GROUND-WATER POTENTIAL OF THE LEADVILLE LIMESTONE ON THE WHITE RIVER UPLIFT IN GARFIELD AND RIO BLANCO COUNTIES, COLORADO

By Ralph W. Teller and Frank A. Welder

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METRIC CONVERSION

The inch-pound units used in this report may be converted to International System of Units (SI) by the following conversion factors:

Multiply	*By*	*To obtain*
acre	0.4047	hectare
acre-foot	1,233	cubic meter
cubic foot per second	0.02832	cubic meter per second
foot	0.3048	meter
gallon per minute	6.309×10^{-5}	cubic meter per second
inch	25.40	millimeter
mile	1.609	kilometer
square mile	2.590	square kilometer

National Geodetic Vertical Datum of 1929: A geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called mean sea level.

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ABSTRACT

The Leadville Limestone of Mississippian age crops out in a large area in the western part of the White River Uplift in northwestern Colorado. Preliminary studies indicate that the Leadville is extensively fractured, cavernous, and water bearing and is recharged by precipitation, snowmelt, and streamflow. Water from 100 springs flowing from the Leadville is chemically suitable for most uses; specific conductance ranges from 45 to 1,950 micromhos per centimeter at 25° Celsius. The water is of the calcium carbonate type and is successfully used in the raising of game fish. On the flanks of the White River Uplift, where the Leadville dips into the subsurface, the formation probably is permeable and water bearing. Exploratory drilling and testing are needed to determine more exactly the water-bearing potential of the Leadville Limestone and its potential as a water supply for expanding energy development in the area.

INTRODUCTION

Expanded development of energy resources in northwestern Colorado is creating additional demands on the limited surface-water resources of the region. Along with the water demands for energy development is the threat of ecological deterioration as the natural flow of streams is decreased. Traditional surface-water impoundment for streamflow regulation is being challenged from both environmental and economic standpoints. Before irreversible management decisions are made to undertake the costly development of surface-water supplies, the potential of the ground-water resources needs to be defined and considered.

During the 1960's investigations by the U.S. Geological Survey determined that large quantities of ground water, perhaps 25 million acre-feet or more, occur above, within, and below oil-shale deposits in the Green River and Uinta Formations of Eocene age in the Piceance Basin of northwestern Colorado. Recent studies indicate that another major source of ground water may be the Leadville Limestone of Mississippian age. The Leadville is exposed throughout a large area on the White River Uplift and is directly recharged by precipitation, snowmelt, and streamflow.

Hydrogeologic evidence indicates that the Leadville Limestone is a major aquifer and that large quantities of ground water have entered and are moving through the formation into the subsurface toward the south, west, and northwest away from the White River Uplift. The Leadville Limestone on the flanks of the White River Uplift at relatively shallow depths of about 1,000 feet may constitute a major underground reservoir (aquifer) containing water that is chemically suitable for most uses. The drilling of several exploratory test holes could confirm this hypothesis.

Purpose and Scope

This report describes a preliminary reconnaissance of the water-bearing properties of the Mississippian Leadville Limestone in the western part of the White River Uplift (synonymous with the White River Plateau). The purpose of this preliminary investigation is to determine areas of the Leadville Limestone suitable for exploratory drilling and testing at relatively shallow depths to confirm the quantity and quality of water in storage.

Location and Size of Study Area

The study area, approximately 420 square miles, is in Rio Blanco and Garfield Counties (fig. 1) in northwestern Colorado on the west flank of the White River Plateau, which is the physiographic expression of the White River Uplift. The Plateau is bounded by the White River on the north, the volcanic Flat Tops on the east, and the Grand Hogback monocline on the south and west. The southern part of the study area is drained by tributaries of the Colorado River; the northern part is drained by the White River and its tributaries. Land-surface altitudes range from about 6,500 feet in the southern valleys to more than 10,000 feet on Burro Mountain.

Previous Investigations

Some of the most detailed geologic work on the White River Uplift was done by Bass and Northrup (1963). The study by Mallory and others (1966) of the geology of the Flat Tops Primitive Area was followed by Mallory's (1971) detailed work on the Eagle Valley Evaporite of Pennsylvanian age.

GEOLOGY

Stratigraphy

Rocks in the study area range in age from Precambrian through Quaternary (see table 1). This investigation is concerned primarily with the Leadville Limestone of Mississippian age.

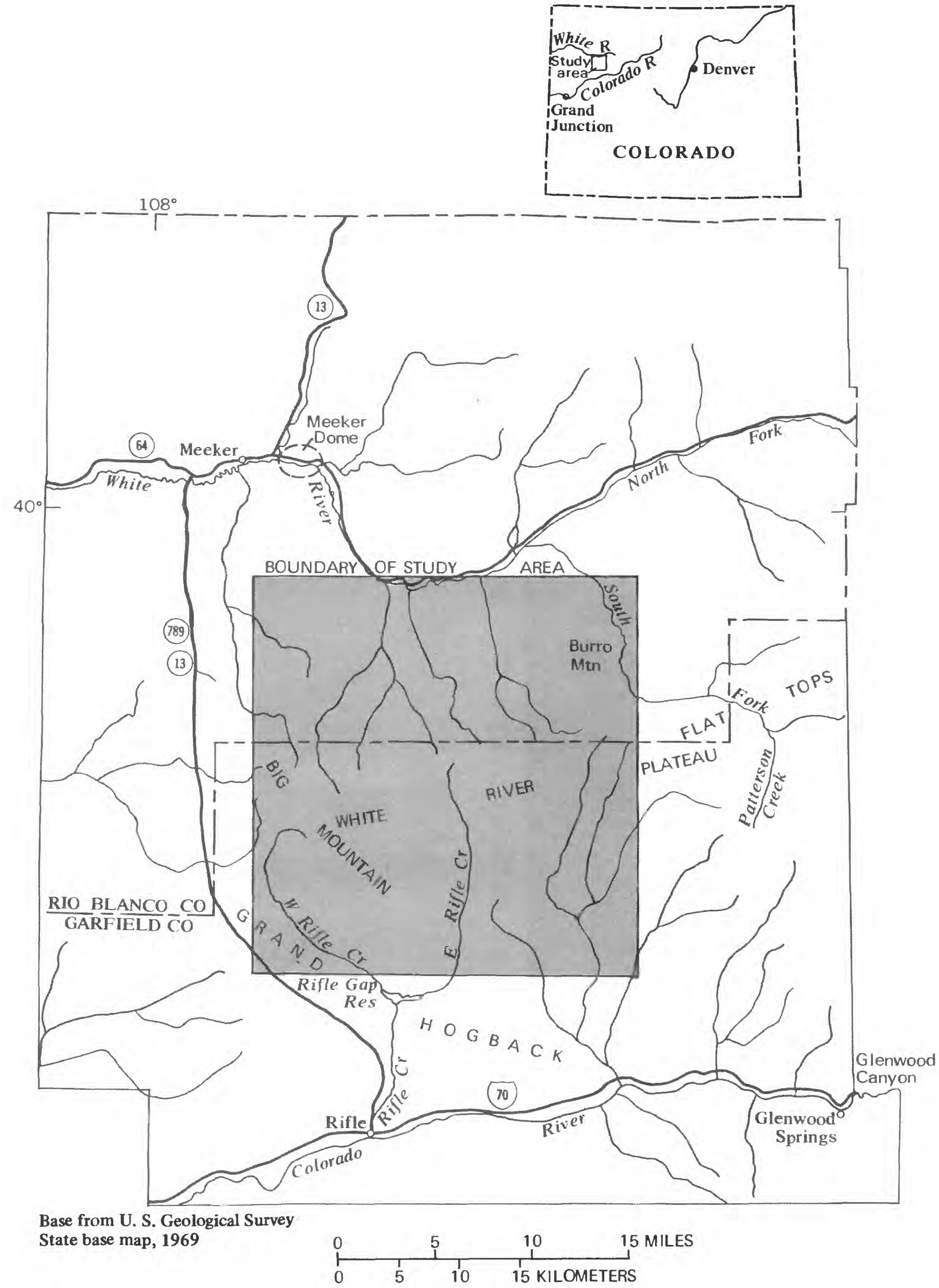


Figure 1.--Location of study area.

