DEPARTMENT OF THE INTERIOR U.S. GEOLOGICAL SURVEY **CORRELATION OF MAP UNITS EXPLANATION** PRECIPITATION IN INCHES FROM UPPER COLORADO REGION STATE-FEDERAL INTER-AGENCY GROUP (1971) LESS THAN 10 BASIN BOUNDARY - MESOZOIC Lower → Permian Cambria G A R F I I > PRECAMBRIAN LIST OF MAP UNITS Qs Surficial deposits. Only areally extensive and thick Mancos Shale and equivalent rocks deposits shown ontier Formation, Dakota Sandstone (upper Volcanic rocks part) and equivalent MONTROSE BASIN BOUNDARY River Granitic rocks Pliocene continental deposits COLORADO PLATEAUS Continental deposits Miocene continental deposits SAN MIGUEL CO Oligocene continental deposits Lower Cretaceous rocks Jurassic sedimentary rocks Eocene continental deposits DOLORES Eocene lacustrine deposits Jurassic and Triassic sedimentary rocks Paleocene continental deposits riassic sedimentary rocks Pliocene volcanic rocks Sedimentary rocks Intrusive rocks Permian sedimentary rocks v, Oligocene and Eocene volcanic rocks Upper Paleozoic sedimentary rocks f, Oligocene and Eocene felsic rocks Lower Paleozoic sedimentary rocks UPPER CRETACEOUS Cambrian sedimentary rocks EXCLUDED FROM STUDY Lance, North Horn, Animas Formations and Granitic rocks equivalent rocks Sedimentary, igneous, and metamorphic rocks EXCLUDED FROM STUDY EXCLUDED FROM STUDY Fox Hills Sandstone, Lewis Shale, Mesaverde Formation or group and equivalent rocks San Juan Basin ---- Basin Boundary Figure 4.—GEOLOGIC MAP Figure 2.—MAP SHOWING GEOGRAPHIC FEATURES AND AREA OF THE STUDY Figure 3.—MAP SHOWING NORMAL ANNUAL PRECIPITATION (1931-60) **EXPLANATION EXPLANATION EXPLANATION EXPLANATION** Tertiary sedimentary rocks Mesozoic sedimentary rocks Paleozoic sedimentary rocks ——— Contact, dashed where approximately located Contact, dashed where approximately located ---- Basin boundary --- Basin boundary ---- Basin boundary Boundary of study area SUBLETT RAWLINS-UPLIFT GREEN RIVER BASIN GREAT DIVIDE BASIN WASHAKIÉ BASIN UINTA UPLIFT ARCH ker BASIN--RIOBLANGO WHITE RIVER UPLIFT GARFIE GARFIEL EAGLE WASATCH-PLATEAU SAWATCH UPLIFT EMERY PLATEAUS GUNNISON UPLIFT W. Fremant Y River River W Fromont River River River CLIFFS SAN MIGUEL UPLIFT GARFIELD ARFOIELD GARFIELD SAN JUAN VOLCANIC FIELD DOLORES SAN JUAN UPLIFT KAIPAROWITS PLATFORM BOUNDARY OF STUDY AREA MAUL WAR BYR WAYKIM MARRIB BASIN ARRIB MARRIB VARRIB EXCLUDED FROM STUDY EXCLUDED FROM STUDY EXCLUDED FROM STUDY EXCLUDED FROM STUDY Figure 8.—MAP SHOWING AREAL EXTENT OF TERTIARY ROCKS INTERIOR—GEOLOGICAL SURVEY, RESTON, VA—1986—W84345 Figure 5.—MAP SHOWING PRINCIPAL TECTONIC FEATURES Figure 7.—MAP SHOWING AREAL EXTENT OF MESOZOIC ROCKS Figure 6.—MAP SHOWING AREAL EXTENT OF PALEOZOIC ROCKS

Base modified from U.S. Geological Survey United States base map, 1:2,500,000, 1972 Table 1.—CHARACTERISTICS OF MAJOR HYDROGEOLOGIC UNITS OF UPPER COLORADO RIVER BASIN

is confined by overlying beds of shale or limestone.

