head of Horsethief Canyon. This also is the last point at which flood-plain deposits have been mined.

Field observations and well logs show that the gravel fill varies from 15 to 29 ft in thickness. Some of the logs suggest that thicker channel deposits lie beyond the *F1*.

Gravel pits of all sizes are scattered along the river from Palisade to Loma. Most activity, past and present, seems to be centered in three areas:

1) 32 1/2 Road to 29 Road,
2) Rosevale to 21 1/2 Road, and
3) 18 Road to 14 Road.

With the exception of the large meander just west of Grand Junction, all pit activity has been confined to sites on the north bank of the river because the bluffs along the south bank have prevented access to the south-bank deposits. Access to the pits below Grand Junction is by county road extensions south from U.S. 6 and 50 and strictly by county roads above Grand Junction. Pits immediately west of the city are accessible by Colorado 340 and Dike Road. Most of the gravel mined in this stretch of the river has been used for concrete and asphaltic aggregates and for road materials. The largest new operation to have begun is the Corn Construction pit and asphalt plant by the river at 32 Road (Figure 44).

Many gravel pits along the river are considered abandoned but most have naturally revegetated. However, many other pits have undergone some sort of reclamation, including agriculture, water supply, recreation, wildlife habitat, and even homesites.

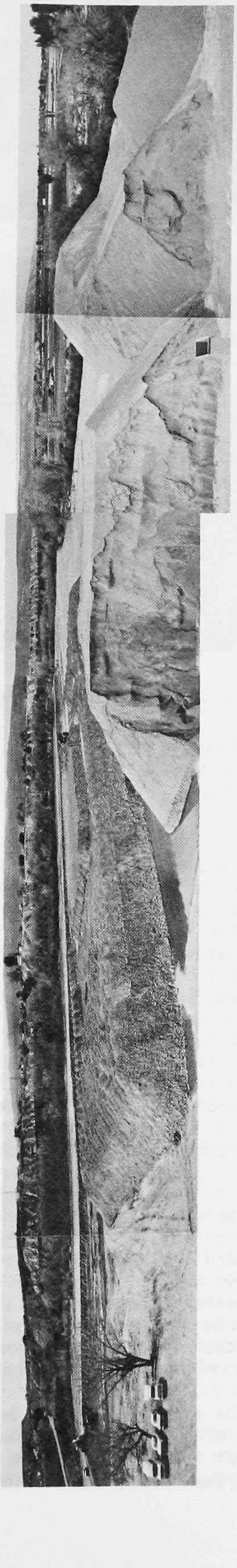


FIGURE 44. Panorama of Corn Construction Company's new gravel pit along the Colorado River at 32 Road. At left is the active pit, followed by stockpiles of pit run and processed materials.

A particularly popular recreational and park site is Connected Lakes Park, a greenbelt project reclaimed from several pits, managed by Mesa County Parks Department, and located west of Grand Junction at the west end of Dike Road. Another attractive park site is the reclaimed pit at West Lake, located at Independence Street and 25 1/2 Road. Views of Connected Lakes Park, West Lake, and another reclaimed site are shown in Figure 45.

RESERVES AND LAND-USE CONSIDERATIONS

In the Gunnison River valley Whitewater will continue to supply most of the aggregate as it has in the past. Future production will come essentially from the flood-plain deposits in two or three river meanders. Future large-scale mining development toward the deposit margins could be limited by 1) rights-of-way along Old Whitewater Road and the D&RGW Railroad, and 2) sediment effects from Whitewater Creek and other unnamed tributary washes. Only the first (lowest), second, and possibly the third terrace levels in section 28 appear to contain substantial reserves. New sites and expansion of existing sites on these terraces might be desirable because the deposits lie well above the water table.

Gravel mining in the valley of Plateau Creek has been confined to hillside and hilltop excavations in terrace and alluvial fan deposits. Future production will more than likely come from these same deposits because of their relatively easy access, great thickness, and elevation above the water table. The flood-plain deposits seem too spatially restricted and reserved for other higher priority land uses. A consistent problem noted in most of the pits is the disposal or placement of oversized materials. Basaltic boulders too large to be processed have little utility for reclamation, but the problem is apparently outweighed by access to the deposit and the large proportion of usable gravel. Should the northern slopes of Grand Mesa be subjected to increased development pressures, the need for local raw construction materials could greatly increase. Other terrace and higher alluvial-fan deposits could become more important gravel sources. Development and mining could compete directly with the valley's important farm and ranch lands, although in terms of acreage, development would be a more critical aspect.

Gravel mining in Upper Grand Valley has taken place on nonirrigated land above Government Highline Canal. I can see no land-use conflicts in this area because of the lack of water and development and because all the relatively small pits were operated for road materials. More mining has taken place on the small terrace remnants that extend along the main creeks southward into irrigated farmland below the canal. Even in this area, however, the pits are located on stony, nonfarmable land and, although several small remnants were completely mined, no serious problems have resulted. Several of the larger mined-out areas have been converted to agricultural use.

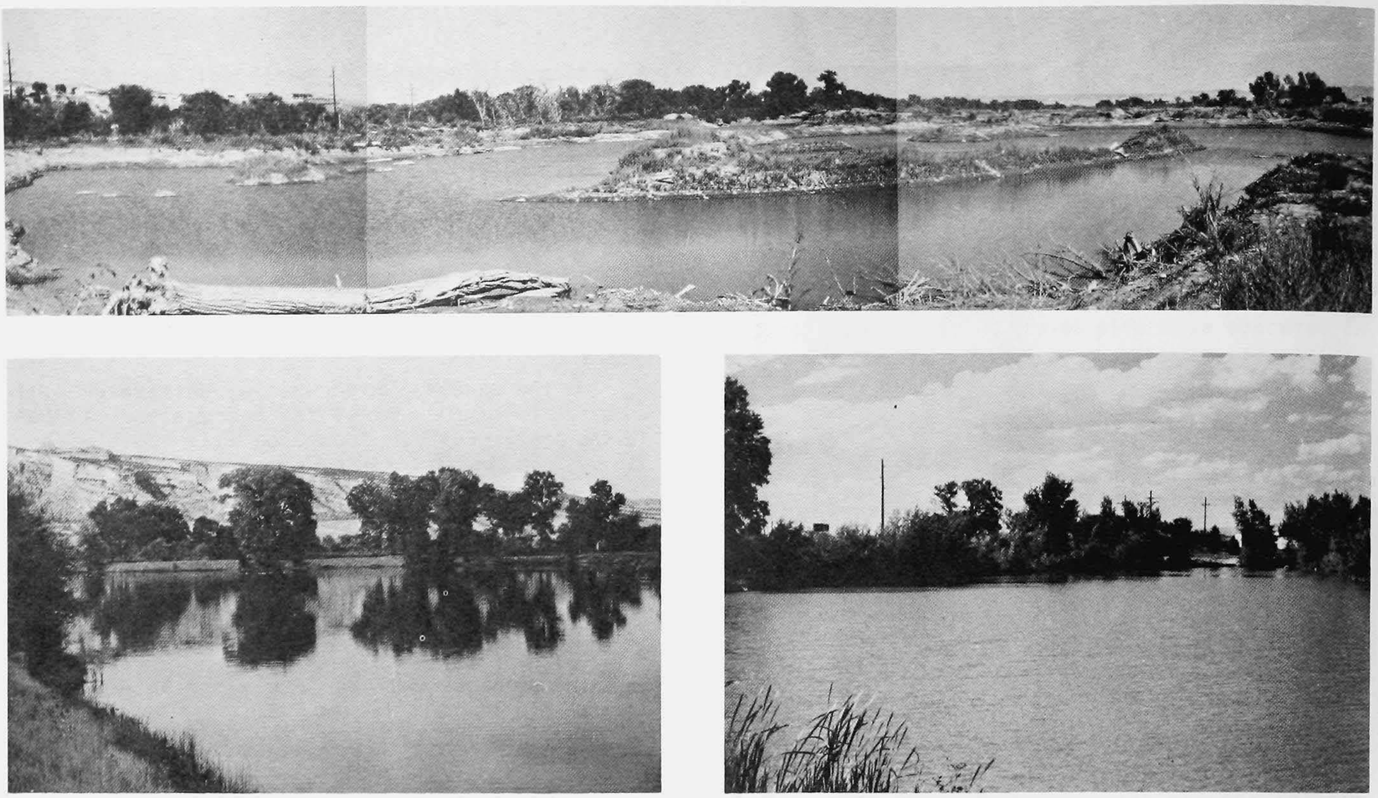


FIGURE 45. Reclaimed gravel pits along the Colorado River in Grand Valley. At top, Connected Lakes Park west of Grand Junction. Several abandoned pits have been converted to an easily accessible fishing and recreational area. At bottom left, part of a large reclaimed pit southwest of Rhone siding. Rising behind this horseshoe-shaped lake, the colorful rocks in Colorado National Monument have been warped across the Lizard Canyon monocline. At bottom right, West Lake, a reclaimed pit on Independence Street at 25 1/2 Road in Grand Junction, is a popular fishing spot and picnic ground.

As implied in the discussion of Gunnison River resources, the upland deposits south of Orchard Mesas represent a sizeable and potentially valuable resource. The gravels could continue to supply road materials for county roads in the area and for much of the new subdivision activity nearby. Some new houses and developments are already located on and near the Colorado River side of these deposits along U.S. 50 and Colorado 146.

The most critical land-use considerations related to gravel mining and development in the county must be noted in the Lower Grand Valley from Palisade to Loma. Several tracts along the river appear to contain large reserves, but their future availability will depend on present zoning, zoning changes, adjacent land uses, reclamation potential, and the county's policy toward gravel mining, development, and flood-plain control. To begin this final discussion, I would like to identify the flood-plain deposits that contain the county's critical gravel reserves and those whose utilization is somewhat more questionable.

Looking first at the stretch of the river between Palisade and Grand Junction, the first substantial reserve extends from the river at Palisade west to 35 Road. Although the tract is almost 3 miles long, it is relatively narrow and restricted between the river and Grand Valley Canal. The second reserve, Oldham Bottoms, is an anomalous bulge that represents a series of ancient river meanders. Despite its size, well over 700 acres, only the northeastern and southwestern ends can be considered available. The rest of the area is devoted to orchards. The northeastern end is a large abandoned meander that extends westward to within several hundred feet of 33 1/2 Road. Very little of the reserve here has been utilized. Gravels in the southwestern end generally lie south of D 1/2 Road and west of 33 1/4 Road and extend into a moderately mined area to 32 Road. I consider all the important reserves in these two tracts to lie on the north (right) bank of the river. Because the river flows against or very close to the bluffs, very few left-bank deposits are available. More importantly the lack of access to these gravels effectively eliminates them from the resource picture. Between 32 Road and 29 Road the reserve has been nearly mined out. The utility of the westernmost meander is questionable because of the farms and residences along C1/2 Road and 29 Road. Untouched tracts in sections 20 and 21 south of the river will likely remain so.