Table 1.--*Generalized geohydrologic section of the White River Uplift*

Erathem	System	Series	Stratigraphic unit	Physical characteristics	Hydrologic characteristics
Cenozoic	Quaternary	Holocene and Pleistocene	Glacial, landslide, and alluvial deposits	Gravel, sand, loess, and clay, undifferentiated; travertine deposits.	Some shallow wells yield less than 50 gallons per minute.
	?	?			
	Tertiary(?)	Pliocene(?) and Miocene(?)	Basalt flows and intrusives	Dense resistant alkali basalt in lava flows, interbedded tuffs and volcanic conglomerates.	Shallow fracture systems draining in springs and seeps.
Mesozoic	Cretaceous	Upper	Mesa Verde Group	Sandstones, shale, and coal.	No data collected.
			Mancos Shale	Sandstone and gray to dark gray marine shale.	No data collected.
		- - - ? - - - Lower	Dakota Sandstone	Sandstone or quartzite; some interbedded dark shale and shaley sandstone.	No data collected.
	Jurassic	Upper	Morrison Formation	Variegated shale and mudstone, sandstone and localized beds of gray and gray-green limestone.	No data collected.
		Middle	Entrada Sandstone	Sandstone, mudstone, and siltstone.	No data collected.
	Triassic	Upper	Chinle Formation		
		Middle and Lower	Moenkopi Formation		
Paleozoic	Permian and Pennsylvanian		Weber Sandstone	Sandstone, mudstone, and conglomerates.	No data collected.
			Maroon Formation		
	?				
	Pennsylvanian	Middle	Eagle Valley Evaporite	Gypsum, anhydrite, interbedded siltstone, and some dolomite.	Evaporites would degrade quality of water in aquifer adjacent to this formation.
			Belden Formation	Limestone, sandstone, and orange to purple or dark gray shale.	Some springs probably at contact between Pennsylvanian strata and karst top of Leadville Limestone.
		Lower	Molas Formation		
	Mississippian	Lower	Leadville Limestone	Limestone, massive, oolitic, intermittently fossiliferous, finely to coarsely crystalline, gray to light-gray; forms the most conspicuous light-gray cliff in the area; and dolomite, interbedded, gray to dark-gray, finely crystalline to dense; contains a few nodules and lenses of gray and dark-gray chert commonly 2 to 4 inches thick and 4 to 18 inches long; generally massive but some beds as much as 4 feet thick are slightly argillaceous and weather with a cleaty vertical fracture.	Large springs issue from the lower one-half of the formation where extensive fracture and solution cavities have formed. Evidence of the fractured and cavernous nature of this part of the formation can be seen in Glenwood Canyon and the Spring Cave area of the South Fork White River upstream from South Fork Campground. Numerous springs discharge along East Rifle Creek upstream from the fish hatchery. Large travertine deposits exist downstream from the hatchery.
	Devonian	Upper	Chaffee Formation	Limestone conglomerate, sandy dolomite, Sandstone, and quartzite.	No data collected.
	Ordovician	Lower	Manitou Formation		
	Cambrian	Upper	Dotsero Formation and Sawatch Sandstone		Some large springs reported on White River Plateau.
Precambrian			Granitic rocks, undivided	Schist, granite, greenstone, pegmatite, and gneiss.	No data collected.

Precambrian Rocks

Precambrian gneiss and schist extensively intruded by granite are exposed in the canyon walls of the South Fork White River and some of its tributaries, such as Patterson Creek (fig. 2), and in Glenwood Canyon of the Colorado River east of Glenwood Springs.

Paleozoic Rocks

Rocks of Paleozoic age (near Glenwood Springs) are described by Bass and Northrup (1963). The oldest are Late Cambrian and consist of the Sawatch Sandstone and Dotsero Formation. The Sawatch is about 500 feet of sandstone and quartzite, and the Dotsero is about 100 feet of sandy glauconitic dolomite. The Ordovician Manitou Formation is a limestone conglomerate about 100 feet thick which is overlain by 50 feet of gray dolomite. Unconformably overlying the Manitou is the Chaffee Formation of Devonian age, which is about 246 feet thick. The lower 94 feet is mostly quartzite and interbedded shale; the upper 152 feet is interbedded limestone and dolomite (pl. 1).

According to Bass and Northrup (1963), the overlying Leadville Limestone "...whose thickness ranges from 175 to 225 feet, consists chiefly of limestone, although the lower one-third of the formation contains interbedded dolomite and limestone, many beds of which contain chert." A thickness map by DeVoto (1980, p. 60) indicates that the Mississippian rocks thicken appreciably westward, attaining a thickness of 500 feet in the Piceance basin and 700 feet at the Utah-Colorado State Line.

The purplish-red clay resting on the weathered surface of the Leadville Limestone is the Molas Formation, which is mainly residual material derived from solution of the underlying limestone. It is about 9 feet thick near Glenwood Springs. The Molas is considered to be the lowermost unit of the Pennsylvanian and is overlain, in ascending order, by (a) the Pennsylvanian Belden Formation, about 900 feet of dark gray limestone and shale; (b) the Pennsylvanian Eagle Valley Evaporite (fig. 3), a sequence of interbedded gypsum and shale about 1,500 feet thick; and (c) the Pennsylvanian and Permian Maroon Formation, a sequence of red sandstone and shale more than 3,000 feet thick. The Eagle Valley Evaporite and the Maroon Formation, though present in a well near Meeker, thin and disappear north and west of that city. The Weber Sandstone is not found inside the project area, but it does approach the uplift on the southern flanks.

Mesozoic Rocks

Mesozoic rocks are exposed on the southwest, west, and northwest margins of the White River Uplift, but at present (1983) an investigation of these rocks is not considered essential to this study. The Cretaceous Mesaverde Group consists of sandstone and intercalated thin shale beds perhaps as thick as 3,000 feet. The Mesaverde forms the topographically prominent Grand Hogback where the strata dip steeply westward into the Piceance basin (fig. 2).