	Table 1.—CHARA	CILMOTICS	OI MAJON	III DROOLOLOGIC OMITO OF C	FFER COLORADO RIVER BASIL	•
Hydrogeologic unit	Age	Approximate areal extent (square miles)	Common range in thickness (feet)	Primary lithologic character	Water-yielding character	General water quality
	,			Tertiary		
Upper Tertiary discontinuous aquifers	Pliocene, Miocene, and Oligocene	2,500	200 to 800	Tuffaceous sandstone, conglomerate, sandy claystone and, tuff.	Generally moderately permeable, but may be drained because deposits are dissected or on buttes. Water issues from small hillside springs from this unit.	Poorly understood. A few water samples from the Brow Park Formation, Bishop Conglomerate, and other inclu aquifers indicate freshwater.
Middle Tertiary aquifers, partly drained aquifers, and confining layers	Early Oligocene and Late Eocene	8,500	1,500 to 9,000	Shale, claystone, siltstone, sandstone, and conglomerate. Tuffaceous	Large range in permeability. Yields to wells are greatest in irrigated areas where local recharge is abundant.	Water is fresh in the Uinta, and Bridger formation near crop areas in the Uinta and Green River basins. Freshw also occurs in the Uinta Formation in the Piceance be Water in the Uinta Formation is very saline at depth in Uinta basin. The Duchesne River Formation cont freshwater in the Uinta basin.
Lower Tertiary aquifers and confining layers	Eocene and Paleocene	21,000	3,000 to 10,000	Shale, mudstone, sandstone, oil shale with interbeds of limestone and tuff, arkose, conglomerate, and coal.	Large range in permeability; the lacustrine beds are permeable where fractured or sandy; fluvial deposits generally are permeable near basin margins where they are coarse-grained material.	Water in the Wasatch Formation in the Green River by range's from fresh in outcrop areas to slightly saline at de In the Uinta basin, water in the Wasatch Formation ran from fresh in outcrop areas to briney at depth. Wate the Green River Formation ranges from fresh in outcareas to briney where evaporite minerals are present
Basal Tertiary aquifers	Mostly Paleocene. Locally early Eocene and Late Cretaceous	29,000	1,000 to 2,500	Fine to coarse sandstone, carbonaceous shale, and coal.	Moderately permeable but heterogeneous.	Poorly understood. Water in the Fort Union Formation Wyoming ranges from fresh to slightly saline. The No Horn Formation in Utah yields freshwater
			A	Mesozoic	A	
Upper Mesozoic confining Layers and aquifers	Mostly Cretaceous, locally Late Jurassic	60,000	4,000 to 15,000	Shale, limestone, coal, sandstone and conglomerate.	Principally a confining unit. Fully saturated sandstone layers below Mancos Shale are moderately permeable.	Mostly fresh to slightly saline water in the Dakota Sandst Water from the Mancos Shale ranges from fresh moderately saline, but may represent water from sands members and not from the shale and included evapo minerals. Water in the Mesaverde Group ranges from fit to slightly saline, except at depth where it is very sa to briney.
Middle Mesozoic aquifers	Jurassic and Late Triassic	80,000	500 to 3,500	Sandstone and shaly sandstone. Upper part of unit ranges from conglomeratic sandstone in southern part of upper basin to shale and limestone in northern part.	A widespread aquifer or group of aquifers with generally little permeability except where fractured. The Glen Canyon Group including the Navajo Sandstone are thick in parts of Utah and Arizona and have large water-supply potential.	Mostly freshwater in sandstones of the Glen Canyon Gr in some regions leakage of saline water from other aqui results in moderately saline to briney water. Water in Carmel Formation is fresh near outcrops but slightly moderately saline near the San Rafael uplift. Widely s tered water samples from the Morrison Formation rat from fresh to slightly saline.
Lower Mesozoic confining layers	Triassic	80,000	500 to 2,000	Mudstone, siltstone, limestone, and shale with sporadic thin bads of sandstone and conglomerate.	Principally a confining unit. Coarse-grained strata at the base of the Chinle and Ankareh Formations, and local interbedded sandstone layers in the Moenkopi Formation are aquifers with limited potential for development.	Poorly understood. Slightly saline to moderately saline win the Chinle and Moenkopi Formations.
				Paleozoic		
Upper Paleozoic aquifers and confining layers	Permian, Pennsylvanian, and Late Mississip – pian, locally Early Triassic	82,000	1,000 to 11,000	Sandstone, limestone, dolomitic limestone, dolmite, shale, evaporite, mudstone, siltstone, and conglomerate.	Probably a series of aquifers interbedded with confining layers. Fractures and solution openings increase the permeability locally. Discharges of wells and springs in this unit vary greatly. Confining layers consist of locally thick evaporites and other unfractured fine-grained rocks	Mostly fresh water in the Weber Formation of the Uinta be Slightly saline to moderately saline water in the Cedar M and White River Sandstone members in south-central U Fresh to moderately saline water in rocks of Pennsy nian age in Colorado. Fresh to briney water in rocks the Paradox basin, depending on relation of flow systo evaporite deposits.
Middle Paleozoic aquifers	Mississippian and Middle Devonian	82,000	200 to 4,000	Cherty limestone and dolomite that are cavernous and frac- tured in some regions. Locally karst topography has resulted in solution cavities and collapse structures. Includes beds of siltstone, sandstone, shale, and mudstone.	Probably a regional aquifer with a wide range in permeabili- ty. Large springs discharge from this unit at several sites. Reported well yields range widely.	Freshwater where unit crops out in Uinta and White R uplifts; water becomes moderately saline as it moves as from outcrops. In the Paradox basin the water is very sa to briney.
Lower Paleozoic confining Layers and aquifers	Ordovician and Middle Cambrian	80,000	100 to 1,600	Dolomite, limestone, dolomitic limstone, shale, conglomerate, sandstone, and mudstone.	Poorly understood. Probably a confining unit except in uplifted regions where solution openings and fractures may increase permeability. Large springs may discharge from the Bighorn Dolomite.	Poorly understood. A few samples of water from dolom formations indicate highly variable quality, ranging for fresh to very saline.
Besal Paleozoic aquifer	Cambrian	80,000	100 to 600	Quartzitic, arkosic, and dolomitic sandstone with interbeds of silt, shale, and conclomerate	Poorly understood. Springs are reported in this unit. Probably a continuous aquifer of low or moderate permeability that	Poorly understood. A few samples from springs indic freshwater.

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RIVER BASIN LOWER COLORADO RIVER BASIN NEW MEXICO 0 200 400 KILOMETERS Figure 1.—INDEX MAP SHOWING UPPER COLORADO RIVER

METRIC CONVERSIONS The inch-pound units used in this report may be converted to SI (International System of Units) by use of the following conversion factors: To obtain SI unit Multiply inch-pound unit 3.048x10 foot (ft) square mile (mi2) square kilometer cubic foot per second (ft3/s) 2.832x10-2 cubic meter per second 1.234x10⁻³ acre-foot per year (acre-ft/yr) cubic hectometer per year

INTRODUCTION The U.S. Geological Survey began a regional aquifer-system analysis of the Upper Colorado River Basin in 1981. Objectives of the study are to identify aquifers and confining beds within the study region, to determine the geologic and hydrologic characteristics of consolidated-rock aguifers of sedimentary origin, to describe the geochemical characteristics of ground water, and to estimate the water-supply capability of the major aguifers. This is the first of a series of reports to describe the various investigation results. The purpose of this report is to describe the general hydrologic features of the basin, the regional stratigraphy, and the regional hydrogeologic units.

LOCATION In 1922 the Colorado River Compact subdivided the Colorado River basin arbitrarily near Lees Ferry, Ariz., into upper and lower drainage basins (fig. 1) for the purpose of water management. The Upper Colorado River Basin has an area of about 113,500 mi² and includes parts of Colorado, Utah, Wyoming, Arizona, and New Mexico. The upper basin also includes parts of four physiographic provinces: the middle Rocky Mountains, the Wyoming basin, the southern Rocky Mountains, and the Colorado Plateau (Fenneman, 1931). The upper part of the drainage basin of the San Juan River, an area of about 14,600 mi², will be a separate study (fig. 2); therefore the total study area for this investigation is approximately 100,000

PRECIPITATION, DRAINAGE, AND STORAGE Normal (1931-60) annual precipitation in the study region ranges from less than 10 in. on the plains to more than 30 in. on mountainous areas (fig. 3). Mean annual snowfall ranges from about 12 in. on the lowland areas to about 400 in. on mountainous areas (U.S. Department of Commerce, 1968). The greater precipitation in the mountains probably provides natural recharge for those aguifers exposed in mountainous regions These aquifers include many that are exposed in uplifts but occur at depth within basins. The average discharge of the Colorado River near the lowest point of the upper basin at the Lees Ferry streamflow-gaging station, was 17,850 ft³/s or 12,923,000 acre-ft/yr for the period 1912-62. Average discharge for the period 1965-79, after the construction of Glen Canyon Dam and Lake Powell, was 12,080 ft³/s or 8,752,000 acre-ft/yr (U.S. Geological Survey, 1981). The disparity in average discharge for the 2 periods is due to differences in surface-reservoir storage, evaporation, usage, and precipitation. Major tributaries to the Colorado River in the upper basin are the Green, Gunnison, Dolores, Dirty Devil, and San Juan Rivers. Major tributaries to the Green River include the Yampa, Duchesne, Streamflow is affected by the storage capacity of reservoirs and lakes as well as by diversion for irrigation, municipal, and industrial uses. Major surface storage facilities in the Upper Colorado River Basin are tabulated