On the west side of Grand Junction, the reserve and mining picture is somewhat reversed from that east of the city. Westward to 24 Road most gravel mining has taken place on the south side of the river in a large meander below No Thoroughfare Canyon. Although older residential development lies south of the pit area, the remaining two-thirds of the deposit (sections 9 and 16) have been heavily mined. The large tract mapped north of the river on the west side of the city is effectively excluded from reserves because of existing roads, development, and unfavorable zoning, and the fact that the eastern half lies within the city limits. Similarly, very little of the resource south of Colorado 340 is probably recoverable.

Progressing westward, nearly all available reserves have been mined on the north side of the river between 24 Road and 20 Road. One remaining stretch of the river contains the marginal *F2* gravels discussed earlier. Possible reserves can be assigned to the wider portion of the deposits between 24 1/2 Road and 24 Road, 23 3/4 Road and 23 Road, and 22 3/4 Road and 22 Road.

Flood-plain deposits between 20 Road and Fruita are relatively narrow, except for one large meander between 19 3/4 Road and 18 1/2 Road. As seen in Figure 45, a portion of this deposit was mined and successfully reclaimed. A few other reserves apparently remain between 18 1/2 Road and Colorado 340 south of Fruita. Nearly all the right-bank reserves have been mined in the mile-long stretch west of Colorado 340. Left-bank resources between 16 1/2 Road and 16 Road are accessible by a dirt road west from Colorado 340.

From 16 Road to the upper end of Horsethief Canyon, gravels were mined and used for road materials, much of them for the construction of Interstate 70. Reserves generally lie between 16 Road and the Gary Western refinery. However, a large untouched reserve currently being farmed lies south of the river southwest of the refinery. The upper end of the deposit (center section 14) is accessible by a 4-mile-long dirt road west from Colorado 340.

In the above discussion I have outlined what appears to me to be the county's most critical gravel reserves. As one can infer, utility of the gravel depends to a great extent on physical configuration and access. North-bank resources are the most utilized because of their convenient access--county road extensions south from the major transportation routes through Grand Valley. In addition to the north-side reserves, I have included in the reserve picture three south-side deposits--one west of Grand Junction and two west of Fruita--solely on the basis of present road access. The other south-side resources can be utilized only if some convenient access is provided, probably by one of four procedures. First, the river could be bridged at some narrow point in or near one of the mining areas on the north bank. Access to and from the deposit would be the same that serves the north-bank pits. A second means of access from the north would result from a southward diversion of the present river channel into an abandoned channel or an overflow, thereby making available some gravels that originally lay south of the channel or in islands. Third, for the sole purpose of extracting gravel, new roads could be constructed from the Orchard Mesas and Redlands terraces down across the bluff line onto the flood plain. As a result of this development, Broadway, C Road, and B 1/2 Road would likely become the major haul routes. Fourth, if residential development were to take place on the flood plain, particularly below Redlands, normal subdivision access roads across the bluff line could be utilized first for gravel haulage before housing construction. Because of the unknown engineering and economic implications of such feats, the designation as reserves is doubtful at this time but should not be discounted.

In addition to the physical constraints on gravel availability, intangibles such as zoning can also limit the extractable reserves. Mesa County zoning maps show that the flood-plain gravels are zoned in one of five different categories, in descending order of coverage:

AFT - Agricultural and Forestry District (Transitional)
R4, R2 - Residential
I - Industrial District
T - Tourist District

The AFT zone covers much more of the deposits than do the other four categories combined. According to the county's zoning regulations, gravel mining is a "permitted" use in the residential (R2 and R4) zone and a "conditional" use in the AFT zone. Mining operations requested under either category must conform to the Supplementary Regulations, Section XIX, Subsection Q (Appendix 1), which refer to excavation boundary setbacks, reclamation and operation standards.

Looking practicably at these zoning categories and the uses permitted, we must eliminate from the reserves those flood-plain gravels now zoned I and T. The I zone includes 1) *F1* deposits west of Grand Junction in NW/4 sec. 15, T1S, R1W, Ute P.M., 2) *F2* and remaining north-bank *F1* deposits in sec. 9, T1S, R1W also just west of the city. The T-zoned land lies south of the U.S. 6 and 50 interchange on Interstate 70 and includes 1) nearly all the *F2* deposit in NW/4 sec. 6, T1S, R1W, 2) *F2* deposits in SW/4 and SE/4 sec. 36, T1N, R2W, and 3) *F2* and remaining *F1* deposits in N/2 sec. 14, T11S, R101W, 6th P.M. Because the latter area, sec. 14, already has been nearly mined out, very little reserve would be lost.

The two significant areas zoned R2 both cover gravels on the south side of the river--1) meander due south of U.S. 6 and 50 interchange on I-70, and 2) meander southwest of Rhone. As seen earlier, the designation of these deposits as reserves is doubtful because of the lack of and, in the case of the meander near Rhone, very limited access. The first R4 area, southwest of Grand Junction, lies between the Gunnison River and the mouth of No Thoroughfare Canyon and between the Colorado River and Redlands Power Canal. As implied before, new gravel operations here are not likely because of the existing development. The second R4 covers the south-bank gravels in secs. 9 and 16, T1S, R1W, an area already heavily mined. Beyond the older residential neighborhood, gravel mining should proceed nearly to completion. The remaining areas zoned AFT constitute the critical reserves for Grand Valley.

Now that I have identified the critical reserves, the next logical step would be the calculation of those reserves (in tons or yards) and the comparison of available supply with projected demand. At this time I have insufficient thickness data to properly estimate in-place reserves; however, I will outline a method of investigation that later could be implemented. By comparing past annual gravel production figures with population counts, one can determine a per-capita consumption ratio, or the number of tons of gravel consumed annually by each resident. Plotting this rate on a graph will show if the rate historically has decreased, increased, or remained constant. On the basis of this trend, one then can project the rate into the near planning future. If few data are available, one can assume a constant consumption rate and finish the analysis on the conservative side. Using available population projections for the county and its cities for the years 1978, 1979, 1981, 1983, 1985, 1990, and 2000, one can calculate the projected gravel production necessary to meet the consumption rate. By comparing the cumulative required production with the reserves, one finally determines if the calculated reserves are sufficient to meet future demand. Of course, all the projected figures are rough estimates, and calculations may be reasonable only to the nearest 5,000,000 or 10,000,000 tons. Other inherent assumptions must be made concerning growth trends, economic and political factors, actual minable acreage, percent waste material, and so on. Other refinements in the calculations include the percentage of total county population in the Grand Valley and the contribution of Gunnison River deposits to total county production.

With the few exceptions noted earlier, much of the Colorado River gravel reserve has, in some way or another, been kept available for mining. Most residential development fortunately has been diverted to higher ground away from the flood plain. Although other problems are involved with development there, at least a fair compromise has been achieved regarding resource extraction. Whether intentional or not, lower quality terrace gravels under Orchard Mesas and Redlands have been historically assigned to residential and permanent agricultural development in preference to gravel conservation. Higher quality gravels in the flood plain, therefore, are preserved for extraction. Flooding potential obviously enters into the logic here, too, perhaps indirectly. The boundaries of my economic flood-plain gravels closely correspond to the U.S. Army Corps of Engineers (1973) boundaries for the Intermediate Regional (100-yr frequency) and the more severe Standard Project floods in the 10-mile stretch between 32 Road and 22 Road. Therefore, by restricting flood-plain uses to agriculture and open space, many hazards can be eliminated, and the important gravel resources can be preserved. However, the AFT zone does permit a variety of permanent structures, and careful consideration should be given to new developments proposed within this zone.

The reclamation of mined lands has become increasingly important at the local level in the last few years, especially with regard to recent state laws. As I have pointed out, one can see various examples of gravel pit reclamation all along the Colorado River. Terrace and upland excavations lend themselves more to such afteruses as agriculture, rangeland, storage, or dry-land recreation and open-space. A more complicated situation exists in flood-plain excavations because most pits intersect the relatively shallow ground-water table. Quite often a pit is dewatered during the operation and allowed to fill afterward. Consequently, most flood-plain reclamation involves ponds, lakes, or water supply and storage. The usual technology includes of partial backfilling, regrading and replanting pit slopes, and installing various recreational facilities. Evaporative water losses from reclaimed lands can be a highly controversial topic both at state and local levels. As more lakes and ponds are created through reclamation, a greater surface area of water is exposed, and more water is evaporated. The gravel industry has become more aware of this problem, and in the last few years I have seen more applicants solve the problem at least legally by purchasing the necessary water rights as determined by hydrologic studies that accompany new applications. What other alternatives might be available? The most obvious recourse is to convert flood-plain excavations to a "dry-land" use, namely by backfilling and most likely converting to agriculture. Two types of backfilling can be considered in this type of operation. The first consists of properly compacted rock, soil, and nonorganic demolition wastes. The second type is the "sanitary" landfill, which despite the ground-water pollution potential, can successfully be operated in a flood-plain if a compacted shale or membrane lining is first installed. With proper compaction, cell cover, and monitoring, a reclaimed site can eventually be converted to any of a number of uses. However, because of zoning difficulties and the traditional social stigma of sanitary landfills, such engineering projects may be totally infeasible and undesirable in Lower Grand Valley.

I believe the county can expect increased gravel mining to support new growth and development in and near Grand Junction. The economics of the industry dictate that the sources of mineral raw materials be located as close as possible to the markets. In a publicized news story last year, a local gravel producer stated that the construction materials industry in Grand Valley was several months behind in meeting the demand for ready-mix concrete. Such a trend points out the need to conserve valuable mineral lands in a rapidly growing urban-suburban area such as Grand Junction. Mesa County is in a favorable position to plan ahead in the area of mineral land conservation and development and to avoid the misuse and loss of resources that have occurred in other metropolitan areas.