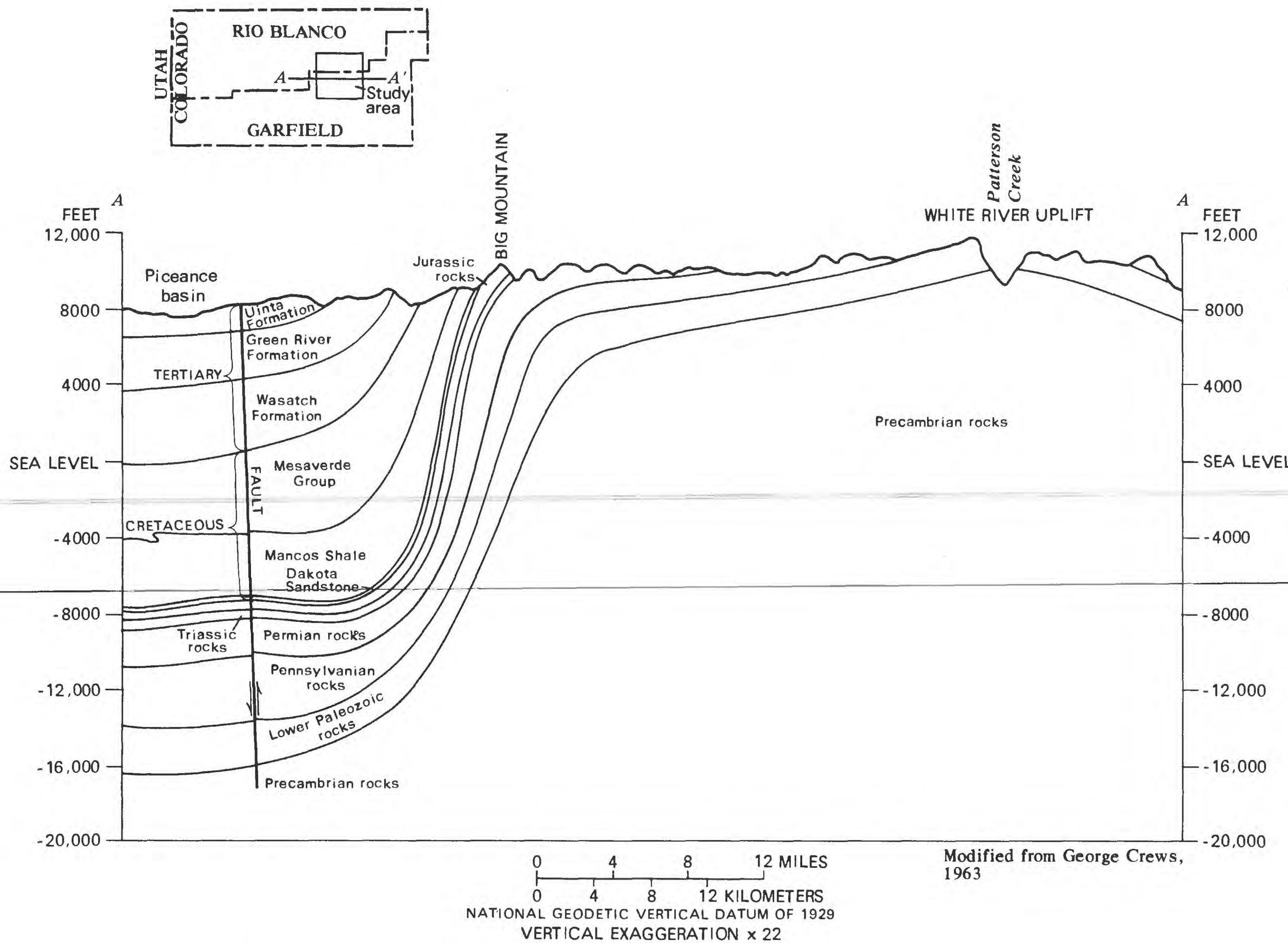


Figure 2.-- Generalized east-west geologic section.

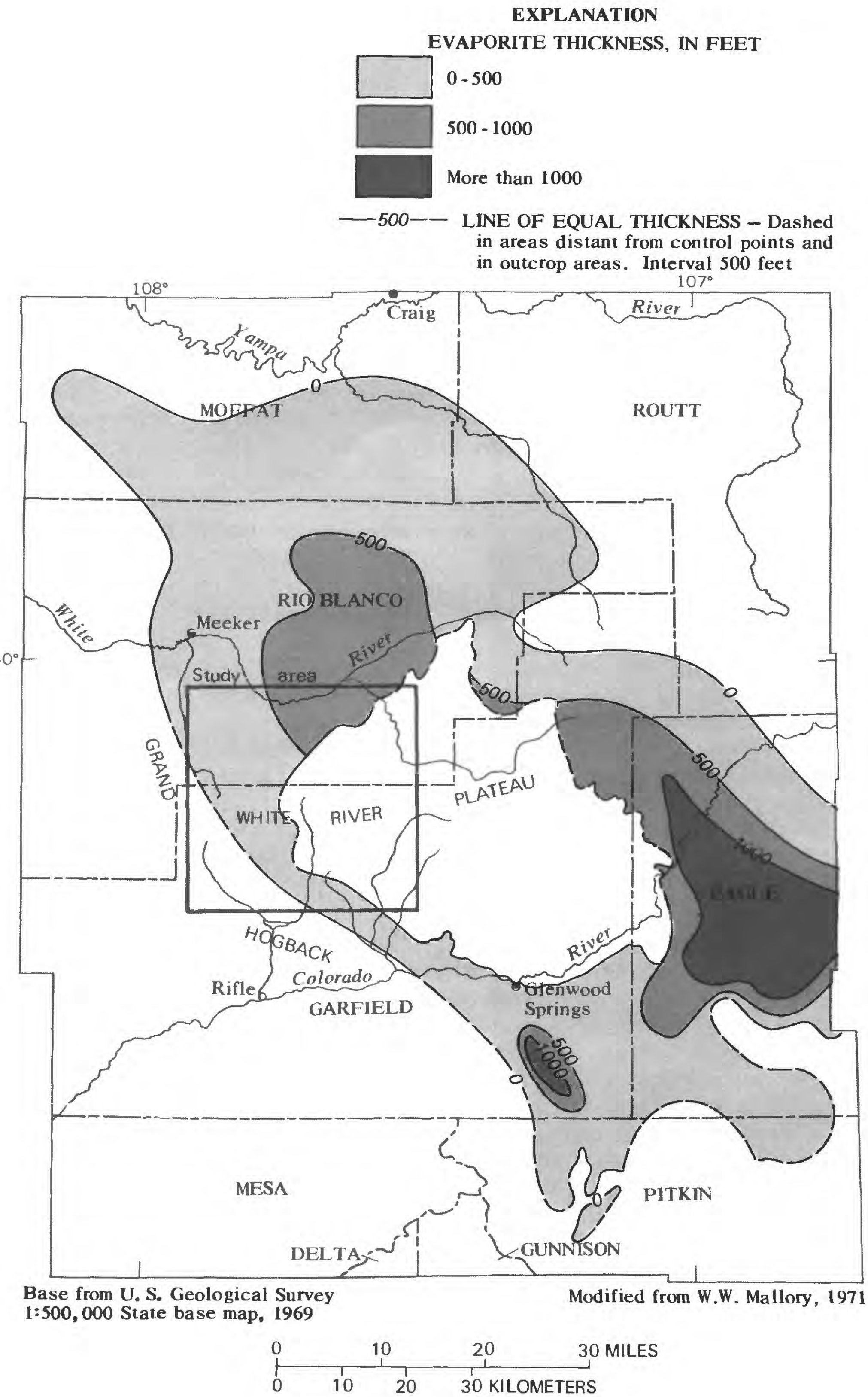


Figure 3.--Extent and thickness of the Eagle Valley Evaporite in northwestern Colorado.

Cenozoic Rocks

Cenozoic rocks are the youngest rocks in the study area and consist mainly of Quaternary alluvium along stream courses, glacial deposits at higher altitudes, and the travertine deposits west of Glenwood Springs. Basalt flows occur extensively north of the South Fork White River, and a few outcrops of this type have been mapped between the South Fork and the Colorado River.

Structure

The White River Uplift is a broad dome about 40 miles long and 20 miles wide with a maximum altitude of more than 12,000 feet above sea level. Bass and Northrup (1963) report numerous faults on the uplift. Outcrops of bedrock are extensively fractured. The Leadville Limestone is relatively flat lying in the central part of the study area but dips steeply away from the uplift on the southern, western, and northern sides of the area, as shown on the structure-contour map (fig. 4). A broad syncline having a north-dipping axis forms a prominent structural reentrant on the north side of the uplift.

HYDROGEOLOGIC CHARACTERISTICS OF THE LEADVILLE LIMESTONE

The importance of an aquifer as a source of ground water is largely related to its ability to store water (porosity) and to transmit water (permeability). Although neither of these characteristics has been determined by testing the aquifer in the study area, some information can be obtained from studies of similar geologic formations in other areas. Porosity and permeability in conjunction with the locations and quantities of recharge and discharge determine the flow pattern in the aquifer.