Surface-storage facility Fontenelle Dam and Reservoir------Wyoming Flaming Gorge Dam and Reservoir---Utah and Wyomin Blue Mesa Dam and Reservoir-----Navajo Dam and Reservoir-----San Juan New Mexico and Colorado Glen Canyon Dam and Lake Powell Colorado Arizona and Utah The thick sedimentary strata underlying the Upper Colorado River Basin include major aquifers. A thorough understanding of the hydrologic characteristics of the aguifers will permit the integration of surface- and ground water resources into overall water-management plans for the Upper Colorado River Basin. **GEOLOGY**

ROCK TYPES

Consolidated sedimentary strata are the common rocks in the Upper Colorado River Basin and the emphasis of this report (fig. 4). Consolidated sedimentary formations of Paleozoic, Mesozoic, and Cenozoic age attain a maximum thickness of tens of thousands of feet in some basins. These

formations include limestone, dolomite, sandstone, and shale, all of which may be aguifers. The formations in the Upper Colorado River Basin are so numerous and diverse in rock type that they have been grouped into 11 hydrogeologic units. These units were selected on the basis of depositional environment, principal rock type, and hydrologic characteristics, and will be used to classify the ground-water resources into broad categories. Unconsolidated sedimentary deposits of gravel, sand, and clay occur as valley-fill alluvium in most reaches of stream valleys and include aquifers that locally are hydraulically connected to streams. The unconsolidated deposits are important sources of water in some valley reaches, but regionally the deposits are a minor part of the ground-water system and are not discussed in this report. Igneous rocks are represented principally by the volcanic rocks of the San Juan volcanic field in Colorado and by those in south-central Utah. Volcanic-rock types include flows, flow breccias, ash-flow tuffs, welder ash-flow tuffs, and water-laid tuffs. Some of these rocks are permeable because of interconnected fractures or pores. Intrusive igneous rocks crop

The Upper Colorado River Basin has been the site of repeated structural deformation (Grose, 1972). Sturctural deformation in Precambrian time affected subsequent deposition; at the beginning of Paleozoic time the relief of the Precambrian land surface was as much 1,000 ft (Kent, 1972). Prominent structural features that were topographically high at the beginning of Paleozoic time were the Uinta peninsula of northeastern Utah and northwestern Colorado and the transcontinental arch that extended northeast across Colorado from northwestern New Mexico. Igneous rock was intruded in Colorado in Late Cambrian to Early Ordovician time. Uplift, subsidence, and faulting continued throughout Paleozoic time but were especially prominent during Pennsylvanian and Permian time. During Late Triassic and Early Jurassic time, mountain building movements to the west affected sedimentation within the study area. In Late Jurassic and Cretaceous time several pulses of mountain building and volcanism resulted in uplift and subsidence. Later structural deformation seems unrelated to the early activities described above. The Laramide Revolution, a major mountain-building period, persisted from Late Cretaceous to Eocene time and resulted in leep-seated and regional deformation, as well as extensive volcanism and minor igneous intrusion. The major structural features of the regionnumerous basins and uplifts—formed during the Laramide Revolution (fig. 5). Because of these structural features, the older formations generally are deeply buried in basins and exposed in uplifts; younger formations generally are exposed or shallowly buried in basins and have been eroded from uplifts. Uplift, subsidence, and normal faulting continued from Oligocene hrough Quaternary time. Structural deformation has been so widespread through geologic time that the resulting structural effects on the permeability

out in scattered small areas of the study region, but probably do not in-

in the study region are not discussed in this report.

clude important aquifers. The hydrologic characteristics of the igneous rocks

and storage characteristics of rocks cannot be evaluated easily. STRATIGRAPHY The depositional conditions and intervening erosion, uplift, subsidence, and fracturing varied considerably throughout the study region from Precambrian through Cenozoic time. A general discussion of the geologic history follows, with an emphasis on the hydrogeologic characteristics of the consolidated sedimentary strata; the characteristics of the intervening erosional periods; and the location and intensity of uplift, subsidence, and

The areal extent of buried and exposed Paleozoic rocks is shown in figure 6. In the early Paleozoic, Cambrian and Ordovician time, rocks were deposited in transgressive and regressive seas, and consist of carbonate and clastic sediments. Sedimentation frequently was interrupted and extensive erosion removed previous deposits throughout large areas. A laterally continuous sequence of sandstone and quartzite of Cambrian age is overlain by a sequence of carbonate and clastic rocks of Middle to Late Cambrian and Ordovician age. The maximum combined thickness of these two units is about 2,200 ft. Rocks deposited in later Paleozoic time are thicker than early Paleozoic deposits. Beginning in Devonian time and continuing through Mississip-

PALEOZOIC ROCKS

pian time, thousands of feet of mostly carbonate rocks were deposited under tectonically stable conditions. Erosion during and after the Mississippian Period removed part of these deposits, but about 4,000 ft remains. Beginning in Pennsylvanian time, a period of mountain building resulted in the deposition of large thicknesses of mostly detrital material sandstone and shale—that was eroded from the emerging Uncompangre uplift and the ancestral Rocky Mountains, located along the eastern margin of the study region. Other Pennsylvanian deposits include carbonate rocks and several thousand feet of evaporite deposits in the Paradox basin. Permian rocks consist mostly of red beds—sandstone, siltstone, and mudstone—that are interbedded with shoreline and shallow marine deposits of sandstone and carbonate rocks. The clastic and carbonate rocks of Pennsylvanian and Permian age attain a maximum thickness of about 11,000 ft.

The areal extent of buried and exposed Mesozoic rocks is shown in figure 7. Siltstone, sandstone, and limestone were deposited in Triassic time on a marine continental shelf; on the central western border area of the study region, the deposits consist of deep-water marine limestone and black shale. After part of the earliest Triassic deposits were eroded, the remaining rocks were covered with a red-bed sequence of mudstone, siltstone, fluvial sandstone, and conglomerate. The continental and marine deposits of Triassic age that extend upward through the Chinle Formation a prominent marker in most of the region) and its equivalents attain a maximum thickness of about 2,000 ft. In Late Triassic and Early Jurassic time, deposition changed from continental and marine to mostly continental; most of the continental sandstone deposited is of eolian origin. The Glen Canyon Group and Nugget Sandstone constitute a wedge-shaped mass of dune and fluvial sedimentary rocks that thickens westward and comprises about one-half the maximum thickness of Mesozoic rocks along the western edge of the region. In Middle to Late Jurassic time, the sandstone was covered by seas that deposited siltstone, sandstone, and limestone; along the western edge of the region, halite and gypsum were deposited. A subsequent marine encroachment produced deepwater deposits of limestone and shale in the west, red beds and evaporites locally, and eolian and shallow-water deposits, such as the Entrada Sandstone, in the eastern part of the region. Mountain building west of the region began to affect regional sedimentation, and subsequently clastic deposition dominated. The sandstone, shale, limestone, and conglomerate deposits of Late Triassic to Late Jurassic age have a maximum thickness of about 5,000 ft. In Late Jurassic time the upper part of the Morrison Formation was deposited by streams and in swamps. The deposits contain much volcanic debris and the resulting bentonitic material is not permeable. Mountain building as indicated by the volcanism, moved eastward in pulses that con-