OTHER NONMETALLIC INDUSTRIES

In addition to the ready-mix, asphalt-mix, and concrete-products plants in the Grand Valley, two other nonmetallic-related operations merit description. In February, 1977, the world headquarters of Pabco Insulation Division of Fibreboard Corporation were dedicated. This huge plant, located one mile west of Fruita on U.S. 6 and 50, manufactures calcium silicate insulation in both pipe covering and block form at a rated annual capacity of 1.6 million cu ft. Marketed under the trade name Super Caltemp, the product specifications include a density of 13 lb/cu ft, flexural strength of 70 psi, and compressive strength of 100 psi at 5 percent deformation (Robert Sheffield, 1977, pers. comm.). The calcium silicate raw materials are brought to the Mesa plant from mines in Nevada. Although the Mesa plant produces only pipe and board products, Pabco's other plants in Texas and Louisiana also manufacture Pabcote insulating cement and Surefit metal jacketing for high-temperature insulation applications.

Another project, still in the planning stages as of April 1978, involves the construction of a *gasahol* plant on a 160-acre site along CS.2 Road about 2.5 miles east of Whitewater (sec. 18, T2S, R2E). Gasahol is a new type of fuel made by blending gasoline and alcohol. The company, Alcohol Fuels Inc. of Whitewater, plans the following features at the facility:

1) 2,500-bbl/day-capacity oil refinery,
2) distillation of alcohol from locally grown wheat and corn,
3) by-product cattle feed, carbon dioxide, dry, ice, and bulk alcohol,
4) generation of plant electricity by use of combustible trash from Grand Junction,
5) generation of plant water supply from corn.

At a full annual production rate of 5 million gallons of alcohol, the plant will employ between 45 and 60 persons.

The generation of electrical power, although itself not strictly a mining industry, is an important attendant activity because it requires great quantities of fossil fuels--coal, natural gas, and petroleum. Table 19 below lists the six power plants in Mesa County, their locations, type, and megawatt capacity. Plate 2 shows these six plants, electrical substations, and principal electrical transmission lines.

Table 19. Mesa County power plant statistics.

Name	Location	Type	Megawatt rating
Upper Molina	NW/4 sec. 33, T10S, R95W, 6th P.M.	hydro	8.64
Lower Molina	SE/4 sec. 12, T10S, R96W	hydro	4.86
Cameo #1	NW/4 sec. 34, T10S, R98W	nat. gas	22
Cameo #2		coal	44
Palisade	NW/4 sec. 2, T1S, R1W	hydro	3
Redlands	SE/4 sec. 16, T1S, R1W	hydro	14
Fruita	SW/4 sec. 20, T1N, R2W	nat. gas	18.65

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APPENDIX I

HOUSE BILL 1041, PART 2

AREAS AND ACTIVITIES DESCRIBED -

CRITERIA FOR ADMINISTRATION

CRS 1973 106-7-2-1. Areas of state interest - as determined by local governments. (1) Subject to the procedures set fourth in part 4 of this article, a local government may designate certain areas of state interest from among the following:

(a) Mineral resource areas;

(b) Natural hazard areas;

(c) Areas containing, or having a significant impact upon, historical, natural, or archaelogical resources of statewide importance; and

(d) Areas around key facilities in which development may have a material effect upon the facility or the surrounding community.

106-7-202. Criteria for administration of state interest. (1) (a) Mineral resource areas designated as areas of state interest shall be protected and administered in such a manner as to permit the extraction and exploration of minerals therefrom, unless extraction and exploration would cause significant danger to public health and safety. If the local government having jurisdiction, after weighing sufficient technical or other evidence, finds that the economic value of the minerals present therein is less than the value of another existing or requested use, such other use should be given preference; however, other uses which would not interfere with the extraction and exploration of minerals may be permitted in such areas of state interest.

(b) Areas containing only sand, gravel, quarry aggregate, or limestone used for construction purposes shall be administered as provided by article 36 of chapter 92, C.R.S. 1963 [article 1 of chapter 34, C.R.S. 1973].

(c) The extraction and exploration of minerals from any area shall be accomplished in a manner which causes the least practicable environmental disturbance, and surface areas disturbed thereby shall be reclaimed in accordance with the provisions of article 13 or article 32 of chapter 92, C.R.S. 1963, whichever is applicable [Open Mining Land Reclamation Act, amended 1976 in article 32, chapter 34, C.R.S. 1973].

(d) Unless an activity of state interest has been designated or identified or unless it includes part or all of another area of state interest, an area of oil and gas or geothermal resource development shall not be designated as an area of state interest unless the state oil and gas conservation commission identified such area for designation.

By action of a resolution adopted on January 10, 1978, Mesa County zoning regulations were revised according to the following:

Supplementary Regulations, Section XIX

Subsection T - Special and Conditional Uses

1. SPECIAL USES.

a) GENERAL. Special Use Permits are required for certain designated land use activities which are of significant but temporary or limited impact. Such permits direct designated land use activities to operate within and according to specific established guidelines and requirements. Special Use Permits may be issued by the Development Department Director (hereinafter referred to as the Director), or a designated representative, upon receipt by the Development Department of all required documents, signatures and fees, and when the proposed activity will not unduly disrupt, endanger or infringe upon the reasonable quiet enjoyment of property or the general development plan for the affected community or area. If, in the opinion of the Director or his designated representative, the proposed land use activity will pose imminent undue disruption, danger or infringement upon the general development plan for the affected community, the respective Special Use Permit applications shall be processed as Conditional Uses as contained in this section.

b) GUIDELINES FOR SPECIAL USE ACTIVITIES. Designated land use activities requiring Special Use Permit and respective guidelines and requirements for issuance of such permits are delineated below.

1) GAS AND OIL WELL DRILLING. The drilling of gas and/or oil wells, and the construction of associated access roads and drill sites require a Special Use Permit for each drill site on all lands within Mesa County. Public notice requirements, life of the permit, and application procedures are as follows:

a) Public Notice. Notice of application for a Special Use Permit for gas and/or oil well drilling shall be advertised by the Development Department in a daily newspaper of County-wide circulation for one regular edition prior to issuance of such Special Use Permit. Such permit shall be issued no sooner than two full working days following publication of legal notice.

b) Life of Permit. Special Use Permits for gas and/or oil well drilling operations shall expire 90 calendar days following the date of issuance. Such permit may be extended once for any period of time up to an additional 90 days by the Director, upon receipt of written request from the drilling company or a legal representative thereof. Written request for extension of such permit shall contain the reason for the request and must be received by the Director prior to the expiration of the original Special Use Permit.

c) Application Procedure. Application for a Special Use Permit for gas and/or oil well drilling shall be made by submission to the Development Department of all documents and fees as shown in Table T-1, Gas and Oil Well Drilling. Special Use Permit Fees and Documents Required.

Table T-1. Gas and Oil Well Drilling Special Use Permit Fees and Documents Required.

Surface Owner	Administration Fees	Required Documents	No. of Copies
Federal Government	$25.00	-Completed Application	1
		-County Road Use Agreement	1
State Government	$25.00	-Completed Application	1
		-County Road Use Agreement	1
Private and Local Government	$75.00	-Completed Application	6
		-Proof of mineral rights ownership	1
		-Surface restoration agreement with surface owner	3
		-County Road Use Agreement	1

MESA COUNTY
SPECIAL USE PERMIT APPLICATION
GAS OR OIL WELL DRILLING

1. APPLICANT COMPANY ____________________

   Office Address ____________________

   Office Telephone ____________________

2. Contact Person ____________________

   Office Address ____________________

   Office Telephone (area code) ____________________

3. Legal Description of Drill Site (to nearest 1/4 section): ____________________

4. No. of Employees __________ Estimated Time to Completion ____________________

5. Surface Ownership (name, address and telephone): ____________________

6. Gas/Petroleum Rights Ownership (name, address and telephone): ____________________

7. Application is for gas/oil drilling. (circle one)

8. County Road Use Agreement submitted (yes/no)

NOTE

All fees and documents must be submitted at time of application, as shown in Table T-1, Section T, SPECIAL AND CONDITIONAL USES, Mesa County Zoning Resolution.

DEVELOPMENT DEPARTMENT USE ONLY

PUBLIC NOTICE
PUBLICATION DATE__________

____
APPLICANT NAME
(print or type)

DATE OF ISSUE
THIS PERMIT__________

____
APPLICANT SIGNATURE

STATE OF COLORADO)
) ss.
COUNTY OF MESA)

The foregoing instrument was acknowledged before me this day of__________, ______. By ______ ______. My commission expires:__________

SUPPLEMENTARY REGULATIONS, SECTION XIX, SUBSECTION Q

Sand and Gravel Pits, Washing and Crushing

No such use shall be permitted unless the following standards and conditions exist or are met:

a. That is it designed, located and proposed to be operated so that it will not be injurious to the neighborhood in which it shall be located or otherwise determental to the public welfare.

b. When the application is filed to the Mesa County Planning Commission (see Supplementary Regulations, Section XIX-T.) the applicant shall provide a plan showing the land from which the sand and gravel will be excavated. This plan shall show the contours of the land on at least five (5) feet contour intervals, any improvements thereon and to a distance of three hundred (300) feet in all directions from the subject.

c. No excavation or processing of sand or gravel shall be permitted near than thirty (30) feet to the boundary of adjacent property, not nearer than one hundred twenty five (125) feet to any existing residence, unless the owner or owners of such adjacent property consent in writing to a lesser distance. The Commission may set a greater distance than above mentioned, when in their opinion it is justified.

d. The Commission shall specify the distance from any public structures when excavations are made in or near stream beds. When excavations are near or adjacent to irrigation ditches, the applicant shall secure a written consent from the Ditch Company or from officials responsible for the canals or ditches, indicating their determination as to setbacks from such canals and ditches. The Commission shall consult with the County Road Department as to setbacks from public rights-of-way when excavation is contemplated near such rights-of-way.

e. The applicant shall agree to leave the excavated area in such condition as may be required by the Commission. In establishing such requirements, the Commission shall take into consideration the following factors:

   (1) The degree of hazard to the public.

   (2) The health of the general public, e.g., mosquito hazard by stagnant ponds.

   (3) The feasibility of leveling the excavated area.

(4) The feasibility of restoring topsoil, if any, to the premises.

f. The applicant shall agree that the operation shall maintain haulage roads within the premises covered by the permit in a reasonable dust free condition.

g. The hours of operation shall be set by the Commission.

h. Crushing and washing may be permitted providing the Commission finds that the following facts prevail:

(1) The use is accessory to the sand and gravel operation, and,

(2) In the finished product, the operator uses the product of the sand and gravel pit on which the operation is proposed. The Commission may set out additional conditions under which these operations may be permitted and the said conditions may vary by location due to abutting land uses.

i. All conditions and uses shall be in full force for a period of five (5) years from the date of Commission action unless a shorter time is set by the Commission. Such conditions and use may be renewable by the Commission for the same period of time or less, without further notice on hearing, provided, however, that the operation has complied with the standards and conditions of the original action.

j. The Commission shall have the power to cancel the use upon proof of violation of any of these standards and conditions.

k. The Commission shall state in writing the degree to which the specific standards and conditions shall be met by the applicant.

l. The applicant shall, in addition to complying with Mesa County Requirements, comply with the State of Colorado requirements for such operations and copies of any State permits including terms and conditions shall be delivered to the Planning Department by the applicant prior to the commencement of any operations.