Porosity

The quantity of water that a geologic formation can store is directly related to the porosity of the rock. Primary porosity consists of the original interstices or void spaces created when a rock unit is formed. Consolidated rocks, like Paleozoic limestone or dolomite, commonly have little interparticle or intercrystalline porosity, but fractures and faults may provide appreciable secondary porosity. Ground water dissolves carbonate rocks, such as limestone or dolomite, along fractures, faults, and bedding planes, greatly increasing the porosity. Because fracture and solution cavities vary considerably in size and development within short distances, it generally is difficult to calculate precise values of the porosity of rocks in a given geographic area.

If a reasonable value for porosity and the extent of the Leadville Limestone are assumed, the volume of water stored in the Leadville can be estimated. On the western flank of the White River Uplift the Leadville Limestone dips westward beneath the ground surface. For this region it is assumed that:

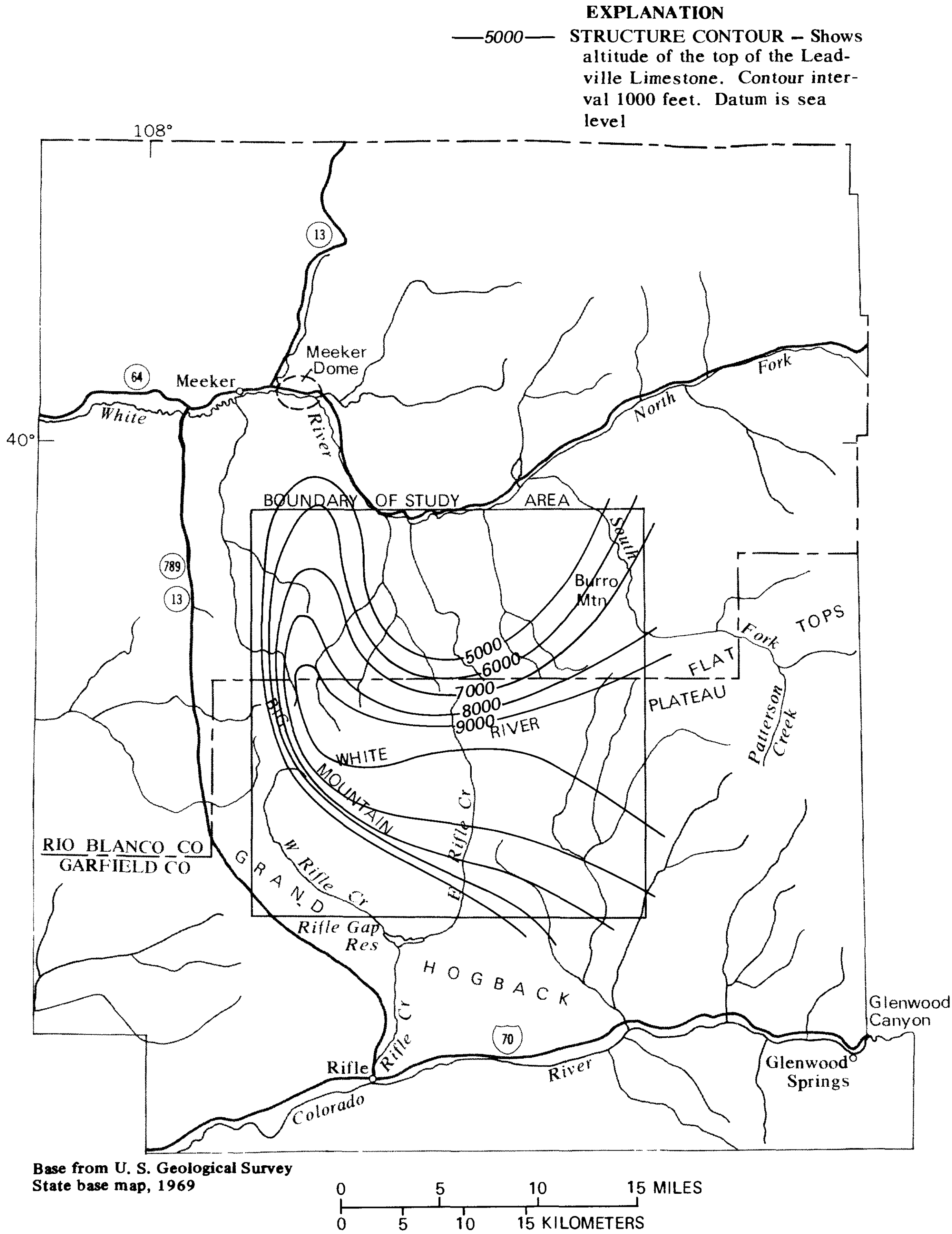


Figure 4.-- Structure contours on top of the Leadville Limestone.

(1) The formation is saturated and under artesian pressure; (2) the water is economically recoverable where drilling depth to the top of the formation is 1,000 feet or less; (3) the formation is 300 feet thick, 1 mile wide (from outcrop to depth of 1,000 feet), and 20 miles long; and (4) the porosity is 10 percent. Based on these values, the calculated quantity of ground water in storage is 384,000 acre-feet. If these values are extended to an area approximately the size of the western one-half of the Uplift, the estimated storage could exceed 10 million acre-feet.

Permeability

The permeability of the Leadville Limestone is a consequence of the locally interconnected fracture, faults, and solution channels that allow water to move through parts of the formation. Evidence that very large quantities of water have moved, and are still moving, through the Leadville Limestone is provided by the prevalence of caves, karst topography, residual soil, travertine, solution-widened fractures, springs, and seeps. The presence of these features indicate that the permeability and porosity of the Leadville may be large.

Most caves and other solution openings in the study area are developed in nearly pure limestone which, when fractured, permits water to enter, move through, and discharge from the formation; this water contains large quantities of dissolved solids. Left behind are equally large voids that increase permeability and relatively small quantities of insoluble residue such as clay. The White River Plateau contains 62 known caves--more than any other area of comparable size in Colorado (Parris, 1973). All the caves are thought to be formed within the Leadville Limestone. Some of these caves have been explored for miles. Large pools of flowing water have been reported in Spring Cave on the South Fork White River, the third largest cave in the State.

Karst topography forms on a limestone surface where the solution action of ground water dissolves parts of the bedrock, creating surface depressions and sinks. The development of karst topography increases the permeability of limestone formations. Wherever the top of the Leadville is exposed in the study area, the karst topography is conspicuous. It is especially well developed in the canyon of the Colorado River (Glenwood Canyon) on the east edge of the city of Glenwood Springs. The karst surface has a topographic relief of several tens of feet and in many places is covered with a residual soil or regolith. This residual soil is so widespread in western Colorado that it has been given the name Molas Formation.

According to Tweto (1949), after deposition of the Leadville Limestone during Early Mississippian time, western Colorado was exposed to an interval of subaerial weathering sufficient to develop a mature topography, or karst, in many areas. Mallory (1960) adds that "Developed by this weathering during the erosion interval was the red Molas Formation, a regolithic to marine deposit widely distributed in western Colorado." Bass and Northrup (1963) describe the regolith near Glenwood Springs, saying that "Lying on a karst surface of the Leadville Limestone is a sequence of dull purplish-red clay that contains smooth nodules and boulders of chert and ranges in thickness from 1 to 25 feet. The sequence constitutes the Molas Formation." In a well drilled on the Meeker Dome (3 miles east of Meeker), the Molas Formation was found on top of the Leadville Formation at depths ranging from 6,050 to 6,080 feet. Turnbow (1961) and Merrill and Winar (1961) confirm that the Molas Formation is present throughout much of southwestern Colorado. Landon and Thurman (1955) state that the Molas "...is generally less than 50 feet in thickness, though as much as 200 feet has been reported..." in northwestern Colorado.