MESOZOIC ROCKS

tinued into Tertiary time. This activity converted the seaways west of the study area to highlands, and the area east of the study region subsided to form the central seaway that bisected the continent during Cretaceous time. Following each pulse of movement, the western highlands provided much debris that was washed into the Cretaceous seas, resulting in a lateral sequence, from west to east, of eroded highlands, piedmont and coastline fluvial deposits, marine sandstone and beach deposits, marine siltstone and shale, and deep-water limestone. The positions of the various elements of this sequence moved eastward or westward, depending on changes in the mountain building that produced eastward thrusting, the rate of subsidence in the area of deposition, and other factors. This complicated sequence of deposition is best seen in geologic sections by Weimer (1960). Rocks of Late Jurassic and Cretaceous age have a maximum thickness in excess of 15,000 ft; in much of the region, however, these rocks are

The areal extent of Tertiary rocks is shown in figure 8. Deposition in early Tertiary time was related to geologic events in Late Cretaceous time. At the end of the Cretaceous, the sea retreated to the east. Initially sediments derived from land areas to the west were deposited with marine sand. As the sea retreated, fluvial sediment was deposited over the newly emergent land on piedmonts and plains. As sediment accumulated, subsidence locally exceeded the volume of material eroded from nearby mountains, and large lakes or swamps formed. Vegetation in the swamps was buried and transformed into coal beds. During Paleocene time, mountain building of the Laramide Revolution intensified and clastic deposits of sandstone and shale were formed.

CENOZOIC ROCKS

Surface-drainage patterns that developed at the end of Cretaceous time were disrupted, resulting in blocked streams and newly formed lakes and swamps. By the end of Paleocene time, thick deposits had been laid down in the Green River basin of Wyoming, part of which were transformed into coal. A large lake formed at the foot of the mountains into which fine sediment was deposited and which bounded the Upper Colorado River Basin on the west in Utah. The sandstone, shale, and coal beds of Paleocene age attain a maximum thickness of about 2,500 ft. The lake expanded in early Eocene time to cover most of the northern part of the Upper Colorado River Basin, but was divided by the Uinta Mountains uplift into two possibly interconnected lakes. These lakes changed considerably in size, salinity, and other characteristics in response to climatic changes. Enormous quantities of salts, mainly carbonates and bicarbonates, precipitated from the water and were incorporated in the lakebed deposits of limestone and shale. Streams, flowing from the moun tains to the plains, deposited fluvial sediment that intertongues with the lakebed deposits. The rocks near the mountains that provided the sediments

of the grain sizes of the sediments by movement has resulted in predominantly sandstone that grades progressively into claystone toward the lakeshores. Eventually the rate of sedimentation exceeded the rate of downwarping and the lakes disappeared except for scattered, small remnants. The shale, mudstone, sandstone, arkose, and conglomerate beds of Eocene age attain a maximum thickness of about 10,000 ft. Predominantly fluvial deposition continued through the rest of Eccene and into Oligocene time, along with other types of deposition resulting from volcanic activities. Thick volcanic flows covered much of the high plateaus in Utah; these rocks include locally productive aquifers. In some places near the mountains, swiftly moving streams carried massive quantities of sand, gravel, and boulders into the basins where this material later became consolidated into conglomerate. Within the basins, silt and clay were deposited in sluggish streams, ponds, and lakes. These clastic deposits of Eocene and early Oligocene age attain a maximum thickness of about By the end of Oligocene time swiftly moving streams eroded coarse material from the mountains to form nearly continuous sand and grave deposits that were graded from the mountains to the basin centers. Deposition probably continued into the Miocene as mountain uplift slowed, but renewed volcanism showered the region with ash. Sandstone, claustone,

commonly are conglomerate or arkose, but at distance the modification

and conglomerate interbedded with tuff blanketed much of the area. Similar deposition continued until nearly the end of the Tertiary Period. By about the end of Tertiary time, regional uplift rejuvenated the streams and caused erosional downcutting in the drainage divides surrounding the lake basins. The resulting rapid erosion formed graded deposits of conglomerate, sandstone, and claystone in the basins. Almost all of the material has been eroded, leaving only scattered remnants. The remaining sandstone, conglomerate, claystone, and tuff beds of Oligocene, Miocene, and Pliocene age are as much as 800 ft thick. Mountain glaciation characterized Pleistocene time, the earliest part of the Quaternary Period. Glaciers occupied much of the higher parts of the mountains. As the glaciers moved down from the mountains they carried a heterogeneous assortment of boulders, gravel, sand, and clay which was deposited where the ice melted. Meltwater sorted part of the material and deposited some of it as terrace deposits along streams. During the subsequent Holocene time, the glaciers receded so that only a few remain along the crests of the highest mountain ranges. Erosion has so dissected ne glacial deposits that they are generally small in extent and discontinuous. They and the alluvium along streams include some locally important

HYDROGEOLOGY Sedimentary rocks of Paleozoic, Mesozoic, and Cenozoic age have been subdivided into 11 units, based on their probable regional hydrologic characteristics (sheet 2 and table 1). These rocks have been altered during and after deposition by eroison, chemical dissolution, and tectonic activity. Because of the large study area associated with large variations in lithologic and hydrologic characteristics, each subdivision is a broad category with rock characteristics that vary locally. The classification of each geologic formation as an aquifer or confining bed was not attemped, because the integrated effects of lithology, structural deformation, and chemical alteration on permeability and the areal variation of each formation are not known. The ranges given for unit thicknesses are common ranges, rather

aquifers, but they are of little regional importance.

Water quality expressed in the table uses the salinity classification described by Robinove and others (1958). The five salinity classifications are defined below:

Dissolved-solids concentration, Salinity classification in milligrams per liter Less than 1,000 1.000-3.000 Slightly saline 3,000-10,000 Moderately saline 10,000-35,000 Very saline More than 35,000 Briny

HYDROGEOLOGIC UNITS OF PALEOZOIC AGE Sedimentary rocks of Paleozoic age in the Upper Colorado River Basin include limestone, dolomite, sandstone, siltstone, shale, and evaporite deposits. Due to effects of erosion, all strata of Paleozoic age are absent in the Uinta and Uncompangre uplifts, the Park Range, and the Sierra Madre. The Paleozoic strata were subdivided into four units that are described below, from older to younger.

Basal Paleozoic Aquifer The oldest hydrogeologic unit, the basal Paleozoic aquifer, is a regional littoral sandstone and quartzite; it consists of seven formations of Cambrian age, most of which directly overlie Precambrian rocks. The unit is exposed in the Green River basin and the Overthrust belt; near the San Juan uplift, the Uinta uplift, and the White River uplift; and is directly overlain by shale, limestone, and dolomite formations that range in age from Cambrian to Mississippian. The hydrologic characteristics and water qualtiy of the basal Paleozoic aquifer are poorly known because in much of the Upper Colorado River Basin it lies at great depths, below the depth penetrated by water wells.