2. See Supplementary Regulations, Section XIX T. for application requirements and procedures.

APPENDIX 2

Table 6. Mesa County Uranium-Vanadium Production
(DOE tabulation of government purchases from 1948 to 1971)

		U_3O_8		V_2O_5	
Mine	tons ore	grade	lbs	grade	lbs
Ajax #1	272	0.19	1,019	1.15	6,265
Arrowhead Inc. 1, 2	13,124	0.33	86,006	1.53	400,906
Arrowhead 4	68	0.15	198	0.84	1,147
Arrowhead 5	1,682	0.35	11,914	1.48	49,820
Arrowhead Inc. 6	3,758	0.49	36,523	1.87	140,406
Arrowhead 1 & 7	6,399	0.32	41,018	1.41	179,980
Arrowhead 10	167	0.19	628	1.03	3,441
Arrowhead 11	1,846	0.34	12,573	1.34	49,464
Arrowhead Inc. 12 & 2	7,867	0.36	57,065	1.64	257,706
Arrowhead 13	25	0.22	111	1.05	523
Arrowhead 14	2,041	0.42	17,317	1.75	71,431
Arrowhead 18	985	0.28	5,564	1.12	22,034
Arrowhead 19	446	0.34	3,058	1.32	11,785
Arrowhead 20	2,512	0.43	21,379	1.68	84,571
Arrowhead 21	2,186	0.30	13,158	1.25	54,822
Arrowhead 22	431	0.42	3,661	1.24	10,662
Arrowhead Inc. 24	1,560	0.35	11,009	1.62	50,413
Arrowhead 27	546	0.37	4,005	1.38	15,083
Arrowhead 28	1,989	0.30	12,097	1.25	49,783
Arrowhead 29	619	0.49	6,115	1.96	24,226
Arrowhead 252	314	0.20	1,284	1.13	7,106
Ascension Mine	3,993	0.29	23,470	0	0
AT-05-1-36	83,259	0.44	733,479	0.14	231,885
Atlas Lone Mesa 1	2,991	0.27	16,168	0.87	51,879
Austin & Austin	728	0.33	4,764	0.78	11,366
Banco 1	15	0.31	94	1.11	334
Belmont 1 & 2	10,839	0.36	77,059	1.58	341,434
Bessie Group	1	0.10	2	0.30	6
Big Indian Lease	16	0.35	113	0.74	236
Big Maverick	42	0.54	450	2.56	2,150
Big Seven	1,337	0.57	15,279	2.78	74,358
Black Mama	18,557	0.28	103,607	1.09	404,505
Black Mesa	362	0.51	3,670	1.58	11,436
Black Rock 2	18	0.14	52	2.39	862
Black Streak	5,076	0.27	27,826	1.44	145,876
Blue Bird	863	0.29	5,047	1.48	25,520
Blue Bird Dump	251	0.11	563	0.62	3,126
Blue Creek	6	0.47	57	1.73	208
Blue Mesa View	9	0.15	27	1.51	271
Blue Ribbon 1	779	0.40	6,277	1.33	20,655
Blue Ribbon 3	2,187	0.30	13,113	1.16	50,698
Blue Ribbon Group	9,466	0.28	52,295	1.18	223,257
Blue Ribbon 32	68	0.13	170	0.65	882
Blue Ribbon 17	16	0.54	172	2.64	844
Bonanza #2	159,183	0.31	981,486	0.46	1,469,879
Bonanza 3	41,310	0.29	238,404	0.06	48,588
Bonanza 5	17,236	0.31	106,434	1.41	487,192
Bonanza 6	5,038	0.25	25,664	1.19	120,322
Bonnie	1	2.05	41	2.80	56
Bud 10S	17	0.11	36	0.96	327
Buick	2,853	0.18	10,305	0.63	36,092
Calamity Homestead	52	0.10	106	1.20	1,248
Calamity Mesa Dump	339	0.14	922	0.76	5,156
Calco	245	0.32	1,548	1.25	6,110
Cave Canyon	195	0.43	1,686	2.15	8,400
Cedar Point 3 L Chief	3,561	0.32	22,802	1.38	98,190
Cherie 1 & 2	0	0	0	0	252
Chico & C Fraction	181	0.47	1,696	1.60	5,791
Cliff Dweller	1,209	0.32	7,800	1.52	36,685

TABLE 6, continued

Climax	43	0.26	227	1.78	1,534
Climax Residue	3,027	0.60	36,382	3.31	200,287
Coal Town Citation	1	1.60	32	2.50	50
Cottonwood 3 & 5	1,583	0.20	6,309	1.57	49,701
Cove 1 Adit	17	0.39	134	1.48	504
Crescent	96	0.22	413	1.13	2,177
Crows Nest	1,722	0.30	10,421	1.43	49,369
Cub	10	0.27	54	0.98	197
Dalilu Yellowbird	307	0.49	3,022	1.91	11,706
Deal Group	7	0.59	83	1.58	221
Depression Group	526	0.58	6,125	3.08	32,391
Depression 2 & 3	530	0.35	3,685	1.88	19,973
Depression 4 & 5	4,025	0.39	31,137	1.65	132,976
Depression 6	12,338	0.36	89,870	1.89	465,691
*Drum Dust	121	4.04	[9,769]	0	0
Durango 2	69	0.23	322	0.85	1,174
Elizabeth 7, 8, 9, 10	4,652	0.19	17,990	1.76	163,967
Elizabeth 17 & 18	2,589	0.37	19,350	2.02	104,756
Emerson	266	0.36	1,906	1.25	6,660
Flat Top	90	0.59	1,060	3.12	56.14
Fordo 6	980	0.28	5,467	0.78	15,335
Fountain of Youth	298	0.17	1,022	0.78	4,654
Fraction	188	0.35	1,325	2.18	8,192
Gateway Tailings	1,429	0.26	7,360	0.69	19,842
Gilmore Lode	445	0.33	2,920	1.35	12,042
Gladys 1	25	0.34	170	1.83	917
Hole 24	7	0.12	17	1.44	201
Hanson Negus	8,325	0.14	23,511	1.12	185,867
Harvey 1	25	0.13	63	0.77	383
Harvey Pick and Shovel	765	0.39	6,005	1.15	17,632
Hope 14	899	0.28	5,101	1.88	33,778
Hubbard Homestead Pack	84,121	0.32	532,183	1.35	2,269,086
Humdinger	45	0.26	232	1.63	1,469
Incline 1G1	110,283	0.27	591,783	0	0
Incline 2G2	8,998	0.26	46,208	1.15	207,836
Incline 3G3	29,008	0.19	108,622	0.89	515,489
Incline 4G4	6,702	0.23	31,149	1.06	141,874
JWL Fraction	15,896	0.37	119,183	1.46	464,107
Jean 1 & 2	98	0.18	360	1.12	2,203
Jody Group	1,833	0.21	7,643	1.88	68,790
Joe	2,486	0.27	13,184	1.01	50,286
Jody Brown 14 & 15	12,206	0.23	55,627	0.73	178,282
John Brown	6	0.45	54	1.42	171
Johnny Mae 3	4,745	0.51	47,966	2.04	193,349
Ju Dee 1	1	0.45	9	1.05	21
July	6,739	0.39	52,955	1.60	215,045
Jumbo 1	844	0.25	4,239	1.71	28,816
Karns Incline	6,532	0.46	59,456	1.93	251,974
Kanarado 3	3	0.30	18	1.65	99
King Solomon	209	0.22	938	0.64	2,670
Klondike	63	0.25	315	1.82	2,295
La Plaza 1	222	0.28	1,240	1.14	5,052
La Sal	17,263	0.33	112,646	1.20	415,796
LaSalle Group	12,357	0.44	108,531	1.53	376,921
La Sal 1 & 2	1,706	0.39	13,458	1.31	44,629
La Sal Group	57,543	0.33	383,735	1.14	1,309,922
La Sal 4	12,773	0.35	88,151	1.29	330,429
La Sal 5 & 7	11,615	0.33	77,511	1.23	286,677
Levada	51	0.47	479	2.06	2,104
Lee 16	66	0.37	492	2.00	2,643
Legal & Lucky Day	5	0.20	20	3.72	372
Liberty Bell	10,355	0.29	60,260	0.99	204,241