The presence of enormous deposits of travertine is additional evidence indicating that considerable porosity and permeability have been developed in the Leadville Limestone. Travertine is composed mainly of calcium carbonate deposited by the evaporation of spring or stream water. Water moving through the Leadville dissolves the calcium carbonate, discharges from the formation, and precipitates the calcium carbonate in stream beds or near springs. Bass and Northrup (1963) observe that "Travertine suitable for building purposes is present in an area of 80 acres or more about 1 mile northwest of Glenwood Springs. The thickness of the travertine ranges from 3 to 40 feet." The source of the calcium carbonate is the Leadville Limestone immediately north of the travertine deposit.

Equally impressive are the travertine deposits at Rifle Falls, where the water of East Rifle Creek pours over massive deposits as thick as 80 feet and as wide as 900 feet that extend upstream more than a mile to the Rifle Falls Fish Hatchery. The hatchery is located immediately downstream from an outcrop of the Leadville Limestone. Springs from the Leadville provide the base flow of the creek as well as calcium for the fish.

Geologic history indicates the processes by which solution-widened fractures developed the significant permeability of the Leadville Limestone. By the beginning of the Pennsylvanian Period, some 330 million years ago, the Leadville Limestone had already been fractured and exposed to ground-water flow and solution for a long time--long enough to develop a mature karstic drainage system including caverns, sinkholes, and residual soil. Later deformation of the region during the Cenozoic Era (beginning 63 million years ago) formed the White River Uplift and created additional faults and fractures which contributed to further development of permeability. Data in a report by Rinkenberger & Associates, Inc. (1981), indicate dominant fracture trends in nearly east-west, north-northeast to south-southwest, and northwest-southeast directions. Bass and Northrup (1963) in their investigation of the White River Uplift north of Glenwood Springs, note that "All brittle beds in the area are jointed. Commonly two sets of joints are present and their trends are at approximate right angles to each other. Joints are well developed and exposed on many parts of the broad plateau part of the area where broad areas of bare rock exposures are common." Both on the ground and in flights over the subject area, one can observe numerous fractures wherever bedrock is exposed.

Springs and seeps are prevalent in the study area. The results of an inventory of the springs and a seepage run along East Rifle Creek are presented in the section on "Springs."

Flow Pattern

Where the geologic formations in the study area are fractured and exposed, ground-water recharge by infiltration of rain, snowmelt, and streamflow takes place. According to Hoeger (1969) the White River Uplift is a major area of recharge. Using potentiometric maps derived from drill-stem-test data, Hoeger concluded that water in the Weber, Entrada, and Dakota Sandstones moves westward and northwestward from the area of recharge toward an area of presumed discharge near the Utah-Colorado State line. The discharge area is characterized by many springs. The flow pattern in the Leadville Limestone probably parallels that of the three formations studied by Hoeger. If so, the springs in the discharge area may derive their water from the Leadville.

SPRINGS

During the 1981 field season, 100 springs were inventoried and onsite measurements made (table 2). Measured discharges of the springs flowing from the Leadville Limestone ranged from 0.37 to 400 gallons per minute. In addition to spring-discharge measurements, a seepage run was made August 18, on East Rifle Creek downstream from the confluence with Huffman Gulch, which is 2.5 miles upstream from the Rifle Falls Fish Hatchery, to the base of Rifle Falls upstream from the diversion point for the Grass Valley Canal (pl. 2). Discharge from the Leadville Limestone to East Rifle Creek along the reach measured 28 cubic feet per second.

Water Quality

Water-quality samples were collected to determine the type of water in the Leadville Limestone and its suitability for industrial and domestic use. Representative analyses of water from seven springs which were analyzed at the U.S. Geological Survey Denver Central Laboratory are presented in table 3. Onsite measurements of specific conductance ranged from 45 to 1,950 micromhos per centimeter at 25° Celsius and temperature ranged from 3.5° to 28° Celsius (table 2). Laboratory analyses of samples from selected springs indicate the water is of the calcium carbonate type. Values for all major constituents analyzed generally were within accepted limits for potable water supplies (table 3). The satisfactory quality of the water is confirmed by the continued use of several springs in the Leadville for domestic purposes (campgrounds, cow camps, and summer cabins) and by the extensive use of water from the Leadville for trout-rearing ponds and domestic supply at the Rifle Falls Fish Hatchery.

Table 2.--*Springs inventoried in the study area*

EXPLANATION

SPRING LOCATION: See text for description of spring-location system

AQUIFER: ML=Mississippian Leadville Limestone
TPMU=Tertiary Pliocene-Miocene, undifferentiated

ALTITUDE: Feet above sea level

YIELD: Gallons per minute

COND: Specific conductance in micromhos per centimeter at 25° Celsius

TEMP: Temperature, in degree Celsius

****: No information

Table 2.--*Springs inventoried in the study area*--Continued

GARFIELD COUNTY

WELL LOCATION	SPRING NAME	AQUIFER	ALTITUDE	YIELD	pH	COND	TEMP	REMARKS
SC00209019BAA1	FOREST LINE	ML	8015.00	3.30	7.5	490	7.0	
SC00209019DBB1	UPPER S FORK	ML	8000.00	127.60	7.3	178	7.0	
SC00309007ABA1	MEADOW CK LK	ML	9590.00	101.50	7.9	310	7.0	
SC00309110BDA1	CLARK CBN 1	ML	9430.00	53.80	7.5	242	4.0	
SC00309110CAA1	CLARK CBN 2	ML	9430.00	9.40	7.4	302	4.0	
SC00309110CAD1	CLARK RDG 6	ML	9422.00	265.70	7.5	325	3.5	
SC00309121ACB1	CLARK RDG 2B	ML	9160.00	3.20	7.5	380	5.0	
SC00309121BAD1	CLARK RDG 2A	ML	9160.00	7.60	7.3	460	5.0	
SC00309121CAB1	CLARK RDG 3	ML	9180.00	7.60	7.4	342	4.0	
SC00309127CDB1	COULTER LAKE	ML	8360.00	228.90	7.6	375	7.0	
SC00309128BAC1	CLARK RDG 1	ML	9110.00	11.20	7.6	300	14.0	
SC00309130CDC1	HUFFMAN	ML	8885.00	13.42	7.2	352	5.0	
SC00309131AAC1	CLINETOP A	ML	8720.00	****	7.4	324	21.0	SPRING COW CAMP
SC00309131CBD1	CLINETOP B	ML	8580.00	1.60	7.4	452	6.0	SPRING COW CAMP
SC00309202CAC1	TWIN B	ML	9185.00	****	9.1	72	23.0	
SC00309202CDB1	TWIN A	ML	9180.00	****	9.1	62	23.0	
SC00309203DDD1	UPPER GV	ML	9105.00	23.86	7.5	320	6.0	
SC00309208BDC1	DUTCH GL	ML	9155.00	55.94	6.9	362	6.0	
SC00309208DCD1	HOOVER GL	ML	9040.00	0.95	7.8	383	11.0	
SC00309210ABC1	LOWER GV	ML	8990.00	3.16	7.6	382	7.0	
SC00309211CAD1	IRISH	ML	9140.00	9.32	7.8	358	8.0	
SC00309212ACD1	MUD	ML	9200.00	****	7.4	****	6.0	BROKEN ARROW RANCH
SC00309219ADC1	BUTLER 1	ML	8960.00	1.70	10.0	420	6.0	
SC00309222ABB1	GARDEN GL 1	ML	7870.00	9.50	7.3	1950	8.5	
SC00309222ADB1	CATARACT A	ML	8100.00	40.00	8.1	358	6.0	
SC00309222BAB1	THREE FORKS 5	ML	7900.00	2.19	7.4	700	7.5	
SC00309222BAD1	GARDEN GL 2	ML	7860.00	0.50	7.7	1700	10.5	
SC00309222BBA1	THREE FORKS 1	ML	7950.00	35.30	7.3	358	6.3	
SC00309222BBA2	THREE FORKS 2	ML	7950.00	4.86	7.3	472	7.0	
SC00309222BBA3	THREE FORKS 4	ML	7940.00	6.05	7.2	590	8.0	
SC00309222BBD1	THREE FORKS 3	ML	7940.00	135.00	7.4	469	6.0	
SC00309222BDB1	CATARACT B	ML	8110.00	15.00	7.5	340	6.0	
SC00309223BAA1	STUMP GL 5	ML	8200.00	3.00	7.7	540	7.5	
SC00309223BAA2	STUMP GL 6	ML	8200.00	14.00	7.5	750	6.0	
SC00309223BAA3	STUMP GL 7	ML	8200.00	6.50	7.5	725	6.0	
SC00309223BAA4	STUMP GL 8	ML	8210.00	400.00	7.6	530	6.5	
SC00309223BAC1	STUMP GL 1	ML	8120.00	3.20	7.7	625	8.0	
SC00309223BAC2	STUMP GL 2	ML	8120.00	2.19	7.7	600	8.5	
SC00309223BAC3	STUMP GL 3	ML	8120.00	0.75	7.6	600	9.0	
SC00309223BAD1	STUMP GL 4	ML	8110.00	14.40	7.6	650	6.5	
SC00309226ACC1	LITTLE BOX	ML	7450.00	12.00	7.4	422	6.0	
SC00309227AAD1	THREE FKS CG	ML	7580.00	9.40	7.4	565	6.0	
SC00309228BDC1	ORPHAN	ML	9030.00	0.37	7.9	395	16.0	
SC00309307DBD1	BIG MTN 4	ML	9330.00	****	7.8	178	15.0	
SC00309308DCD1	BIG MTN 2	ML	8810.00	****	7.4	350	12.5	
SC00309317ABB1	BIG MTN 1	ML	8900.00	****	7.6	480	9.5	