Lower Paleozoic Confining Layers and Aquifers Stratigraphically above the basal Paleozoic aquifer is a sequence of mostly limestone and dolomite of Cambrian and Ordovician age, the lower Paleozoic confining layers and aquifers. Included are 10 formations that are widespread, but absent in parts of Colorado and Utah. Two of the 10 formations, the Bighorn Dolomite and Gallatin Limestone possibly are aquifers where exposed in Wyoming: most of the other formations are confining layers or thin aquifers. This hydrogeologic unit also is exposed in the Green River basin and the Overthrust belt, and near the San Juan uplift, the Uinta uplift, and the White River uplift. The lower Paleozoic confining layers and aquifers are directly overlain by limestone of Devonian and Mississippian age. The hydrologic characteristics of this unit are poorly known because it is deeply buried in much of the basin.

Middle Paleozoic Aquifers Areally extensive marine deposits of mostly limestone and dolomite of Devonian and Mississippian age comprise the unit called the middle Paleozoic aguifers. Principal formations include the Madison Limestone. Darby Formation, and their equivalents. This unit is exposed in the Green River basin, the Overthrust belt, the San Juan uplift, the Uinta uplift, and the White River uplift. The middle Paleozoic aguifers unit is overlain mostly by sandstone, limestone, and shale of Mississippian and Pennsylvanian age. Carbonate formations of Mississippian age are productive aquifers in parts of the Rocky Mountains region and northern Great Plains. This unit may be a regional aquifer with a wide range of permeability.

Upper Paleozoic Aquifers and Confining Layers Uplift and erosion during Mississippian, Pennsylvanian, Permian, and early Triassic time resulted in the deposition of clastic material, especially sandstone and red beds. Thick evaporite beds, the Eagle Valley Formation and the Paradox Member of the Hermosa Formation, also were deposited in Pennsylvanian time. The upper Paleozoic aquifers and confining layers unit includes 23 formations. This hydrogeologic unit is exposed in the Green River basin, the Monument uplift, the Overthrust belt. the Paradox basin, the San Juan uplift, the San Rafael swell, the Unita uplift, and the White River uplift, and is directly overlain by siltstone, mudstone, limestone, and shale of Triassic age. The unit includes a series of aquifers, probably confined by the intervening layers with low permeability. The Goose Egg and State Bridge Formations are included in this hydrogeologic unit, even though the formations are partly Triassic in age.

HYDROGEOLOGIC UNITS OF MESOZOIC AGE The Mesozoic sedimentary rocks were divided into three hydrogeologic units based on lithologic characteristics and on water-bearing properties determined by examining yields of wells penetrating the formation represented by each unit.

Lower Mesozoic confining layers The continental and marine deposits designated as the lower Mesozoic confining layers include siltstone, mudstone, limestone, and shaley deposits. The permeability of these rocks is low. This unit probably confines the underlying aquifers of late Paleozoic age. The Lower and Middle Triassic rocks include the Moenkopi Formation in Utah, Arizona, and southwestern Colorado; the Dinwoody Formation, Woodside Shale, and the Thaynes Limestone in the Green River basin of Wyoming; and the Chugwater Group in the Great Divide basin of Wyoming. The Chinle Formation in Arizona, Colorado, and Utah and the Ankareh Formation in Wyoming make up the Upper Triassic rocks. This hydrogeologic unit is directly overlain mostly by sandstone aguifers of Late Triassic to Late Jurassic age. In the unit, sandstone and conglomerate deposits that yield water to wells intertongue locally with predominantly fine-grained deposits. The Shinarump Member of the Chinle Formation produces water in southeastern Utah. Parts of the Ankareh and Chinle Formations also might yield water to wells. Middle Mesozoic aquifers

The middle Mesozoic aquifers unit consists mainly of continental deposits. The deposition produced several thick, laterally extensive sandstone formations that make up a major aguifer system in the study area This unit was eroded and is absent in parts of the uplifted areas of Utah and Colorado, but is present almost everywhere else. Upper Triassic and Lower Jurassic strata such as the Wingate and Navajo Sandstones dominate the southwestern part of the study area, but thin and are absent in western Colorado. The Nugget Sandstone in Wyoming and its equivalent, the Glen Canyon Sandstone in northern Utah and Colorado, generally are deeply buried and used only locally for domestic water supply. The Middle Jurassic Entrada Sandstone or its equivalent grades from a limy shale west of the San Rafael swell to a productive sandstone aguifer in eastern Utah and western Colorado. Its Wyoming equivalent, the Preuss Formation, is a potential aquifer. Middle Jurassic strata such as the Bluff, Cow Springs, and Junction Creek Sandstones are aquifers in southeastern Utah and western Colorado where the Upper Triassic and Lower Jurassic strata are thin. The Upper Jurassic Morrison Formation includes several sandstone members that locally are aquifers along the Utah-Colorado border and in northern Arizona. Finer grained strata within the middle Mesozoic aquifers unit separate the sandstone layers. These fine-grained strata restrict flow between sand stone layers; however, the degree of restriction varies areally because the

thickness and content of fine material varies. The Kayenta Formation, separating the Wingate and Navajo Sandstones, is mostly a shaley sandstone that locally contains red to brown mudstone, but in places is sandier and permeable. The Carmel Formation, between the Navajo and Entrada Sandstones, and the Summerville Formation that separates the Entrada from younger sandstones, are both primarily thin shaley marine or lacustrine deposits, but contain some sandstone and sandy siltstone. The middle Mesozoic aquifers are overlain directly by the fine-grained rocks of late Upper Mesozoic confining layers and aquifers Upper Jurassic fine-grained deposits of the Morrison Formation (the Brushy Basin Shale Member in northern Arizona and southeastern Utah) and most of the Cretaceous formations. This hydrogeologic unit primarily is a confining bed of the middle Mesozoic aquifers, but includes several coarse-

The upper Mesozoic confining layers and aquifers unit includes the grained sedimentary layers below and above the Mancos Shale and its equivalents. Strata that may be potential aquifers below the Mancos include the Burro Canyon Formation in southeastern Utah and southwestern Colorado; the Dakota Sandstone in much of Utah, Colorado, and Wyo ing; the Muddy Sandstone in Wyoming; the Bear River Formation in northcentral Utah and southwestern Wyoming. Within the Mancos Shale are the Ferron and Emery Sandstone Members in central Utah. Above the Mancos Shale are the sandstones of the Mesaverde Group in central Utah, northwestern Colorado, and Wyoming. All these sandstones may be thin, discontinuous, and only partly saturated so that their water-yielding significance is local. The Mancos Shale dominates the upper Mesozoic unit and includes the Masuk, Blue Gate, and Tununk Shale Members in central Utah. Approximately equivalent formations include the Aspen, Hilliard, Baxter, and Mowry Shales in Wyoming and north-central Utah. Aggregate thickness of these shales exceeds 6,000 ft in places and they restrict water movement between the Mesozoic and overlying Tertiary sandstone aquifers.