*see text for explanation

TABLE 6, continued

Liberty Bell 2	53	0.52	550	1.97	2,086
Lincoln	7,318	0.24	35,157	0.79	116,043
Little Johnny	2,270	0.18	8,193	0.78	35,558
Little Maverick 1	72	0.37	527	1.85	2,658
Locus 1, 2 & 3	2	0.13	5	0.75	30
Lode Claim	63	0.28	356	1.42	1,795
Log Cabin	156	0.20	611	1.27	3,972
Lone Peak	2	1.20	48	2.25	90
Look Out	13	0.97	253	4.34	1,128
Lost Dutchman	7,040	0.25	34,542	0.84	118,465
Lost Dutchman 17	61,738	0.26	322,250	1.05	1,293,825
Lucky Day	138	0.11	302	0.97	2,686
Lucky Hole	2	0.50	20	3.92	157
Lucky Pine 2	28	0.32	180	1.38	770
Lucky Strike	43	0.16	134	0.79	678
Lucky Strike 7	1	0.25	5	1.35	27
Lumsden 1	5,330	0.32	33,764	1.66	177,103
Lumsden 2 & 6	47,282	0.36	336,008	1.40	1,325,897
Mammoth	5,124	0.15	15,018	0.09	70,291
Mammoth Lincoln	1,833	0.16	6,023	0.70	25,613
Mark 2	97,019	0.28	537,893	0.85	1,653,150
Mary 3	4,200	0.31	25,932	1.72	144,260
Maverick 6	38	0.28	215	1.34	1,019
Maverick	9	0.53	96	3.94	709
Mesa 5 (Beaver Mesa)	25,100	0.23	114,816	1.08	539,681
Mesa 8	51,434	0.21	216,548	1.02	1,053,868
Mesa Creek	41	0.23	185	0.89	733
Mill Site Lode	82	0.22	369	0.99	1,622
Mineral Channel 3	827	0.43	7,039	1.64	27,065
Mineral Channel 5	84	0.74	1,236	2.30	3,869
Mineral Channel 10 & 12	4,662	0.21	19,562	0.96	89,072
Mining Lease 34	15	0.15	46	0.71	213
MLB C-G-26	0	0	0	0	0
MLB C-G-27	0	0	0	0	0
Montezuma	4	0.40	32	3.14	251
Monroe 18	149	0.22	660	1.58	4,712
Nielson	7	0.48	67	2.14	299
Nielson Mother D	43	0.34	295	1.78	1,534
Newheisel	4,516	0.28	25,643	0	0
New Verde	72,100	0.32	465,920	1.35	1,951,777
October Adit	53,411	0.31	331,194	0.91	970,686
October 7,9,10,11	0	0	0	0	0
Outlaw Economy	6,368	0.33	41,921	1.45	185,281
Pack Rat 1 & 2	46,993	0.32	300,994	1.46	1,373,280
Payday 1 thru 7	12	0.11	27	1.09	261
Pay Lode	180	0.21	757	1.23	4,414
Payrock Group	761	0.25	3,812	1.35	20,497
Peach Ten Inc. 1 & 2	3,469	0.28	19,473	2.04	141,224
Pie Face 1	118	0.18	431	1.00	2,363
PPT Concentrate	10	0.68	137	1.73	346
Protector	6,291	0.29	36,293	1.06	133,065
Purple Heart	9	0.18	33	0.09	17
Radium 7	16	0.35	113	2.53	811
Rae Marie Group	4,449	0.35	31,138	1.24	110,284
Rae Marie 3	586	0.39	4,525	1.14	13,369
Rainbow	191	0.29	1,124	1.38	5,259
Rainy Day	3,264	0.20	12,981	1.33	86,738
Rajah 1	880	0.19	3,364	0.59	10,367
Rajah 11 & 63	34,233	0.28	190,243	1.06	728,209
Rajah 30 Shaft	292,647	0.25	1,484,991	0.78	4,538,721
Rajah 67 & 68	112,673	0.27	598,010	1.13	2,555,105
Rajah 72	114	0.31	711	1.80	4,104
Ranch View	15	0.50	149	1.55	465
Raven 3	685	0.34	4,694	1.56	21,426

TABLE 6, continued

Rena	269	0.30	1,640	1.34	7,224
Ronnie 1	11,817	0.31	73,215	1.32	311,640
Ronnie 2	1,606	0.30	9,576	1.38	44,427
Rosebud	519	0.41	4,254	1.16	12,076
Rudot 1	259	0.28	1,449	1.28	6,614
Salute 3	13	0.24	63	0.64	167
Scott 2	7	0.26	36	1.37	192
Shelby Dean 2	8	0.42	67	2.71	434
*Silver Moon	4	0.09	[7]	0.57	[46]
Small Spot	2,616	0.68	35,372	2.78	145,438
Snow Shoe	1,493	0.34	10,023	1.33	39,669
Soldier Boy	883	0.28	4,910	2.06	36,295
Spring	2,757	0.45	24,592	1.99	109,535
Stormy Treasure	5	0.17	17	0.82	82
Strode 1	3	0.93	56	2.90	174
Sun	309	0.51	3,130	2.35	14,493
Sun Spot/Cloud 1	10,044	0.29	57,627	1.13	227,496
Supply 11	15	0.29	86	1.29	386
Supply 14	14	0.11	31	1.29	360
Surprise	142	0.20	576	1.41	3,992
Tenderfoot Group	8	0.21	34	1.67	267
The Duke	270	0.28	1,539	1.20	6,465
Thorton Tunnel	13,777	0.27	74,848	0.85	233,769
Trojan 18 & 20	616	0.60	7,430	2.11	25,988
Vanadium King 1	17	0.19	65	1.40	476
Vanadium King 2	48	0.46	439	1.66	1,589
Wasp 1	485	0.46	4,509	2.11	20,512
Wray Mesa	61	0.24	295	2.21	2,697
Yellow Cat (Bird?)	6	0.19	23	1.48	177
Yellow Jacket 9	194	0.34	1,324	1.50	5,806
Yellow Jacket 2	2,386	0.37	17,471	1.46	69,481
Yellow Jacket Inc. 1	4,110	0.31	25,626	1.34	110,433
Zee Lease Rajah 49	101,285	0.25	510,499	0.87	1,765,306

*see text for explanation

TABLE 18. Grain-size classification for sand and gravel

Wentworth					Unified Soil Classification					Modified Unified Soil Classification					
Component		mm	in.	U. S. sieve series	U. S. sieve series	mm	in.	Component		U. S. sieve series	mm	in.	Component		
Gravel	Boulder													Boulders	Gravel
		256	10								256	10			
	Cobble								Cobbles					Cobbles	
					3-in.	76.1	3			3-in.	76.1	3			
								Coarse	Gravel				Coarse	Pebbles	
		64	2 1/2	2 1/2-in.	3/4-in.	19.0	3/4			3/4-in.	19.0	3/4			
	Pebble							Fine					Fine		
					#4	4.76	0.187			#4	4.76	0.187			
		4	5/32	#5											
Sand	Granule							Coarse	Sand				Coarse		Sand
		2	5/64	#10	#10	2.00	5/64			#10	2.00	5/64			
	Very Coarse														
		1	0.0394	#18											
	Coarse							Medium					Medium		
		1/2	0.0197	#35											
					#40	0.42	0.0165			#40	0.42	0.0165			
	Medium														
		1/4	0.0098	#60											
	Fine							Fine					Fine		
		1/8	0.0049	#120											
	Very Fine														
					#200	0.074	0.0029			#200	0.074	0.0029			
		1/16	0.0025	#230											
	Silt								Fines (silt & clay)						Fines (silt & clay)
		1/256	0.00015	#400											
	Clay														

The grain size terms used in this report are adapted from two other common systems. The first system is the Wentworth scale, which is based on a modified geometric progression. The gravel cutoff is placed at 2 mm (5/64-in.; #10 screen) and that for sand is placed at 1/16 mm (0.0025 in.; #230 screen). This is the standard scale used in most geologic descriptions. The second scale is the Unified Soil Classification, an engineering scale with the gravel cutoff at 4.76 mm (0.187 in.; #4 screen) and the sand cutoff at 0.074 mm (#200). This report uses the Unified Soil Classification modified by the addition of the Wentworth gravel terms. For visual classification (as in the map explanation) the 1/4-in. size may be used as equivalent to the #4 sieve size (Asphalt Institute, 1969, p. 69-86).

APPENDIX 3

DIRECTORY OF MESA COUNTY MINERAL PRODUCERS AND INDUSTRIES

Metallics

Copper:

Rohrig and Brown Associates
446 North 23d St.
Grand Junction, CO 81501
(303) 434-6086; 242-1612

Uranium Mining and Exploration:

Cotter Corporation
1129 Colorado Ave.
Grand Junction, CO 81501

Inspiration Development
747 Rood Ave.
Grand Junction, CO 81501
(303) 243-2301

Pioneer Uravan
2429 Industrial Blvd.
Grand Junction, CO 81501
(303) 245-0197

Taminco, Inc.
415 Walnut St.
Grand Junction, CO 80501
(303) 243-0585

W. D. Tripp Mining Co.
2656 Paradise Drive
Grand Junction, CO 81501
(303) 243-5449

Union Carbide Corp.
1600 Ute Ave.
Grand Junction, CO 80501
(303) 245-3700

Whitelock Corp.
660 Rood Ave.
Grand Junction, CO 80501
(303) 245-4419

Plateau Mining Co.
P.O. Box 506
Clifton, CO 81520
(Belmont No. 1 and
Arrowhead No. 8)

Frank T. Wilson
P.O. Box 2356
Grand Junction, CO 80501
(B-Chitty-U)

S and M Exploration
P.O. Box 211
Gateway, CO 81522
(Black Jack)

Raja Ventures, Ltd.
2721 North 12th St.
Grand Junction, CO 81501
(Bonanza, La Sal,
Lost Dutchman, New
Verde, Packrat,
Thornton, Rajay 49-Zee
Lease)

Tom Myers
P.O. Box 246
Gateway, CO 81522
(Bujan)

Ralph Foster and Sons
2950 A1/2 Road
Grand Junction, CO 80501
(Economy, Mesa No. 5,
Mineral Channel No. 5)

Hubbard Mining Co.
P.O. Box 242
Gateway, CO 81522
(Hubbard)

Marion Birch
P.O. Box 703
Moab, Utah 84532
(Liberty Bell)

Four Corners Mining
and Milling Co.
P.O. Box 46
Uravan, CO 81436
(Maw)

Ince Minerals Corp.
P.O. Box 241
Gateway, CO 81522
(October Adit, Peaches)

Mendisco and Urralburu
Mining Co.
P.O. Box 546
Nucla, CO 81424
(Rajah No. 30)

Robert Graham
P.O. Box 141
Gateway, CO 81522
(Rosebud)

John Beres Mining Co.
P.O. Box 171
Cory, CO 81414
(Stafford No. 5)

Vernon Moores and Sons
Star Route #4
Gateway, CO 81522
(Wedge)

North Star Equipment
Rental and Exploratio
P.O. Box 109
Gateway, CO 81522
(Winfield-McCormick)

Mineral Fuels

Coal:

Cambridge Mining Corp.
P.O. Box W
Palisade, CO 81526
(CMC or Roadside Mine)

Cameo Coal Co.
P.O. Box CC
Palisade, CO 81526
(Cameo No. 1 Mine)

McGinley Coal and Energ
5670 East Evans Ave.
Denver, CO 80222
(McGinley Mines)

Coal Minng Partners
c/o Charles Silengo
598 Grand Valley Drive
Grand Junction, CO 8150
(Anchor-Tresner Mine)

Natural Gas, Petroleum, Pipelines:

Gary Western Co.
Gary Community Rural Sta.
Fruita, CO 81521
(Gary Western refinery)

Continental Oil Co.
Fruita Gas Products Plant
P.O. Box 602
Fruita, CO 81521

bulk plant
631 South 9th St.
Grand Junction, CO 81501
(303) 242-5857

Chevron Oil Co.
725 South 5th St.
Grand Junction, CO 81501
(storage tank)

Mobil Oil Co.
611 South 7th St.
Grand Junction, CO 8150
(303) 242-2820
(storage site)

Standard Oil Co.
435 South 11th St.
Grand Junction, CO 8150
(303) 245-3616
(storage site)

Texaco Oil Co.
430 2nd Ave.
(303) 242-2731
(bulk plant)

KMOCO
2850 North Ave.
Grand Junction, CO 81501
(303) 242-0900
(storage site)

Western Slope Gas
2478 Industrial Blvd.
Grand Junction, CO 81501
(gas wells, compressor
sta.)