Table 2.--*Springs inventoried in the study area*--Continued

GARFIELD COUNTY--CONTINUED

WELL LOCATION	SPRING NAME	AQUIFER	ALTITUDE	YIELD	pH	COND	TEMP	REMARKS
SC00309317ADD1	HOWEY RES	ML	8780.00	11.20	7.8	460	15.0	
SC00309317BAC1	BIG MTN 3	ML	8860.00	27.50	7.6	355	5.0	
SC00309318AAA1	BAR HL 2	ML	9190.00	12.00	7.4	376	7.0	
SC00309318ABA1	BAR HL 1	ML	9230.00	11.20	7.4	360	4.5	
SC00309321DBB1	RED ELEPHANT	ML	8835.00	3.20	7.2	350	13.0	
SC00309323ABC1	BEAR GL 1	ML	9140.00	****	7.3	400	7.0	
SC00309325BAB2	BEAR GL 2	ML	9020.00	4.50	8.8	310	28.0	
SC00309325BAB1	BUTLER 2	ML	9080.00	37.30	7.7	402	5.5	
SC00309325CCB1	SALT GL	ML	9050.00	0.92	7.5	500	7.0	
SC00309329CAD1	MULLEN GL 4	ML	8860.00	0.67	7.6	500	7.5	
SC00309329CBA1	MULLEN GL 5	ML	8680.00	3.50	7.6	485	8.0	
SC00309336AAA1	RIFLE CK C C	ML	9030.00	2.10	7.3	380	6.0	RIFLE CREEK COW CAMP
SC00309336AAB1	CORRAL GL	ML	9050.00	13.50	7.6	410	6.0	
SC00409005DCC1	POW	****	9540.00	****	****	320	7.5	
SC00409007DCD1	EDWARDS 3	ML	9340.00	5.80	7.6	422	7.6	
SC00409008CBA1	CLINETOP C C	****	9480.00	3.20	7.7	340	5.0	
SC00409018ABA1	EDWARDS 1	ML	9300.00	****	7.7	437	9.5	
SC00409211BBA1	RIFLE CK 7	ML	7122.00	141.76	7.1	450	13.0	RIFLE MOUNTAIN PARK
SC00409211CCB1	RIFLE CK 4	ML	6960.00	****	7.4	640	15.0	
SC00409211CCB2	RIFLE CK 5	ML	6960.00	****	7.4	640	15.0	
SC00409211CCD1	RIFLE CK 2	ML	6960.00	****	7.4	625	15.5	
SC00409211CCD2	RIFLE CK 3	ML	6960.00	****	7.4	605	15.0	
SC00409215DCA1	RIFLE CK 1	ML	6980.00	****	7.0	602	15.5	
SC00409425ADD1	JOE HILL	ML	7440.00	5.80	7.8	700	7.0	
SC00509101BBB1	ELK CREEK	ML	6020.00	120.30	7.1	407	12.5	
SC00509109CBD1	WEST ELK C	ML	6080.00	28.30	7.8	1250	14.0	

Table 2.--*Springs inventoried in the study area*--Continued

RIO BLANCO COUNTY

WELL LOCATION	SPRING NAME	AQUIFER	ALTITUDE	YIELD	pH	COND	TEMP	REMARKS
SC00109132BCC1	DOBBS	ML	8150.00	0.97	7.6	325	12.0	
SC00109236DAA1	RUSSEL CAMP	ML	7850.00	1.54	7.7	418	10.0	
SC00209019BDD1	LOWER S FORK	ML	8000.00	369.90	7.7	247	7.0	
SC00209105BAA1	CARTER	ML	8560.00	****	6.9	260	6.0	
SC00209105BCB1	CABIN LAKE A	ML	8300.00	5.00	7.9	316	9.0	
SC00209105CBA1	SHADOW LAKE	ML	8310.00	****	7.3	450	7.5	
SC00209106ACB1	SEVENTH LAKE	ML	8110.00	34.28	7.5	350	8.5	
SC00209106ADA1	CABIN LAKE B	ML	8280.00	3.20	7.7	402	18.0	
SC00209119CDB1	SPRING CAVE	ML	7958.00	****	7.3	380	5.5	
SC00209126CCA1	HINER	TPMU	9890.00	4.57	6.3	71	4.0	
SC00209222DAB1	WIDOW	ML	8410.00	****	7.3	465	7.0	
SC00209317DCB1	MACHINE	ML	8160.00	****	5.8	45	16.5	
SC00209317DDD1	INDIAN	ML	8900.00	****	9.2	100	8.0	
SC00209320BDB1	HAY FLAT	ML	8990.00	****	8.5	240	16.0	
SC00209320CBD1	JANES	ML	9140.00	****	9.8	150	16.0	
SC00209321BCD1	BLOODSWORTH	ML	9060.00	****	6.8	55	16.0	
SC00209329CDB1	MULLEN GL 3	ML	9100.00	****	7.5	485	13.0	
SC00209333BCB1	MULLEN GL 2	ML	8980.00	****	8.2	355	24.0	
SC00209333DBC1	MULLEN GL 1	ML	8740.00	****	8.5	410	12.0	
SC00209335CAC1	MID MILLER	ML	8980.00	****	7.4	340	15.0	
SC00309227CDC1	SALT CREEK	ML	8300.00	5.70	7.4	420	6.5	
SC00309228CCC1	GEORGE B	ML	8600.00	4.50	7.7	410	6.0	
SC00309233BBC1	GEORGE A	ML	8750.00	22.90	7.4	440	5.0	
SC00409005BDC1	BUTTERMILK	ML	9560.00	****	7.9	420	15.5	
SC00409007DDC1	EDWARDS 2	ML	9320.00	3.20	7.8	380	5.5	
SC00409106AAA1	MANSFIELD CK	ML	8440.00	1.90	7.3	465	5.0	
SC00409212DDD1	WEST ELK A	ML	8220.00	31.00	7.4	530	5.0	
SC00409213AAC1	WEST ELK B	ML	7600.00	15.70	7.3	650	6.0	