HYDROGEOLOGIC UNITS OF CENOZOIC AGE Basal Tertiary aquifers

The basal Tertiary aquifer unit consists of interstratified sandstone mudstone, shale, and coal beds. This unit includes the Fort Union, Hoback North Horn, Evanston, and Middle Park Formations, as well as stratigraphically equivalent beds. The Evanston and North Horn Forma tions are included in this hydrogeologic unit, even through they are partly Cretaceous in age. The Coalmont Formation also is included, even though it is partly Eocene in age. Below this unit is a regressive marine sandstone the Fox Hills Sandstone and equivalents, on which continental fluvial and marsh sediments of the Lance, North Horn, and Fort Union Formations were laid down. The unit crops out on the periphery of the Green River, of the Green River and Wasatch Formations. Wells completed in this unit provide water in quantities adequate for livestock, domestic use, and small

Lower Tertiary aquifers and confining layers The lower Tertiary aquifers and confining layers, primarily the Wasatch and Green River Formations, consist of fluvial, mostly piedmont deposits intertonguing with fine-grained lakebed sediments. The fluvial deposits of the Wasatch Formation and its equivalents are coarse near the mountains from which the sediments were derived, and become finer with greater distance. The lakebeds include enormous quantities of oil shale, bedded trona deposits, nahcolite, and dawsonite, as well as sandstone and tuff beds. This hydrogeologic unit crops out on the periphery of the Green River, Piceance, and Uinta basins and is overlain by the middle Tertiary aguifers, partly drained aguifers, and confining layers unit. The coarsegrained fluvial deposits include lenticular sandstone, arkose, and conglomerate that supply water to many wells in the Green River basin. Most of the wells are adequate for stock or domestic use but larger yields are possible from wells penetrating more than 500 ft of the fluvial deposits. The lakebeds that form the Green River Formation largely are fine grained and permeability is low. Local sandstone and tuff beds are sufficiently permeable to provide small yields to wells. Fractures increase permeability at some locations. Leaching of abundant evaporites has resulted in relatively permeable zones of the Green River Formation in the northern part of the Piceance basin of Colorado and in the Uinta basin of Utah. Yields from the Green River Formation generally are small except where rocks have been fractured or evaporites have been leached.

Middle Tertiary aquifers, partly drained aquifers, and confining layers The middle Tertiary hydrogeologic unit is composed of fluvial beds of the Bridger, Washakie, Uinta, and Duchesne River Formations. These claystone, tuffaceous fine-grained sandstone, shale, algal limestone, and conglomerate strata are interbedded and crop out in the central parts of the Green River, Washakie, Piceance, and Uinta basins. The overa permeabaility of the unit is minimal but the coarse-grained rocks prevailing near the edges of the outcrop areas may have fairly significant permeability. In Utah some fairly large yields are obtainable from wells completed in relatively coarse-grained rocks near the outcrop edges or in fractured zones. In Wyoming or in the Piceance basin of Colorado these coarsegrained rocks are likely to be partly drained. Where recharge is abundant, as in irrigated areas, this hydrogeologic unit in conjunction with overlying, younger gravel and sand probably can provide enough water to wells for domestic and stock uses.

Upper Tertiary discontinuous aquifers Tuffaceous sandstone, conglomerate, sandy claystone, and tuff comprise the uppermost Tertiary hydrogeologic unit. This unit includes the Bishop Conglomerate, and the White River, Browns Park, North Park, and Troublesome Formations as well as various isolated unnamed units. The formations were deposited by swift-moving streams flowing from the mountains and once blanketed most of the Green River, Uinta, Sand Wash and Piceance basins. Although the formations are areally extensive in some places, in most places erosion has removed all but isolated remnants, most of which cap buttes near the edges of the basins. Where this hydrogeologic unit is extensive, it provides water to many small hillside springs and fairly large yields to wells. Extensive deposits of this unit underlie parts of north western Colorado and northeastern Utah and blanket part of the flanks of the Sierra Madre in Wyoming. Because of the generally large permeability of the sediments and the gentle slope of their surfaces where they cap buttes, these rocks are readily recharged by precipitation. Much of the recharged water drains fairly quickly through hillside springs, but part is transmitted to underlying aquifers. The water from springs and wells in the upper Tertiary unit generally is suitable for most uses. In some places the beds may be uraniferous, and radiochemicals may be dissolved in the

The purpose of the ongoing regional aquifer-system analysis of the Upper Colorado River Basin is to study the aquifers of consolidated sedimentary rocks in all regions except the upper part of the San Juan Normal annual precipitation is greater in the mountains than in the plains. Surface drainage is by the Colorado River, and numerous tributaries. Several major surface reservoirs regulate streamflow; regional ground-water reservoirs have not been studied thoroughly. Repeated structural deformation, variable depositional conditions, and erosion have resulted in a variety of rock types that occur in numerous basins and uplifts. Through Paleozoic time the deposits evolved from clastic; to carbonate; to interbedded clastic, carbonate, and evaporite. Mesozoic deposits are clastic and carbonate. Tertiary deposits evolved through time from clastic, to lake and swamp deposits, to additional clastic deposits. The consolidated sedimentary strata have been divided into 11

hydrogeologic units on the basis of depositional environment, principal rock type, and hydrologic characteristics. **SELECTED REFERENCES**

Ahern, John, Collentine, Michael, and Cooke, Steve, 1981, Occurrence and characteristics of ground water in the Green River basin and Overthrust belt, Wyoming: Laramie, Wyoming, Water Resources Research Institute, 2 v.

Anderson, D. W., and Picard, M. D., 1972, Stratigraphy of the Duchesne River Formation (Eocene-Oligocene?), northern Uinta Basin, northwestern Utah: Utah Geological and Mineralogical Survey Bulletin 97, Baars, D. L., 1962, Permian System of Colorado Plateau: American Association of Petroleum Geologists Bulletin, v. 46, no. 2, p. Boettcher, A. J., 1972, Ground-water occurrence in northern and central parts of western Colorado: Colorado Water Resources Circular

Bowers, W. E., 1972, The Canaan Peak, Pine Hollow, and Wasatch Formations in the Table Cliff region, Garfield County, Utah: U.S. Geological Survey Bulletin 1331-B, 39 p. Bradley, W. H., 1964, Geology of Green River Formation and associated Eocene rocks in southwestern Wyoming and adjacent parts of Colorado and Utah: U.S. Geological Survey Professional Paper 496-A, Brogden, R. E., and Giles, T. F., 1976, Availability and chemical characteristics of ground water in central La Plata County, Colorado

U.S. Geological Survey Water-Resources Investigations 76-69, 1 __1976, Availability and chemical quality of ground water in the Crystal River and Cattle Creek drainage basins near Glenwood Springs, west-central Colorado: U.S. Geological Survey Water-Resources Investigations 76-70, 1 sheet. Cashion, W. B., 1967, Geology and fuel resources of the Green River Formation southeastern Uinta Basin, Utah and Colorado: U.S. Geological Survey Professional Paper 548, 48 p. _____1973, Geologic and structure map of the Grand Junction quadrangle, Colorado and Utah: U.S. Geological Survey Miscellaneous Investigations Series Map I-736, scale 1:250,000.