Northwest Pipeline Corp.
819 21 1/2 Road
Grand Junction, CO 80501
(303) 242-0491
(gas compressor station)

Arrow Gas Co.
582 24 1/2 Road
Grand Junction, CO 81501
(303) 242-8000

Flying Diamond Oil Corp.
1700 Broadway, Suite 900
Denver, CO 80290
(303) 573-6624

Gipson-Kelley, Inc.
P.O. Box 2920
Grand Junction, CO 81501
(303) 242-4124

Burton W. Hancock
1799 Hamilton Ave.
San Jose, CA 95125
(408) 264-3114

Terra Resources
P.O. Box 2500
Casper, WY 82602
(303) 861-4072

Gasco, Inc.
420 Capitol Life Center
1600 Sherman St.
Denver, CO 80203
(303) 861-4072

AMAX Petroleum Corp.
900 Town and Country Lane
Suite 400
Houston, TX 77024
(713) 467-2200

Alcohol Fuels, Inc.
P.O. Box 36
Whitewater, CO 81527

Rocky Mountain Natural
Gas
Grove Creek Road
Collbran, CO 81624
(303) 487-3737
(gas wells, compressor
sta.)

Union Oil Co. of
California
P.O. Box 3100
Midland, TX 79701
(915) 684-8231
P.O. Box 2620
Casper, WY 82602
(307) 234-1563

Fees-Krey, Inc.
2111 Broadway
Grand Junction, CO 81501
(303) 242-2044

Sun Oil Co.
P.O. Box 100
Rangely, CO 81648
(303) 675-3036

Mountain Fuel Supply Co.
180 East First St. South
Box 11368
Salt Lake City, UT 84139
(801) 534-5555

Don M. Rounds Co.
320 Petroleum Club Bldg.
Denver, CO 80202
(303) 623-0296

El Paso Natural Gas Co.
P.O. Box 1492
304 Texas St.
El Paso, TX 79978
(915) 534-2600

Norris Oil Co.
P.O. Box A-1
2590 East Main St.
Ventura, CA 93001
(805) 648-5193

CIG Exploration
Gas Producing
Enterprises, Inc.
P.O. Box 749
1050 17th St.
Denver, CO 80201
(303) 572-1121

Adolph Coors Co.
Mailing Route 338
Golden, CO 80401
(303) 279-6565

Nonmetallics

Jim Arnold Construction
454 28 1/2 Road
Grand Junction, CO 81501
(303) 242-3111

Associated Building
Products
3241 D Road
Cilfton, CO 81520
(303) 434-5189

Corn Construction Co.
2868 Highway 70-A,
Grand Junction, CO 81501
(303) 242-3380

Dolan Trucking Co.
3049 Bookcliff Ave.
Grand Junction, CO 81501
(303) 243-0568

Fruita Ready Mix Sand
and Graven
997 17 Road
Fruita, CO 81521
(303) 858-3914

United Sand and Gravel
618 Dike Road
Grand Junction, CO 81501
(303) 243-4900

Whitewater Building
Materials Corp.
940 South 10th St.
Grand Junction, CO 81501

Colorado Survault Co.,
Inc.
292 Canon St.
Grand Junction, CO 81501
(303) 242-2020

Grand Valley Stone Supply
576 1/2 25 Road
Grand Junction, CO 81501
(303) 243-7089

Rock 'n' Wood Center
1346 Pitkin Ave.
Grand Junction, CO 81501
(303) 245-2660

Valley Building Supply
Co.
1100 D Road
Grand Junction, CO 81501
(303) 245-3305

Dri Mix Concrete
2462 1/2 Highway 6 & 50
Grand Junction, CO 81501
(303) 245-0058

C Mays Concrete
Construction Co.
2486 Commerce Blvd.
Grand Junction, CO 81501
(303) 243-5669

C. J. Abbot, Inc.
101 South 3d St.
Grand Junction, CO 81501
(303) 243-5414

Asphalt Construction,
Inc.
416 Dike Road
Grand Junction, CO 81501
(303) 242-0981

Elam Construction, Inc.
1225 South 7th St.
Grand Junction, CO 81501
(303) 242-5370

El Paso Asphalt Repair,
Inc.
492 29 Road
Grand Junction, CO 81501
(303) 245-1472; 242-1927

Gilsabind Co.
995 Highway 6 and 50
Mack, CO 81525
(303) 858-3678

Tusco Engineering Co.
5701 Dexter St.
Denver, CO 80216
(303) 289-3196

Coors Porcelain Co.
2449 River Road
Grand Junction, CO 81501
(303) 245-4000

Fibreboard Corporation
Pabco Insulation Div.
1110 16 Road
Fruita, CO 81521
(303) 858-3694

Mesa County Road Dept.
1000 South 9th St.
Grand Junction, CO 81501
(303) 243-9200

Colorado Division of
Highways, District 3
606 South 9th St.
Grand Junction, CO 81501
(303) 242-2862

American Forest and Stone
Products
2524 Hill Ave.
Grand Junction, CO 81501
(303) 243-0996

Dangler and Son
Construction
135 Landsdown Road
Grand Junction, CO 81501
(303) 243-5135; 245-0234

Al Grasso Masonry, Inc.
103 North 1st Ave.
Grand Junction, CO 81501
(303) 243-3209

Glen Pritchard Masonry
327 Acoma Drive
Grand Junction, CO 81501
(303) 245-3745

Steamboat Masonry
934 4th Ave.
Grand Junction, CO 81501
(303) 242-4635

Thomas Hayward Chemical
Company
P.O. Box 832
Grand Junction, CO 81501
(303) 245-0408

Petrochem Co.
P.O. Box 2612
Grand Junction, CO 81501
(303) 242-3079

McKesson Chemical Co.
P.O. Box 788
Grand Junction, CO 81501
(303) 242-3741

MINERAL RESOURCE-RELATED PUBLICATIONS OF THE COLORADO GEOLOGICAL SURVEY

BULLETINS

32	Prairie, Peak, and Plateau--A Guide to the Geology of Colorado. John and Halka Chronic, 1972.	4.00
37	Bibliography and Index of Colorado Geology, 1875 to 1975. American Geological Institute, 1976.	Softbound 7.50 mailed 8.50 Hardbound 10.00 mailed 11.00
39	An Appraisal of Colorado's Geothermal Resources. J.K. Barrett and R.H. Pearl, 1978.	7.00
40	Radioactive Mineral Occurrences of Colorado, and Bibliography. J.L. Nelson-Moore, D.B. Collins, and A.L. Hornbaker, 1978.	37.00 mailed 40.00

SPECIAL PUBLICATIONS

5-A	Sand, Gravel, and Quarry Aggregate Resources, Colorado Front Range Counties. S.D. Schwochow, R.R. Shroba, and P.C. Wicklein, 1974.	3.00
9	1975 Summary of Coal Resources in Colorado. A.L. Hornbaker, R.D. Holt, and D.K. Murray, 1976.	1.00

MAP SERIES

1	Geologic, Energy and Mineral Resources Maps of Routt County, Colorado. A.E. Miller, 1975.	5.00
3	Geology of Moffat County, Colorado. A.E. Miller, 1977.	8.00
5	Geology for Planning in the Redlands Area, Mesa County, Colorado. S.S. Hart, compiler, 1976.	7.00
10	Metal Mining Activity Map of Colorado (excluding uranium and vanadium with directory). A. L. Hornbaker, 1978.	3.00
11	Map and Directory of Colorado Uranium and Vanadium Mining and Milling Activities. J.D. Collier, A.L. Hornbaker, and W.L. Chenoweth, 1978.	4.00

RESOURCE SERIES

1	Geology of Rocky Mountain Coal--A Symposium. D.K. Murray, ed., 1977.	4.00
3	Colorado Coal Directory and Source Book. L.C. Dawson and D.K. Murray, 1978.	6.00

OPEN-FILE

75-3	Mineral Resources Maps of Moffat County. Charles S. Robinson and Associates, 1975.	5.00

MISCELLANEOUS

Geologic Map of Colorado. U.S. Geological Survey, 1935 (in color).	5.00 mailed 6.50
Preliminary Geological Map of Colorado. Ogden Tweto, 1976 (USGS Map MF-788, black and white).	1.50

REGIONAL (1°x2°) GEOLOGIC COVERAGE OF MESA COUNTY

Geologic and structure map of the Grand Junction quadrangle, Colorado and Utah. W.B. Cashion, 1973 (USGS Map I736).

Geology, structure, and uranium deposits of the Moab quadrangle, Colorado and Utah. P.L. Williams, 1964 (USGS Map I-360).

Geologic map of the Leadville 1°x2° quadrangle, northwestern Colorado. Ogden Tweto, R.H. Moench, and J. C. Reed, Jr., 1978 (USGS Map I-999).