Table 3.--*Chemical quality of water from selected springs, September 5, 1981*

[Mg/L=milligram per liter; µg/L=microgram per liter]

Local identifier	Dissolved solids (sum of constituents) (mg/L)	Dissolved silica (SiO_2) (mg/L)	Dissolved iron (Fe) (µg/L)	Dissolved manganese (Mn) (µg/L)	Dissolved calcium (Ca) (mg/L)
SC00209019DBB1	150	15	12	2	38
SC00209119CDB1	147	5.8	<10	3	39
SC00209126CCA1	65	23	610	5	9.0
SC00309110CAD1	177	7.8	<10	2	65
SC00309127CDB1	215	10	<10	5	67
SC00309336AAB1	224	8.0	16	11	75
SC00409211BBA1	339	10	<10	<1	80

Local identifier	Dissolved magnesium (Mg) (mg/L)	Dissolved sodium (Na) (mg/L)	Percent sodium	Sodium adsorption ratio	Dissolved potassium (K) (mg/L)	Dissolved sulfate (SO_4) (mg/L)
SC00209019DBB1	10	2.0	3	0.1	1.2	<5.0
SC00209119CDB1	11	.8	1	.0	.6	<5.0
SC00209126CCA1	2.4	2.5	14	.2	.5	<5.0
SC00309110CAD1	1.3	1.3	2	.0	.5	<5.0
SC00309127CDB1	9.0	2.0	2	.1	.8	<5.0
SC00309336AAB1	7.1	1.2	1	.0	.8	<5.0
SC00409211BBA1	23	7.1	5	.2	2.0	64

Local identifier	Dissolved nitrogen, NO_2+NO_3 (N) (mg/L)	Dissolved fluoride (F) (mg/L)	Dissolved phosphorus (P) (mg/L)	Alkalinity as $CaCO_3$ (mg/L)	Hardness ($CaCO_3$) (mg/L)	Noncarbonate hardness ($CaCO_3$) (mg/L)
SC00209019DBB1	0.09	0.1	0.010	130	140	6.0
SC00209119CDB1	.32	.1	<.010	140	140	3.0
SC00209126CCA1	.51	.1	<.010	34	32	.00
SC00309110CAD1	.25	.2	<.010	160	170	8.0
SC00309127CDB1	.61	.1	<.010	200	200	4.0
SC00309336AAB1	.55	.2	.010	210	220	7.0
SC00409211BBA1	.26	.1	<.010	240	290	55

Numbering System

The system used to locate and number springs (fig. 5) uses the 14-character code of the U.S. Bureau of Land Management's land-subdivision system. The first character is an S, which indicates that the spring is located in the area covered by the Sixth Principal Meridian. The next letter denotes the quadrant formed by the intersection of the base line (parallel) with the principal meridian. The quadrants are designated A, B, C, or D in a counterclockwise manner with the northeast quadrant being A. The first three numbers designate the township, the next three designate the range, and the last two designate the section. Each section is then divided into quarters designated A, B, C, or D in a counterclockwise rotation, with the northeast quarter being A. This is done again for the quarter-quarter section and the quarter-quarter-quarter section. The three letters following the number designation of township, range, and section indicate the spring position first in the quarter section, then in the quarter-quarter section, and then in the quarter-quarter-quarter section. The final number is the order in which the spring in the designated quarter-quarter-quarter section was inventoried. A spring numbered SC00509101BBB1 would be the first one located in the NW$\frac{1}{4}$NW$\frac{1}{4}$NW$\frac{1}{4}$ sec. 1, T. 5 S., R. 91 W.

NEED FOR FUTURE INVESTIGATIONS

Seepage-Run Analysis

Seepage runs on East Rifle Creek during the 1981 field season indicate significant ground-water discharge into tributaries draining the White River Plateau. Additional seepage data need to be collected on the South Fork White River and other major streams to better determine how much water the Leadville Limestone contributes to the Colorado and the White River drainages. These data could be used to establish discharge conditions prior to ground-water development in the area and to monitor the possible effects on gaining streams of test-well pumping.

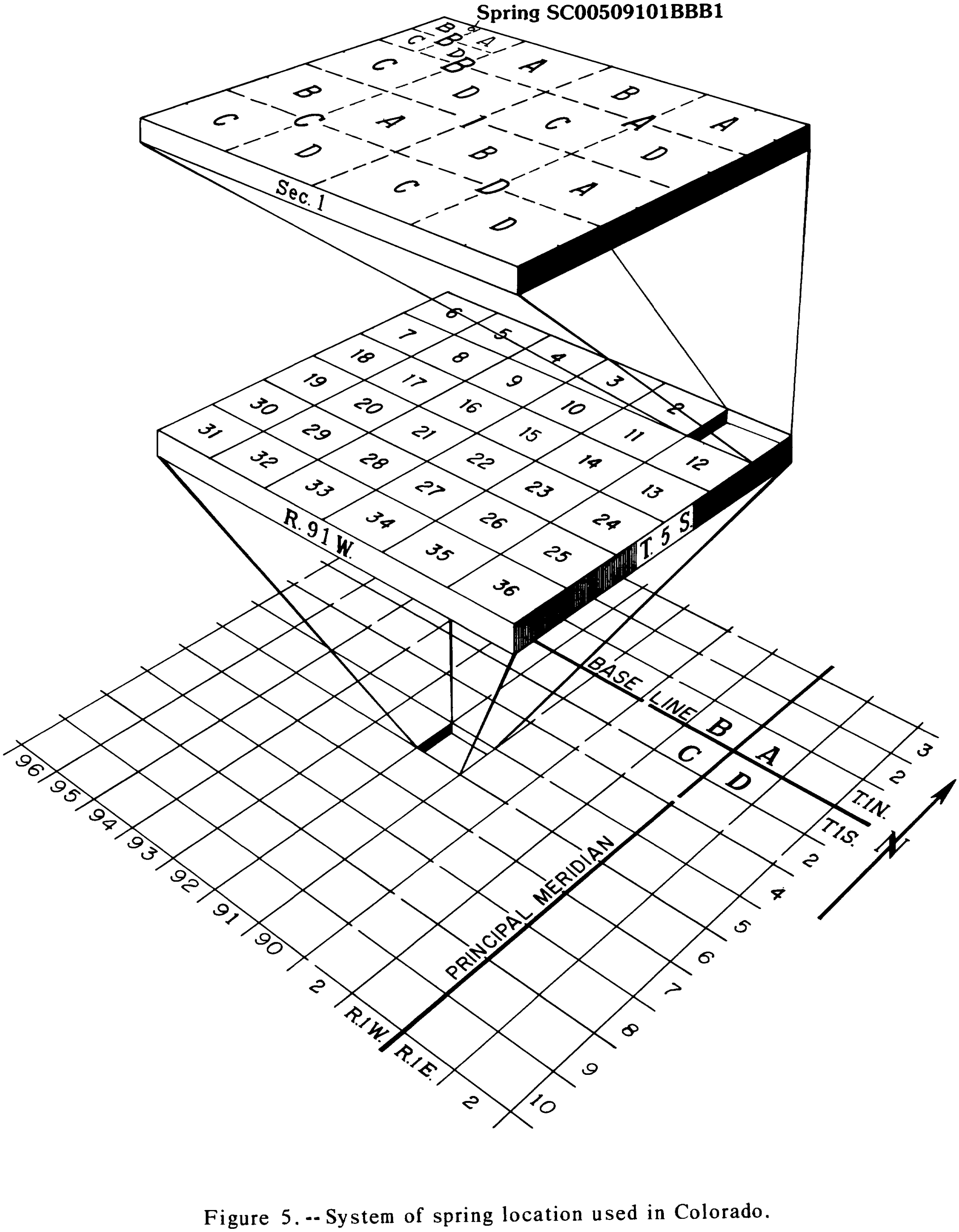


Figure 5.--System of spring location used in Colorado.