Collentine, Michael, Libra, Robert, Feathers, K. R., and Hamden, Latif, 1981. Occurrence and characteristics of ground water in the Great Divide and Washakie basins, Wyoming: Laramie, Wyoming, Water Resources Research Institute, Report to U.S. Environmental Protection Agency, 2 v. Craig, L. C., 1981, Lower Cretaceous rocks, southwestern Colorado and southeastern Utah, in Geology of Paradox basin, Denver: Rocky Mountain Association of Geologists 32nd Field Conference Guidebook, p. 195-200.

Denson, N. M., 1965, Miocene and Pliocene rocks of central Wyoming,

in Changes in stratigraphic nomenclature: U.S. Geological Survey Bulletin 1224-A, p. A70-77. Denson, N. M., and Pipiringos, G. N., 1974, Geologic map and sections showing areal distribution of Tertiary rocks near the southeaster terminus of the Wind River Range, Fremont and Sweetwater Counties, Wyoming: U.S. Geological Survey Miscellaneous Investigations Map Denson, N. M., Zeller, H. D., and Stephenson, E. V., 1965, South Pass Formation on the southwest flank of Wind River Mountains, Wyoming, in Changes in stratigraphic nomenclature: U.S. Geological Survey Bulletin 1224-A, p. A27-29.

Fenneman, N. M., 1931, Physiography of the Western United States: New York, McGraw-Hill Book Co., 534 p. Fouch, T. D., 1976, Revision of the lower part of the Tertiary system in the central and western Unita basin: U.S. Geological Survey Bulletin Fouch, T. D., Lawton, T. F., Nichols, D. J., Cashion, W. B., and Cobban, W. A., 1982, Chart showing preliminary correlation of major Albian to middle Eocene rock units from the Sanpete Valley in central Utah to the Book Cliffs in eastern Utah, in Nielson, D. L. ed., Overthrust belt of Utah: Utah Geological Association Publication 10, Goode, H. D., and Feltis, R. D., 1962, Water production from oil wells of the Uinta basin, Uinta and Duchesne Counties, Utah: Utah

Geological and Mineralogical Survey Water-Resources Bulletin 1, 32 Grose, L. T., 1972, Tectonics, in Geologic atlas of the Rocky Mountain region: Denver, Rocky Mountain Association of Geologists, p. 35-44. Hackman, R. J., and Wyant, D. G., 1973, Geology, structure, and uranium deposits of the Escalante quadrangle, Utah and Arizona, U.S. Geological Survey Miscellaneous Investigations Map I-744, 2 sheets scale 1:250,000. Hansen, W. R., 1969, The geologic story of the Uinta Mountains: U.S

Geological Survey Bulletin 1291, 144 p. Haynes, D. D., and Hackman, R. J., 1978, Geology, structure, and uranium deposits of the Marble Canyon 10 x 20 quadrangle, Arizona: U.S. Geological Survey Miscellaneous Investigations Series Map I-1003, scale 1:250,000. Haynes, D. D., Vogel, J. D., and Wyant, D. G., 1972, Geology, structure, and uranium deposits of the Cortez quadrangle, Colorado and Utah: U.S. Geological Survey Miscellaneous Investigations Series Map I-629, scale 1:250,000. Hintze, Lehi, 1973, Geologic history of Utah: Provo, Utah, Brigham Young University Geology Studies v. 20, pt. 3, 181 p. Hood, J. W., 1976, Characteristics of aquifers in the northern Uinta Basin area, Utah and Colorado: Utah Department of Natural Resources, Technical Publication no. 53, 71 p.

> Dirty Devil River basin area, Utah, with special emphasis on the Navajo Sandstone: Utah Department of Natural Resources, Technical Publication no. 68, 143 p. Imlay, R. W., 1980, Jurassic paleobiology of the conterminous United States in its continental setting: U.S. Geological Survey Professional Paper 1062, 134 p. Johnson, R. C., and May, Fred, 1980, A study of the Cretaceous-Tertiary unconformity in the Piceance Creek basin, Colorado: U.S. Geological Survey Bulletin 1482-B, 27 p. Kent, H. C., 1972, Review of Phanerozoic history, in Geologic atlas of the Rocky Mountain region: Denver, Rocky Mountain Association of

Hood, J. W., and Danielson, T. W., 1981, Bedrock aquifers in the Lower

King, P. B., and Beikman, H. M., 1974 (1975), Geologic map of the United States, exclusive of Alaska and Hawaii: U.S. Geological Survey Special Geologic Map, 3 sheets, scale 1:2,500,000. Knight, R. L., and Cooper, J. C., 1955, Suggested changes in Devonian terminology of the four corners area, in Geology of parts of Paradox, Black Mesa, and San Juan Basins: Four Corners Geological Society 5th Field Conference Guidebook, p. 56-58. Lines, G. C., and Glass, W. R., 1975, Water resources of the thrust belt of western Wyoming: U.S. Geological Survey Hydrologic Investigations Atlas HA-539, 3 sheets, scale 1:250,000.

Kent, H. C., and Porter, K. W., eds., 1980, Colorado geology: Denver

Rocky Mountain Association of Geologists, 258 p.

Love, J. D., 1970, Cenozoic geology of the Granite Mountains area, central Wyoming: U.S. Geological Survey Professional Paper 495-C, 154 p. Love, J. D., and Christiansen, A. C., 1980, Preliminary correlation of stratigraphic units used on 1° x 2° geologic quadrangle maps of Wyoming, in Stratigraphy of Wyoming: Casper Wyoming Geological Association, p. 279-282. Love, J. D., Christiansen, A. C., Bown, T. M., and Earle, J. L., compilers, 1979, Preliminary geologic map of the Thermopolis 1° x 2° quadrangle, central Wyoming: U.S. Geological Survey Open-File Report 79-962, scale 1:250,000.

MacLachlan, M. E., 1981, Stratigraphic correlation chart for western Colorado and northwestern New Mexico: Socorro, New Mexico Geological Society 32nd Field Conference Guidebook, p. 75-79. _1986, General geology of the Piceance basin, in Taylor, O. J., compiler, U.S. Geological Survey Professional Paper 1310 (in press). Molenaar, C. M., 1981, Mesozoic stratigraphy of the Paradox basin—An overview, in Geology of the Paradox basin: Denver, Rocky Mountain Association of 32nd Field Conference Geologists Guidebook, p.