DEPARTMENT OF NATURAL RESOURCES
COLORADO GEOLOGICAL SURVEY
JOHN W. ROLD, DIRECTOR

Resource Series 2
Plate 2

RESOURCE AREAS, DATA POINTS

- mineral resource occurrence area, dashed where approximate or inferred, dotted where concealed
- · specific or point occurrence
- boundary of buried valley
- ▲D-3 oil shale sample locality
- abbreviated well log, lithology thickness (ft), rock units and resource zones
- distribution of grain sizes in gravel deposit, in percent by weight: undersize or silt and clay (blank), oversize (hachure), gravel (black), sand (dots)
- ◐ USGS uranium drill hole, ore encountered
- ○ USGS uranium drill hole, weak mineralization

Metallics

Uranium and Vanadium (Uranium mineral belt):

UV-1	Salt Wash Member of Morrison Formation
UV-2	Brushy Basin Member of Morrison Formation
UV-3	Burro Canyon Formation and Dakota Group overlying the Morrison Formation

Copper (Unaweep and Dominguez districts):

Cu-1	mineralization in Precambrian rocks
Cu-2	mineralization in Chinle Formation and Wingate Sandstone

Mineral Fuels

Coal (Book Cliffs and Grand Mesa fields, Gunnison River district):

CbB	high-volatile B bituminous
CbC	high-volatile C bituminous
CsA	subbituminous A
	burned zone

Oil Shale (Battlement and Grand Mesas):

OS	Parachute Creek Member of Green River Formation
OSm	Mahogany zone in Parachute Creek Member (shown only on Battlement Mesa)

Natural Gas:

- approximate outline of natural gas field

Nonmetallics

Igneous rocks:

bs	basalt
db	diabase
gd	granodiorite
mzq	quartz monzonite
pgz	pegmatite, zoned

Sedimentary rocks:

cl	claystone, shale
	evaporites--
gy	gypsum
ha	halite
ls	limestone
	gem stones--
qag	agate
qam	amethyst
qch	chalcedony
qop	opal
	sand and gravel--

F1 — landform; resource classification

Landforms

F	flood-plain deposits
V	valley-fill deposits
T	terrace deposits
A	alluvial fan
U	upland deposits
G	glacial deposits
E	wind-blown sand

Resource Classification

Coarse aggregate (at least 30% retained on #4 screen, visual estimation):

1	gravel--relatively clean and sound
2	gravel--significant fines, decomposed or weak rock, and/or calcium carbonate

Fine aggregate (more than 70% passing #4 screen, 60% retained on #200 screen, visual estimation):

3	sand

Unevaluated resource:

4	probable sand/gravel resource

EXPLORATION, MINING

Metallics

- ✕ prospect
- adit
- tunnel
- shaft
- surface mine

Nonmetallics

- ✕ prospect
- pit
- pit with excavation boundary
- ⚒ quarry
- underground excavation

Mineral Fuels

Coal:

- ✕ prospect
- adit, accessible
- adit, inaccessible
- surface mine, inactive
- surface mine, abandoned

Natural Gas and petroleum:

- ○ location or drilling well
- ø suspended location
- dry hole
- dry hole, show of gas
- dry hole, show of oil
- dry hole, show of gas and oil
- ● oil well, producing
- ☼ gas well, producing
- gas well, field discovery
- gas well, abandoned
- gas well, suspended
- SI shut in

American Gilsonite 6"

oil pipeline, with name and pipe diameter

Western Slope 4"

natural gas pipeline, with name, pipe diameter, valve, compressor station, metering station

PROCESSING

- plant
- mill
- smelter
- natural gas processing plant
- refinery
- (un)loading facility

STORAGE, DISPOSAL

- dump, tailings
- stockpile--pit run, raw ore, processed material
- liquid storage, surface
- gas storage, underground
- radioactive material (mill tailings)

POWER GENERATION

Redlands 14 (h) electrical generating plant, with name, megawatt capacity, and type:

(h)	hydroelectric
(m)	natural gas
(c)	coal

- △ electrical substation
- 115 kv power transmission line; voltage capacity in kilovolts (kv)

GEOLOGIC STRUCTURE

BOOK CLIFFS
axis and name of monocline; arrows point in direction of dip

SAGERS WASH
axis and name of syncline

HUNTER CANYON
axis, name, and plunge of anticline

normal fault; bar on downthrown side; dashed where approximate or inferred, dotted where concealed

subsurface division between intrusive salt cells in Sinbad Valley

DA
distinct alignment (determined from aerial photographs); usually indicates fracturing or faulting

ABBREVIATIONS

(ab) ⚒ ss (da)

mine or processing symbol — lithology or material mined — operating status — known or inferred use of mined or processed material

Commodities

ba	barite
C	coal
cg	conglomerate
cl	clay
clb	bentonite
g	*gravel
gi	gilsonite
gr	granite
gü	grüs
K	potash
mim	muscovite
ml	marlstone
ov	*overburden
q	quartz
ru	rubble, talus, colluvium
rx	*bedrock
s	sand
ss	sandstone

*used only in well logs

Processed Material and Uses

(ah)	alcohol
(asm)	asphaltic mix
(asp)	asphaltic products
(bo)	unspecified borrow material
(CO_2)	carbon dioxide
(cc)	concrete (ready-mix)
(ccp)	concrete products
(clC)	ceramic clay products
(clI)	industrial clay products
(clS)	structural clay products
(da)	architectural dimension stone
(dr)	irregular dimension stone
(fa)	fly ash
(gh)	gasahol
(in)	insulation materials
(rr)	riprap

Operating Status

Nonoperable
- (np) proposed
- (nc) under construction

Operable
- (oa) active
- (oi) inactive

Abandoned
- (ab) existing
- (ar) naturally revegetated
- (ad) dismantled; site
- (ac) converted

Reclaimed
- (rw) wet (graded, partially backfilled)
  - (rws) water supply, storage
  - (rwr) recreation, open space
  - (rww) wildlife
  - (rwe) recreation and wildlife
- (rd) dry (graded, partially backfilled, bermed)
  - (rda) agriculture
  - (rdr) recreation, open space
  - (rds) storage
  - (rdd) development
- (rlo) landfill, operating

TRANSPORTATION

- hard surface, heavy-duty road
- hard surface, medium-duty road
- improved light-duty road
- unimproved dirt road
- trail
- railroad, single track
- railroad, multiple track
- railroad, abandoned grade or line