Isotope Studies

A reconnaissance study needs to be made of selected stable isotope ratios in water from the Leadville Limestone. The stable isotopes of carbon, hydrogen, and oxygen have been used to study recharge of ground water, leakage between aquifers, relations between surface and ground water, hydrology of fractured rocks, and mineral-water interactions (Fritz and Fontes, 1980). If the isotope ratios are sufficiently distinctive in water samples from the Leadville, these and subsequent samples can be used to study aspects of water movement and quality.

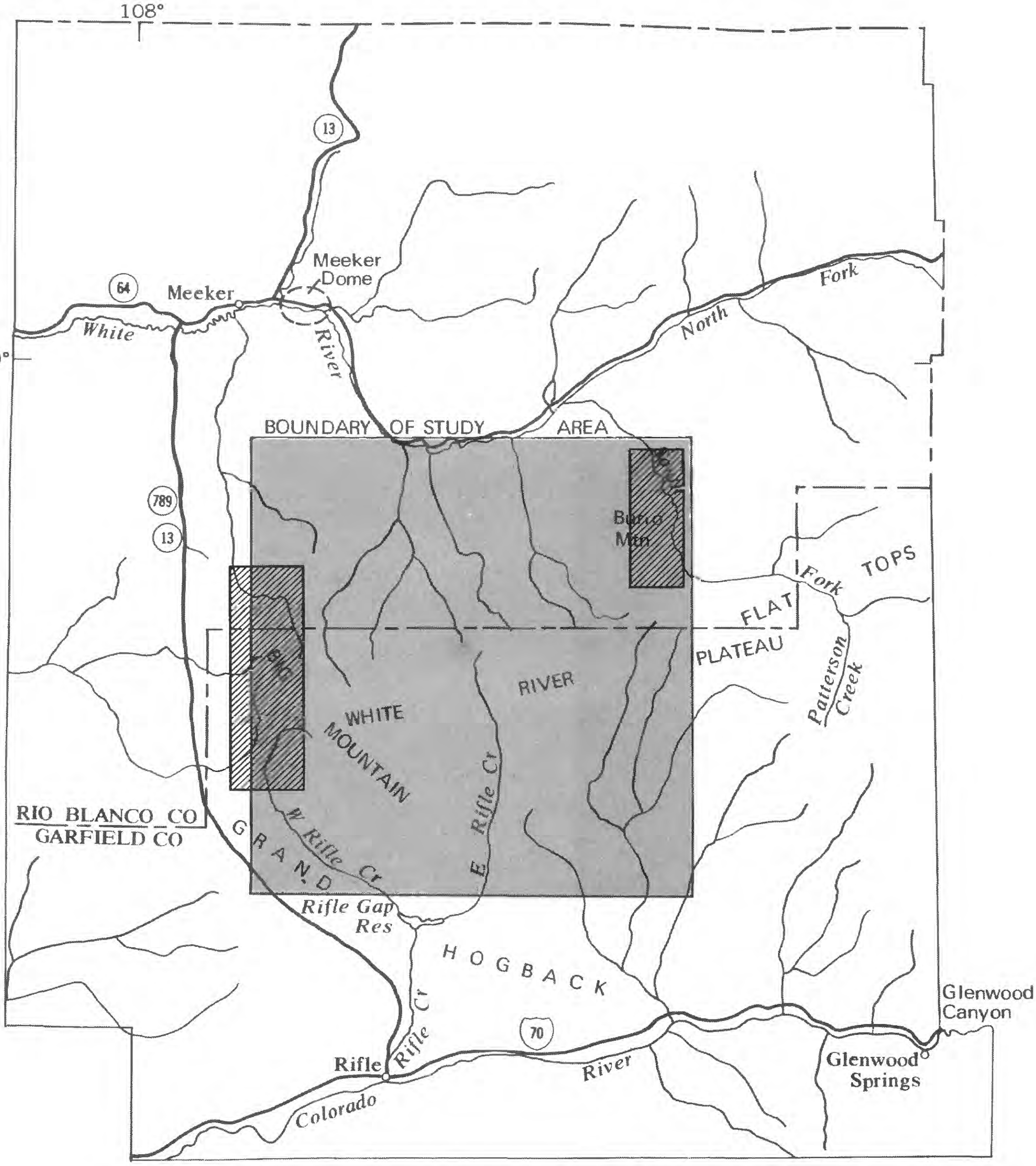
Exploratory Drilling

A proven method of determining whether the Leadville Limestone in the subsurface actually contains large quantities of water in storage is through exploratory drilling and testing. Some considerations for the selection of exploration sites are:

1. Proximity to facilities.
2. Topography and drainage.
3. Physical accessibility.
4. Legal accessibility and drilling permits.
5. Geology, including overburden and drilling depth.
6. Potential drilling problems.

No specific site for test drilling has been selected because geohydrologic and economic data are inadequate. Onsite reconnaissance may be needed. However, logical exploration sites selected would be on the western and northern sides of the study area where the Leadville is near the land surface and has low angles of dip (fig. 6). Because of the cost of drilling deep wells and the uncertainty of hydrologic conditions at great depths, geohydrologic data obtained from wells less than 1,500 feet deep probably would be sufficient to determine if deeper wells were needed.

The drilling program could be completed during three field seasons. During the first field season, site selections could be made, site surveys completed, and necessary permits and permission agreements acquired. Drilling specifications and contracts also could be written at this time. During the second field season three test holes could be drilled and logged on the primary test site. Depending on conditions or problems encountered, such as artesian flow, dry holes, or contamination from other zones, drilling and aquifer testing could be completed within 12 months. During the third season three additional test holes could be drilled, logged, and tested on the secondary test site to confirm primary test results and evaluate the areal extent of porosity, permeability, and quantity of water stored in the aquifer.



108°
40°
13
64
Meeker
Meeker Dome
White
River
North
Fork
BOUNDARY OF STUDY AREA
789
13
Burro Mtn
Fork
TOPS
FLAT
PLATEAU
BIG
WHITE
MOUNTAIN
RIVER
Patterson Creek
RIO BLANCO CO
GARFIELD CO
GRAND
W Rifle Cr
E Rifle Cr
Rifle Gap Res
HOGBACK
Rifle Cr
70
Rifle
Colorado
River
Glenwood Canyon
Glenwood Springs

CONCLUSIONS

Northwestern Colorado contains the largest reserves of shale oil in the world, and the coal beds of the area are some of the most extensive in the United States. Development of the shale oil and coal may require large supplies of water and, therefore, may create additional demands on the surface-water resources of the region. The availability of ground water, however, is not well known. Other formations studied in the Piceance basin have been estimated to contain several million acre-feet of water generally chemically suitable for most uses, and the ground-water resources of all of northwestern Colorado probably are much larger.

Preliminary studies indicate that large quantities of water may be available in the Mississippian Leadville Limestone on the southern, western, and northern flanks of the White River Uplift. The Leadville is about 200 feet thick, has solution openings, and is very permeable--at least in places. Much of this permeability, as evidenced by the extensive paleokarst topography throughout most of western Colorado, had developed by the beginning of the Pennsylvanian Period. The Leadville provides water to at least 100 springs and probably forms a major aquifer system that might yield calcium carbonate type water to shallow wells on the flanks of the White River Uplift. The quantity of ground water in storage in the Leadville Limestone in the western one-half of the White River Uplift area may exceed 10 million acre-feet. Exploratory drilling and testing of the Leadville Limestone to depths of 1,500 feet are needed to evaluate the potential of this aquifer for providing large supplies of water.

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