Molenaar, C. M., and Halvorsen, D. U., 1969, Nomenclature chart of the Grand Canyon and adjacent areas, in Four Corners Geological Society Guidebook, 5th Field Conference, Geology and Natural History of the Grand Canyon Region, p. 68. Mutschler, F. E., 1969, Desolation and Gray Canyons: Denver, Powell Society, 85 p. Nelson, M. E., 1973, Age and stratigraphic relations of the Fowkes For-

mation, Eocene, of southwestern Wyoming and northeastern Utah: University of Wyoming Contributions to Geology, v. 12, no. 1, p. Oriel, S. S., and Platt, L. B., 1980, Geologic map of the Preston 1º x 2º quadrangle, southeastern Idaho and western Wyoming: U.S. Geological Survey Miscellaneous Investigations Series Map I-1127, Oriel, S. S., and Tracey, J. I., Jr., 1970, Uppermost Cretaceous and Ter-

tiary stratigraphy of Fossil Basin, southwestern Wyoming: U.S. Geological Survey Professional Paper 635, 53 p. O'Sullivan, R. B., 1978, Stratigraphic sections of Middle Jurassic San Rafael Group from Lohali Point, Arizona to Bluff, Utah: U.S. Geological _1980, Stratigraphic sections of Middle Jurassic San Rafael Group from Wilson arch to Bluff in southeastern Utah: U.S. Geological __1981. Stratigraphic sections of some Jurassic rocks from near Moab, Utah, to Slick Rock, Colorado: U.S. Geological Survey

O'Sullivan, R. B., and Beikman, H. M., 1963, Geology, structure, and

uranium deposits of the Shiprock quadrangle, New Mexico and Arizona: U.S. Geological Survey Miscellaneous Investigations Series Map I-345, scale 1:250,000 Peterson, Fred, and Pipiringos, G. N., 1979, Stratigraphic relations of the Navajo Sandstone to Middle Jurassic Formations, southern Utah and northern Arizona, U.S. Geological Survey Professional Paper 1035-B,

Pirpiringos, G. N., and Denson, N. M., 1970, The Battle Spring Formation in south-central Wyoming: Casper Wyoming Geological Association Guidebook, 22nd Annual Field Conference, 1970, p. 161-168. Pipiringos, G. N., and Imlay, R. W., 1979, Lithology and subdivisions of the Jurassic Stump Formation in southeastern Idaho and adjoining areas: U.S. Geological Survey Professional Paper 1035-C, 25 p. Pipiringos, G. N., and O'Sullivan, R. B., 1978, Principal unconformities in Triassic and Jurassic rocks, Western Interior United States—A preliminary survey: U.S. Geological Survey Professional Paper

Reynolds, M. W., 1976, Influence of recurrent Laramide structural growth on sedimentation and petroleum accumulation, Lost Soldier area, Wyoming: American Association of Petroleum Geologists Bulletin, v. 60, no. 1, p. 12-33. Robinove, C. J., Langford, R. H., and Brookhart, J. W., 1958, Salinewater resources of North Dakota: U.S. Geological Survey Water-Supply Paper 1428, 72 p. Rocky Mountain Association of Geologists, 1972, Geologic Atlas of the

Rocky Mountain region: Denver, 331 p. Roehler, H. W., 1973, Stratigraphy of the Washakie Formation in the Washakie Basin, Wyoming: U.S. Geological Survey Bulletin 1369, __1974, Depositional environments of rocks in the Piceance Creek Basin, Colorado, in Rocky Mountain Association of Geologists 25th Field Conference, 1974, Energy resources of the Piceance Creek Basin, Colorado: Denver, p. 57-64.

Rowley, P. D., Anderson, J. J., and Williams, P. L., 1975. A summarv of Tertiary volcanic stratigraphy of the southwestern High Plateaus and adjacent Great Basin, Utah: U.S. Geological Survey Bulletin 1405-B, 20 p. Rowley, P. D., Tweto, Ogden, Hansen, W. R., and Carrara, P. E., 1979, Geologic map of the Vernal 1° x 2° quadrangle, Colorado, Utah, and Wyoming: U.S. Geological Survey Miscellaneous Field Studies Map MF-1163, scale 1:250,000.

Rubey, W. W., 1973, New Cretaceous formation in the western Wyoming thrust belt: U.S. Geological Survey Bulletin 1372-I, 35 p. Rubey, W. W., Oriel, S. S., and Tracey, J. I., 1975, Geology of the Sage and Kemmerer 15-minute quadrangle, Lincoln County, Wyoming: U.S. Geological Survey Professional Paper 855, 118 p. _____1980, Geology map and structure sections of the Cokeville 30-minute quadrangle, Lincoln and Sublette Counties, Wyoming: U.S. Geological Survey Miscellaneous Investigations Series Map I-1129, scale 1:62,500. Rush, F. E., Whitfield, M. S., and Hart, I. M., 1982, Regional hydrology

of the Green River—Moab area, northwestern Parodox basin, Utah U.S. Geological Survey Open-File Report 82-107, 86 p. Shawe, D. R., Simmons, G. C., and Archbold, N. L., 1968, Stratigraphy of Slick Rock district and vicinity, San Miguel and Dolores Counties, Colorado: U.S. Geological Survey Professional Paper 576-A, 108 p.

Stewart, J. H., Poole, F. G., and Wilson, R. F., 1972, Stratigraphy and origin of the Chinle Formation and related Upper Triassic strata in the Colorado Plateau region: U.S. Geological Survey Professional Paper 690, 336 p. Tweto, Odgen, 1976, Geologic map of the Craig 1° x 2° quadrangle, northwestern Colorado: U.S. Geological Survey Miscellaneous Investigations Series Map I-972, scale 1:250,000. U.S. Department of Commerce, 1968, Climatic atlas of the United States

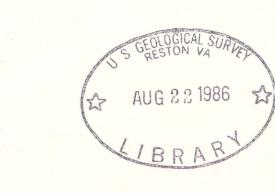
[reprint, 1974]: National Oceanic and Atmospheric Administration, U.S. Geological Survey, 1981, Water resources data for Arizona, water year 1979: Tucson, p. 39. Upper Colorado Region State-Federal Inter-Agency Group, 1971, Water Resources, Appendix V, Upper Colorado Region Comprehensive framework study: Pacific Southwest Interagency Committee, Water

Resources Council, 66 p. Weimer, R. J., 1960, Upper Cretaceous stratigraphy, Rocky Mountain area: American Association of Petroleum Geologists Bulletin, v. 44, Welder, G. E., 1968, Ground-water reconnaissance of the Green River

basin, southwestern Wyoming: U.S. Geological Survey Hydrologic Investigation Atlas HA-290, 2 sheets, scale 1:250,000. Welder, G. E., and McGreevy, L. J., 1966, Ground-water reconnaissance of the Great Divide and Washakie basins and some adjacent areas, southwestern Wyoming: U.S. Geological Survey Hydrologic Investigation Atlas HA-219, 3 sheets, scale 1:250,000.

Wengerd, S. A., and Strickland, J. W., 1954, Pennsylvanian stratigraphy of Paradox Salt basin, Four Corners region, Colorado and Utah: American Association of Petroleum Geologists Bulletin, v. 38, no. 10, p. 2157-2199; Correction, v. 39, no. 2, p. 259, 1955.





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