MINERAL RESOURCES OF MESA COUNTY

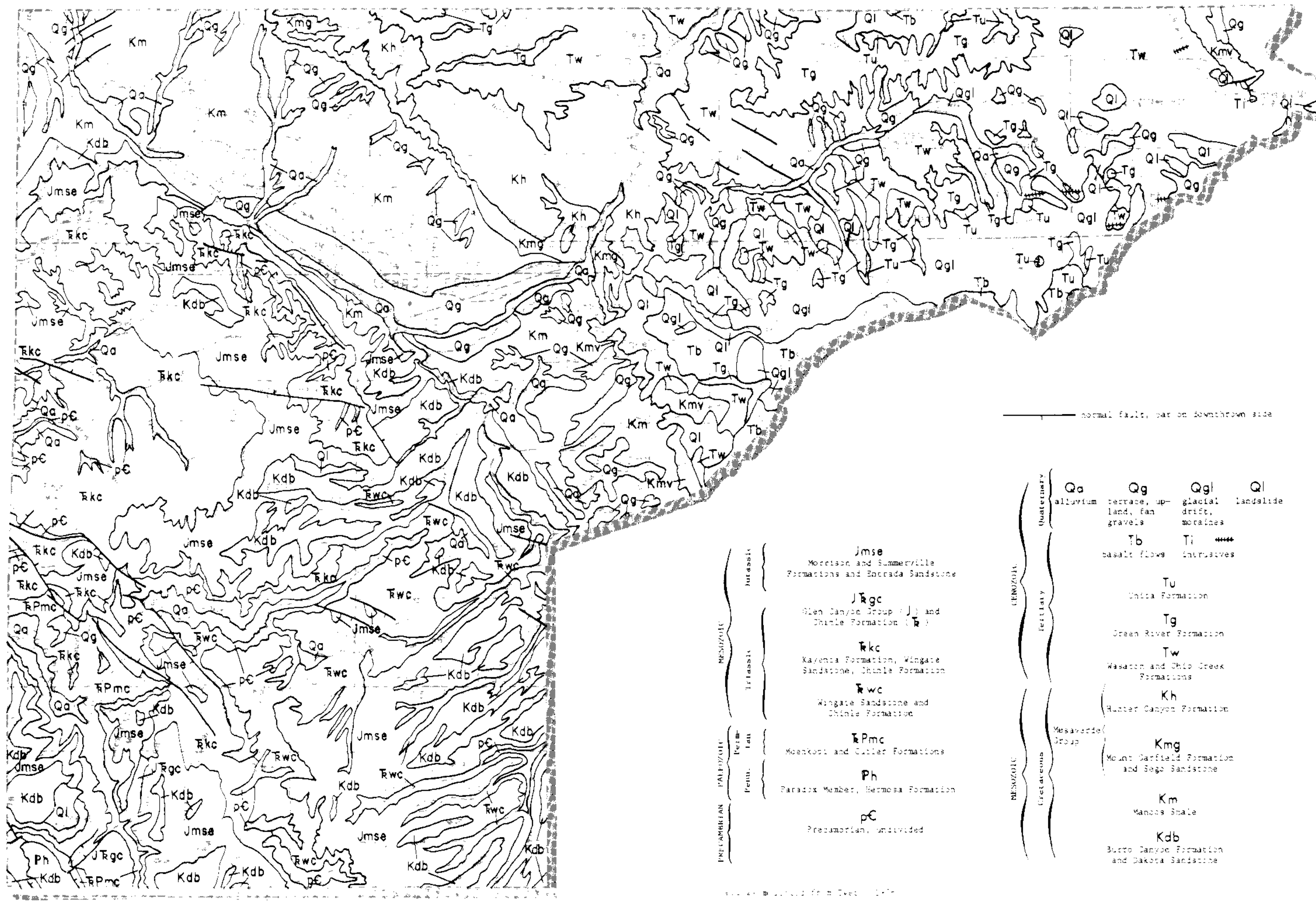
BY STEPHEN D. SCHWOCHOW

1978

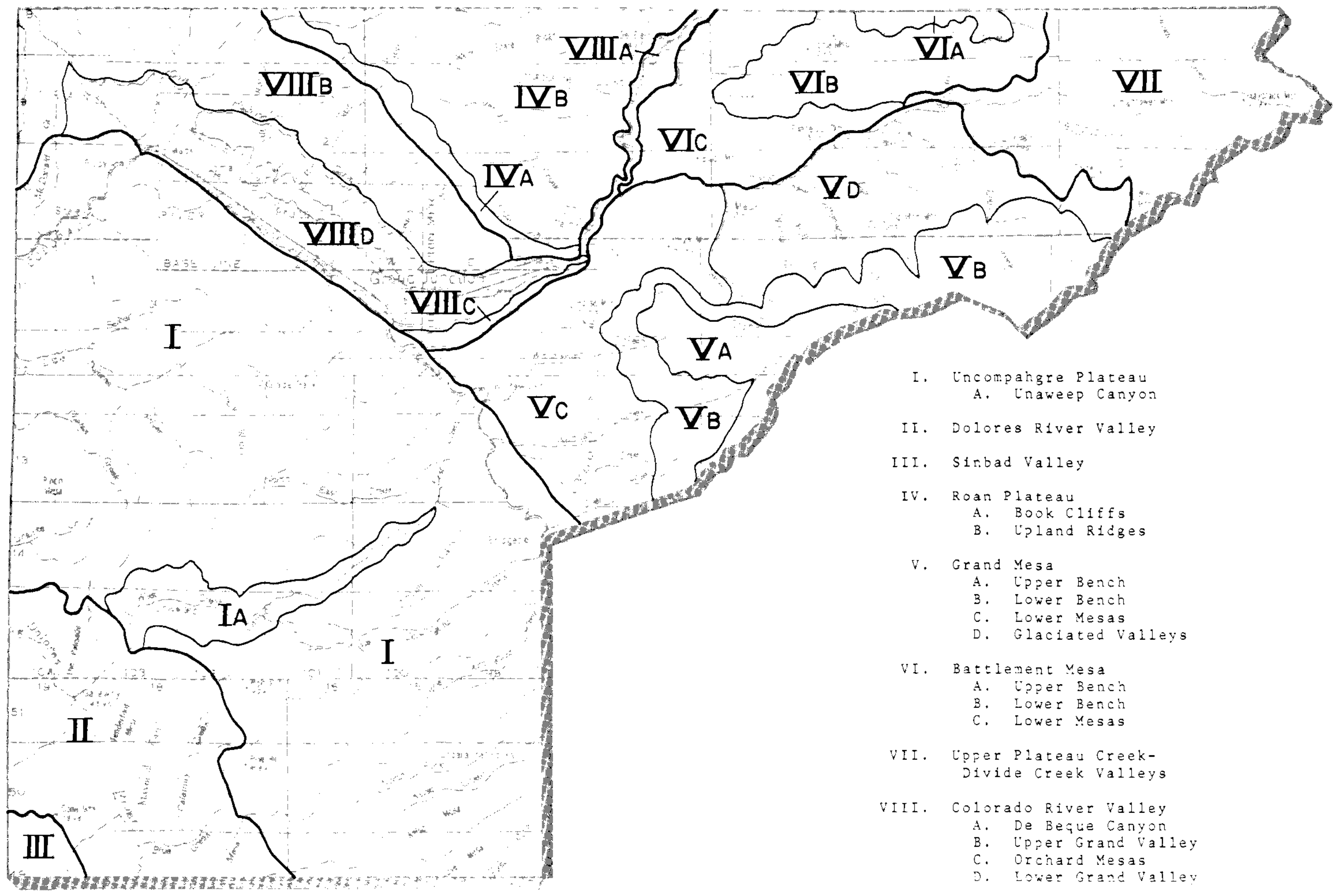
ROBERT H. GAST
DIANA ADAMS
Executive Drafting Services

DEPARTMENT OF NATURAL RESOURCES
COLORADO GEOLOGICAL SURVEY
JOHN W. ROLD, DIRECTOR

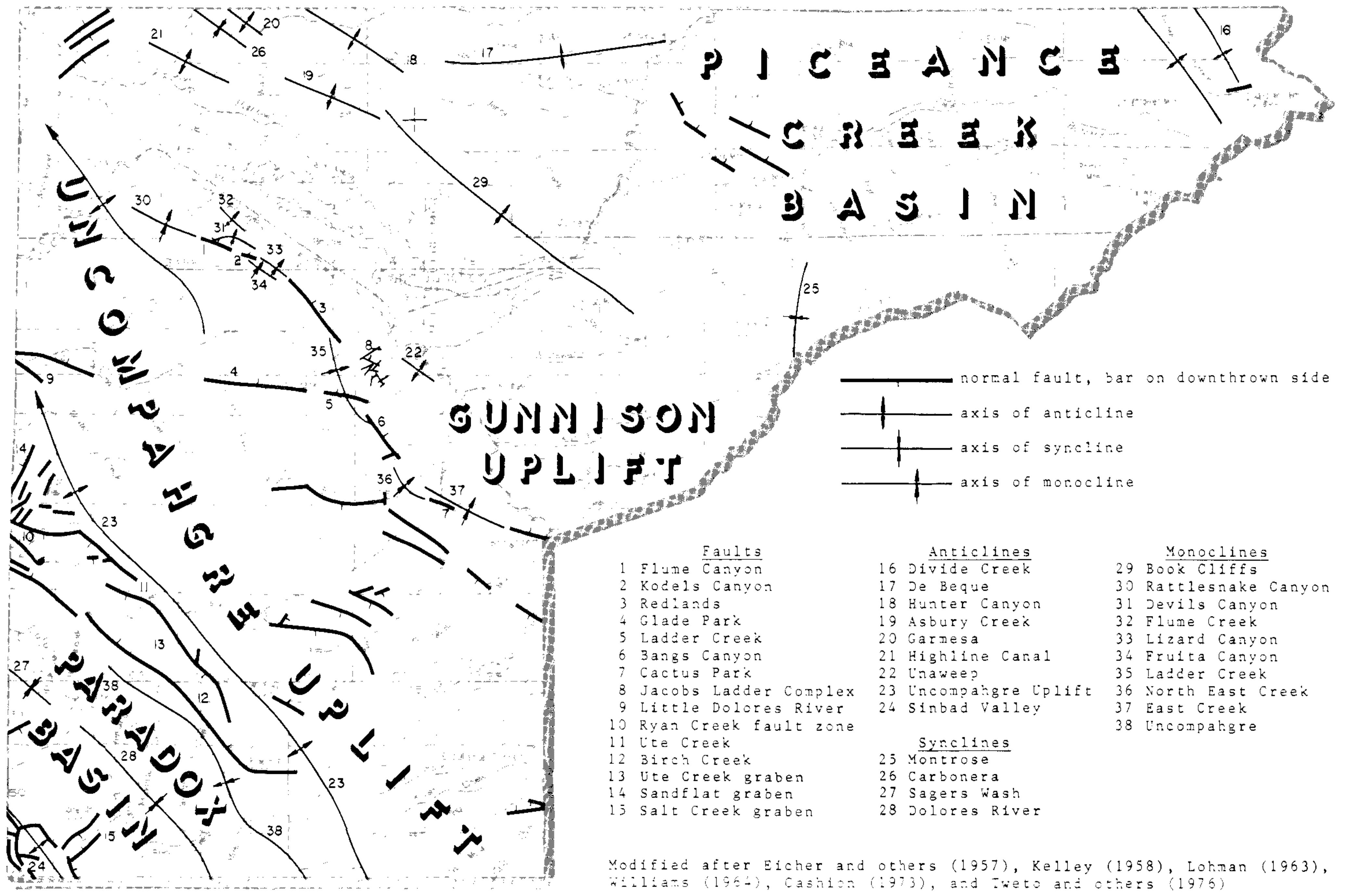
Resource Series 2
Plate 1



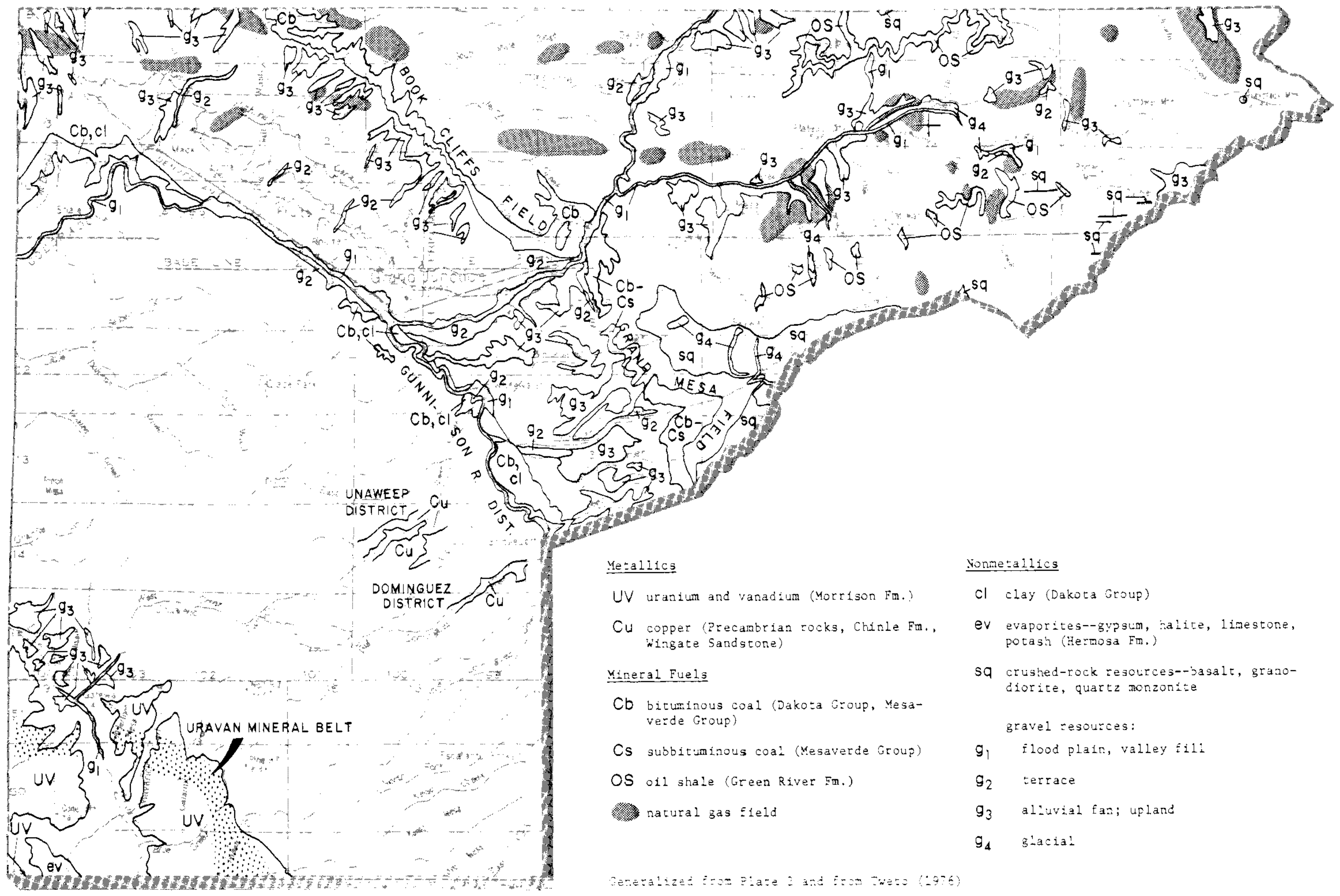
a. GEOLOGY



b. PHYSIOGRAPHY



c. STRUCTURE



d. ECONOMIC GEOLOGY

MESA COUNTY—THE GEOLOGICAL SETTING

BY STEPHEN D. SCHWOCHOW

1978

SCALE 1:500,000

5 0 5 10 15 20 MILES

5 0 5 10 15 20 25 KILOMETERS

Base map from U.S. Geological Survey, 1969 (rev. 1972)

Design and drafting by S. D. Schwochow